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J. Valenta, D. Ekendahl

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A programme for dose quality audits for high-energy radiotherapy beams in non-reference conditions in Argentina
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SESSION 11b: Radiation Imaging
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SESSION 11c: Radiation Imaging
National QA Implementation in Nuclear Medicine

SPECT: How much acceptance testing is reasonable?
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H. Korpela, R. Parkkinen

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Molecular imaging in quality health care

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Quality health care results from translating fundamental bench discoveries and making them available to patients. During the past decade, “molecular imaging” has emerged both as a new tool/technology and as a research and clinical discipline. Molecular imaging is an interdisciplinary approach involving biologists, physicists, physicians, mathematicians, conventional chemists, radiochemists and other specialists who have joined forces for better understanding and visualizing of both normal physiological processes and the molecular processes preceding the morphological manifestations of disease in vivo.

Molecular imaging has been defined as “non-invasive, quantitative, and repetitive imaging of targeted macromolecules and biological processes in living organisms” [1] or as “the visual representation, characterization, and quantification of biological processes at the cellular and sub-cellular levels within intact living organisms” [2]. Weissleder [3] defined molecular imaging in the most simple terms as “studying diseases non-invasively at the molecular level” [3]. Regardless of these semantic differences molecular imaging can contribute significantly to the preclinical and clinical drug and disease evaluation process.

It is interesting to note, that despite major advances in imaging technology, cancer mortality has remained largely unchanged over the last three decades [4]. Imaging has thus far enabled us to look through a magnifying glass at disease processes but has failed to dramatically influence disease outcomes. Emerging data suggest that molecular PET imaging is about to change this situation.

High resolution molecular imaging devices designed for small animal research have developed into valuable tools for drug evaluation and imaging probe design. These include microPET, microCT, microMRI and optical imaging devices. These have enabled us to study drug effects in vivo by monitoring longitudinally their effects on tumour cell metabolism or proliferation.

The only currently available molecular imaging tool for human studies is positron emission tomography (PET). Many different molecular imaging probes targeting physiological processes such as glycolysis, lipid synthesis, amino acid transport, cell surface receptors, gene expression and others are available for evaluating in animal experimental studies and humans the extent of disease as well as treatment effects in vivo.

With the advent of PET/CT anatomic and molecular images can be fused affording assignment of normal or abnormal molecular imaging findings to specific anatomical structures. The major vendors have invested millions of dollars into bringing together the highest quality CT with state-of-the-art PET instrumentation. As a result more than 1000 PET/CT scanners have been installed worldwide over the last four years.
These technological advances come at a time of increasing health care expenditures worldwide. One must therefore carefully evaluate whether the increasing costs are met by increasing effectiveness of the technology. As an additional problem, health care systems vary substantially between countries and cultures and cost-effectiveness analyses need to be tailored towards specific health care environments.

A paradigm shift from morphological to molecular imaging is occurring on every level of preclinical and clinical research and in clinical practice. Animal tumour models are being used for serial non-invasive monitoring of preclinical drug effects in vivo using molecular imaging technology. This molecular imaging application reduces the numbers of animals required for preclinical studies and might allow for some predictions of drug effectiveness in humans. Molecular imaging should be used in phase I, II and III trials to identify drug success and failure early. Applications of molecular imaging to patient stratification will define appropriate patient populations for smaller, more rapid clinical trials. Recent studies in lung cancer, lymphoma, esophageal cancer and gastrointestinal stromal tumour have clearly indicated that FDG PET/CT imaging can be used to appropriately change the management of cancer patients. Clinical molecular imaging, currently restricted primarily to PET, is therefore already considered the gold standard for monitoring effects of many conventional cancer treatments and will now be used to monitor the effects of “targeted” treatments in all phases of clinical trials.

This presentation will introduce molecular imaging tools including instrumentation and imaging probes and will describe the concept of targeted imaging. Animal experimental studies will be used to demonstrate promising treatment approaches in vivo and how imaging can be used to monitor therapeutic effects.

Further, clinical molecular PET/CT imaging assays will be introduced and its impact on patient stratification and management as well as its cost effectiveness will be reviewed and discussed within the confines of different health care systems.

Finally, initial clinical trials that use molecular PET rather than anatomical CT imaging for prospectively arriving at patient management decisions will be presented.

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Innovative technologies in radiation oncology

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Over the recent years high precision radiotherapy has been implemented widely in clinical routine. Modern techniques such as fractionated stereotactic radiotherapy (FSRT) and intensity modulated radiotherapy (IMRT) have enabled the radiation oncologist to apply high doses of radiation to defined target volumes while sparing normal tissues, especially organs at risk. This is especially important in regions were tumour volumes and sensitive normal tissue are in close proximity, such as in the skull base. Thus, it was possible to increase the total tumour dose and subsequently increase local control rates, while the risk for radiation induced side effects can be minimized. This is especially important for tumours of the skull base, we risk organs such as the optic system, brain stem and spinal cord that are in close vicinity. In tumours of the head and neck, IMRT enables the application of effective RT doses while side effects including xerostomia can be minimized through sparing of the parotid glands. Therefore, not only treatment outcome with regard to local control and overall survival could be increased, but also patients’ quality of life could be optimized through reduction of treatment-induced side effects.

A main challenge for the radiation oncologist are moving targets. With modern technical improvements in tumour tracking, adaptive radiotherapy will enable safe and effective treatment of moving targets such as tumours of the lung while surrounding healthy tissue can be spared.

However, in certain tumour entities, overall treatment results still remain unsatisfying.

Therefore, particle therapy seems to be a promising alternative.

One main benefit of particle therapy is the inverted dose profile, resulting in low RT doses in the entry channel and behind the defined target volume, while the required dose can be directed into the target area. With carbon ion radiotherapy, this physical privilege is accompanied by distinct radiobiological effects within the tissue, resulting in a higher relative biological effectiveness (RBE). Therefore, an increase in local tumour control and subsequent improvement of overall survival can be expected.

We have shown in a number of studies that radioresistant tumours such as chordomas, chondrosarcomas and adenoicystic carcinomas certainly benefit from carbon ion RT. Other extracranial tumours including sacral chordomas, lung cancer and sarcomas have been treated with carbon ion RT effectively.
Carbon ion therapy is currently available in a few centres in Japan. At the University of Heidelberg we perform treatment with carbon ions at the Gesellschaft für Schwerionenforschung (GSI) in Heidelberg. Currently we can offer treatment in three beam time blocks per year allowing the treatment of about 60 patients per year. In 2007, a combined proton-carbon ion particle therapy center at the University of Heidelberg, Department of Radiation Oncology, will take up clinical routine and allow the treatment of about 1000 patients per year.
The role of imaging in radiation oncology

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“If you can’t see it, you can’t hit it, and if you can’t hit it, you can’t cure it.” This statement from the Canadian Medical Physicist Harold Johns very well describes the problem in which radiation therapy has been during the last century, at least until the introduction of 3D imaging in the form of CT into radiation therapy planning in the mid 70s. During the last three decades, not only 3D imaging with X ray computerized tomography (CT), but also ultrasound and magnetic resonance imaging (MRI) were introduced to characterize tumour morphology for improved delineation of target volumes. CT and MRI have in the meanwhile proven to be indispensable in terms of delineating target volumes and organs at risk, and they today provide the tool to visualize at least a snapshot of the target at the very beginning of the radiation therapy procedure. This snapshot is adequate for those tumours, which do not change their shape and position from day to day, and which will not move during irradiation, like brain or head and neck tumours. However, there are many tumours that undergo temporal changes, and if these changes surpass a certain limit, they have to be taken into account.

With “4D imaging” and integration of imaging techniques into the irradiation units, the time has come to also start the assessment and correction of the temporal alterations of the target volume and to observe the temporal changes during the whole course of the treatment. This is leading to “image guided radiotherapy” (IGRT) which is characterized by either 2D or even 3D imaging modalities into the radiotherapy workflow. The vision is to detect deformations and motion between radiotherapy fractions (inter-fractional IGRT) and during beam delivery (intra-fractional IGRT). From the technical point of view two different strategies are being pursued: cone beam imaging using either MV-imaging or KV-imaging in the combination with conventional linear accelerators, or rotational therapy in combination with a CT-like gantry and imaging capability (“tomotherapy”).

Consideration of the temporal changes of target volumes and organs at risk, and correcting for movements and deformations either by gating or tracking of the irradiation beam lead a step further to “time adapted radiotherapy” (ART). Many institutions are currently addressing this technical challenge with the goal of implementing IGRT and ART in radiotherapy as a faster, safer and more efficient treatment technique.

Another recently advancing technique is “biological adaptive radiotherapy”. The background for this approach is the fact that the old hypothesis of radiotherapy – i.e., that the tumour consists of a homogenous tissue and therefore a homogeneous dose distribution has to be delivered to the target - can no longer be sustained. It is known today that a tumour may consist of various sub-volumes with different radiobiological properties, as for instance [1]:

- Hypoxia: hypoxic areas within the tumour are known to be highly radioresistant
- Cellular proliferation is one of the hallmarks of malignant cells
- Apoptosis is considered to be a predominant form of cell death induced by radiation
- Angiogenesis is an essential step in tumour progression and metastasizing
- Receptor molecules, such as growth factors and hormones, may affect radiosensitivity of tumours and cells.

New imaging methods are currently being developed and investigated to characterize these properties more appropriately, e.g. by functional and molecular imaging using new tracers for positron emission tomography (PET) and by functional magnetic resonance imaging (fMRI) and by magnet resonance spectroscopy (MRS). In this context, the development and use of devices combining morphological imaging with biological imaging (e.g. PET/CT or PET/MRI) and also high field (3T) and ultra high field (7T) MRI will probably play a role in the future, not only for diagnostics, but also in the context of radiation oncology [2,3].

The biological imaging challenge in radiotherapy is on one hand to develop concepts to improve tumour staging and target volume definition, to derive prognostic and predictive information and to monitor the tumour during high precision treatment [4]. The consequent next step is to include and integrate biological information into radiotherapy planning and beam delivery, first by extending the morphological towards a biological planning target volume including sub-volumes of different radiosensitivity, and second by delivering appropriate inhomogeneous dose distributions, e.g. with the new tools of photon and particle IMRT techniques (“dose painting”). It has been shown that this is technically feasible, although issues in temporal and spatial variations in target localization, quality assurance, etc. still create controversy. Whether therapeutic ratios can be improved in that way has yet to be explored by appropriate clinical trials.

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Recent developments of significance in medical imaging

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In the century or so since the discovery and application of X rays to imaging the human body, clinical medical imaging has broadened its armamentarium, exploiting other physical phenomena such as ultrasound and nuclear magnetic resonance (in magnetic resonance imaging/MRI).

In each developing field the level of sophistication of the technology has steadily increased over the years but certainly the most important, paradigm-shifting event was the invention of X ray computed tomography (CT). This changed X ray imaging from a two dimensional projectional technique which lost huge amounts of information to a 3D, technique preserving much of the previously lost information.

Indeed, although MRI is based on entirely different physical principles it may reasonably be claimed that CT paved the way for clinical MRI.

In each field a consistent theme of great importance has been the development of “contrast enhancing agents” (CEA), which have not only contributed to improved image quality and information content but have allowed the development of functional/physiological imaging.

As the technologies became capable of rapid repeat image data set acquisitions, CEA could be used as tracers in dynamic studies from which could be derived fundamental physiological and pathophysiological indices such as perfusion, fractional vascular volumes, capillary permeability and glomerular filtration rate in the kidney in health and disease.

The last decade has seen the most astonishing developments in CT with a progression from slice by slice data acquisition to spiral/helical technology acquiring true volume data sets. Even the last five years have been marked by astonishing developments in this field alone with a progression from single detector row to 2, 4, 8, 16 and 64 row machines (“multi-slice”) that can acquire image data sets of, say, abdomen and pelvis of better than 0.5 mm isotropic spatial resolution in 15 seconds or so. Such data sets allow high quality 3D image generation and manipulation of the highest quality.

While there have been significant developments and improvements in image quality — and CEA and data acquisition times — in MRI and in ultrasound, it is fair to say that the developments in CT are the most striking. However, these have come at a price. X ray image data are purchased with photons and high quality CT can only be achieved with a higher radiation dose burden to the patient. These sophisticated CT machines have a variety of in-built systems to modulate radiation dose burden but the issue continues to generate anxiety.
In nuclear medicine there have been many developments but perhaps the most important is positron emission tomography (PET); and now PET systems are being yoked together with multi-slice helical CT in “PET CT” machines. These generate both functional and anatomical images and, though PET alone and PET CT have numerous important applications, their importance to oncological and cardiac imaging would be difficult to overstate.

A survey of the developments of greatest significance in recent years will be presented. A critical examination of the radiation dose controversy surrounding modern CT and PET CT will be appended.
Session 3a:
*Radiation Treatment*
CLINICAL ASPECTS OF TREATMENT PLANNING
AND NEW TECHNOLOGIES
QA in the era of 4D treatment planning in radiation therapy

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The ultimate goal of radiotherapy is to deliver therapeutic dose in a precise and accurate manner to the target volume while minimizing dose to surrounding normal tissue. Advancement in technology over the past several decades brings highly developed means to reach this objective. Planning and delivery of radiation therapy have evolved to a multi-step process which is individualized for each patient. In simple terms, radiotherapy treatment planning can be defined as the process of arrangement of beams to irradiate a defined target volume to the prescribed dose. This process includes anatomy definition (tumour and normal tissue), radiation beam design and calculation, delivery of the treatment plan, and verification of delivery.

Through the decades in the radiotherapy field, each stage in the treatment process has been extended from a two dimensional approach to three dimensions, and recently into “4D” that includes incorporation of time (motion). Consequently, treatment planning and delivery have become increasingly complex, and the radiation therapy physicist is faced with the problem of how to assure quality of treatment for the patient. The QA approach can be: to first examine accuracy at a general level (through use of phantoms, for example), and next, at the patient-specific level. QA methods are required for each step in the process, with a definitive QA check of the overall delivery of the treatment. A document such as AAPM task group 53 [1] is a good starting point for putting together a quality assurance plan for the treatment planning system.

A primer for implementing intensity modulated radiation therapy (IMRT) was published in 2004 [2]. The approach described is a safe and effective way to introduce IMRT into clinical practice, and ensure continuing quality of treatment on an on-going basis. Recommendations for planning a new IMRT program, the IMRT process, planning strategies, delivery techniques, training requirements, equipment commissioning, treatment verification, etc are all described in detail.

A new task group was recently formed [3] to “modernize” quality assurance in the clinic and for the treatment planning process. The specific charges of the task group are:

1. Review and critique the existing guidance from the AAPM in documents such as TG-40, 56, 59, 43 old and new, 60, 64, and guidance from ACR and ACMP reports on QA in Radiation Oncology, ESTRO report on QA in radiotherapy, IEC publications on functional performance of radiotherapy equipment, and finally ISO guidelines on quality management and quality assurance. The objective will be to determine the specific areas that have been omitted and need better coverage, and also to develop a suitable general quality assurance program.
2. Identify a structured systematic QA program approach that balances patient safety and quality versus resources commonly available and strike a good balance between prescriptiveness and flexibility.

3. After the identification of the hazard analysis for broad classes of radiotherapy procedures, develop the framework of the QA program.

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Clinical impact of new radiation therapy techniques

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The cornerstone of external beam radiation therapy is the delivery of a therapeutic dose to the target tissues. Traditional “2D” techniques broadly rely on the physician to assimilate the clinical information (history, examination, and radiographs) to define the target volume which is then localized via fluoroscopy on a traditional simulator. This approach required an in-depth understanding of the relationship between surface anatomy, radiographically visible anatomy (i.e. bones on simulator films) and three dimensional soft tissue anatomy. Radiation therapy treatment beams were generally limited to orientations wherein the physician/planner could understand the three dimensional relationship between the internal structures and their projection onto a simulator film.

Three dimensional treatment planning allowed the more direct incorporation of three dimensional imaging information into the planning process. The 3D relationship between internal targets and normal tissues seen on 3D imaging (e.g. computed tomography - CT), were therefore more accurately known. This facilitated the use of “non-standard” beam orientations, and more conformal shaping of the treatment beams. Software allows incorporation of multi-modality three dimensional imaging with, for example, positron emission tomography (PET), magnetic resonance imaging (MRI), and single photon emission computed tomography (SPECT). Therefore, the vast anatomic/functional information from multiple three dimensional imaging modalities can be used in concert to facilitate accurate treatment delivery. Software allows such three dimensional information to be displayed and viewed from any orientation. Beam orientations and shapes are then chosen to encompass the target yet minimize, as possible, normal tissue exposure. Thus, 3D tools allow three dimensional anatomic information to be more accurately incorporated into the planning process.

In almost all instances, the target is fully encompassed within each of the 3D planned treatment beams. Further, each RT beam typically delivers a similar intensity of radiation (i.e. dose) to each part of the target. Thus, significant RT doses are typically delivered to all tissues in the “shadow” of the target, as seen in the “beams eye view” (BEV). Selection of the beam orientation is therefore critical with 3D planning. Compensators (such as wedges) can be added to the beam to modify the intensity profile of the beam. However, such compensators are relatively simple and provide only uniform and monotonic modulation of the beams intensity (e.g. the entire anterior part of a lateral photon beam given less intensity than the posterior aspect of that same field).

With intensity modulated radiation therapy (IMRT), each portion of the beam, or “beamlet”, is modulated to provide a unique intensity. Thus each beam can deliver highly variable doses to each region of the tumour. The purposely non-uniform doses from several beam orientations are combined to deliver the desired dose in a three dimensional space. It is typically not practical for a planner to “forwardly design” the necessary non-uniform intensity
profiles that will yield the desired dose distribution. Rather, the physician defines the desired three dimensional dose distribution and software is used to compute the necessary beam intensity or profiles (i.e. the amount of modulation necessary). Since this process of defining dose, and then beam intensities, is the reverse order from conventional planning, this process as been termed inverse planning.

In general, multiple radiation beams (>5–7) are needed to yield an acceptable dose distribution. IMRT appears to be superior to 3D conformal therapy for irregularly shaped tumours, particularly those with concavities. IMRT can be delivered by linear accelerator, or other machines such as the CyberKnife or Tomotherapy unit.

With all of these advanced technologies, care must be taken to assure adequate target coverage. Treatment fields and dose distributions need to be designed such that they account for inter- and intra-fraction motion of tumour. These technological advances require increased efforts on the part of physicians, dosimetrists, therapists, and physicists. An integrated team approach is required to assure that these technologies are applied in a clinically logical and effective manner.
What is the prostate movement during fractionated irradiation?

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Purpose

To find the largest displacement of prostate position during radiotherapy.

Methods

We analysed 20 patients treated with radical radiotherapy for localized prostate cancers between October 2004 and July 2005. Patients were immobilized using thermoplastic Orfit masks and Leg Support and Foot Support Orfit System. All patients were treated conformally, using high energy photons. The total dose was 74 Gy, delivered in 37 fractions during seven and a half weeks. We evaluated the positions of prostate once a week using CT scans. CTs, all planning procedures and irradiation were performed using the same positioning system. Prostates were delineated and the changes in their positions were measured using appropriate device the “Eclipse” program. All procedures were performed by the same group of persons.

Results

We did not observe any major prostate displacement in cranio-caudal and lateral axes. Some movements of prostate were observed in anterior-posterior (AP) axis. The mean of prostate movement in AP axis was 0.57 cm and ranged between 0.0 cm and 2.21 cm. In 89% of measurements the prostate displacement was smaller than 14 mm. In 90% of patients, all measurements of prostate displacement were smaller than 20 mm.

Conclusions

During prostate cancer patients radiotherapy, anterior-posterior displacements should be checked because of significant prostate motions. Prostate AP margins (PTV) should be increased to about 1.5–2.0 cm to avoid geographical misses.
FIG. 1. Movements of prostate observed in AP axis.

TABLE 1. PROSTATE MOTION OBSERVED IN AP AXIS

<table>
<thead>
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<td>NO</td>
<td>16 pts (80%)</td>
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Image-guided non-invasive stereotactic radiosurgery/radiotherapy

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The objective of this study is to develop a non-invasive intracranial stereotactic radiosurgery technique with the same high degree of accuracy as that of the current invasive head ring SRS technique. The proposed methodology is to use the image registration to correlate the daily CT images with the planning images and use the head frame with bite block assembly, such that the target isocenter is coincided with the LINAC isocenter through stereotactic setup. In addition, the treatment delivery system (Varian LINAC/CT-on-rails unit) is equipped with a 6D robotic couch top, which the head frame interface device could always be maintained perpendicular to the couch-top surface. Through the head phantom study and the limited patient treatments to demonstrate, a new era of treating intracranial SRS without the pins screwed into the patient’s skull but achieve the same precision of treatment delivery, is available now.

A stereotactic QA head phantom was used to evaluate the proposed technique. The QA head phantom was attached to a head ring and the phantom was leveled by adjusting the robotic arms of the 6D couch-top. A set of planning CT scans was acquired. Then, a sphere ball inside the QA phantom was chosen as the target. A plan was generated for this test as seen in Fig. 1: to remove the phantom, then reattach the head phantom to the head frame interface device. The phantom was not leveled at this time to simulate a different setup (the phantom had a 0.3 degree roll and the weight of the phantom was tilted down by 0.4 degree.). A set of CT images was acquired to represent as the daily CT prior to the treatment. The daily CT images were registered with the planning CT images. Then, the 9-rod on the daily CT images was identified and the dose distributions were optimized based on the daily CT images; a daily isocenter was used. The localized target laser frame (LTLF) was set to the coordinates of the new isocenter, then the AP and RT LAT EPID portal images were acquired. For the clinical cases, first, a customized GTC frame was made for each patient. A five point GTC alignment device was attached to the GTC frame as shown in Fig. 2. A surgical ink pen embedded in an aluminum rod was used to mark five points on the patient’s skin and then tattoo them with ink. The five tattoo points were used to aid us to reposition the GTC frame on the patient to be within 1 mm from the original setup. We leveled the GTC frame to remove the sagging due to the patient’s weight (showed in Fig. 3). Then, planning CT images were acquired with the LINAC/CT-on-rails unit. A treatment plan was generated for the patient. Prior to the treatment, the same processes were used to acquire
the daily CT images. First, the daily CT images were registered with the planning CT/MRI images. Next, all the nine localization rods on the daily CT images were identified. Finally, the dose distributions were optimized and the isocenter of AP, LAT, and VERT coordinates with respect to the GTC frame were updated. Setup of the new isocenter coordinates on the LTLF was done, and the lateral wall lasers and ceiling laser were aligned with the cross on the LTLF. A pair of the AP and RT LAT EPID portal images was also acquired to verify the isocenter setup accuracy with respect to the AP and RT LAT planned DRRs.

Results. In the head phantom study, the daily isocenter setup was verified to be within 0.2 mm accuracy based upon the portal images vs. the planned DRRs as shown in Fig. 4. We proceeded to apply this new technique for treating fractionated SRT patients to gain the clinical experience before we launch for a single fraction radiation treatment. Prior to each treatment, a new treatment plan was generated. We optimized the dose distributions based on each daily CT images. As shown in Fig. 5, comparison of the PTV dose-volume histograms clearly revealed that the prescribed dose enclosed the target for each treatment. It is interesting to note that the mean deviations of the daily isocenter from the planned isocenter are 0.2±0.12, -0.4±0.24, and -0.1±0.07 mm in AP-, LAT-, and VERT-direction, respectively from ten treatments. This finding reinforces our previous SRT study indicating that the five point GTC frame alignment device is an essential tool to ensure the reproducibility of the GTC frame on the patient. In one of the patients, we took a pair of the AP and RT LAT EPID portal images superimposed with the AP and RT LAT planned DRRs and displayed in split screen to examine the accuracy of aiming the target isocenter (shown in Fig. 6).

Conclusion. The image-guided non-invasive-frame stereotactic radiosurgery has the capability of delivering high level accuracy of dose to the lesion without the pain and discomfort due to the pins fixed to the patient’s skull.
The EORTC Emmanuel van de Schueren Fellowship for QA in radiotherapy: Final report on the QA programme, 2002 to 2004

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The Radiation Oncology Group (ROG) of the European Organization for Research and Treatment of Cancer (EORTC) has been developing and conducting quality assurance (QA) procedures for radiation physics, patient and trial oriented since the early eighties. During the last five years, QA activities of the ROG have been supported by the Emmanuel van der Schueren (EVDS) fellowship programme, which was initiated to promote QA in ROG clinical trials and in RT practice in general on a pan-European level. This review summarizes the QA work of the 2nd EVDS fellow and the achievements during the fellowship period from March 2002 to March 2004.

The QA work included development and implementation the QA projects for seven different EORTC trials. Various stages of these projects were completed mentors in close collaboration with the study coordinators of the individual trials. A technology questionnaire to assess the technical infrastructure of the participating centres, dummy runs (DR) on a fictitious patient to document systematic errors, individual case reviews (ICR) on real patients to detect specially random errors in an early phase of the trial and case review form (CRF) evaluations to verify radiotherapy parameters and outcome formed the base of the QA-related work. The phase III randomized trials that formed the subject of this were:

1. conformal RT in localized prostate cancer ± hormonotherapy (EORTC 22991),
2. adjuvant RT ± temozolamide for glioblastoma multiforme (EORTC/22981),
3. ‘boost versus no boost’ trial in breast conserving therapy for early stage breast cancer (EORTC 22881),
4. definitive pelvic RT ± LH-RH analogue for high risk carcinoma of the prostate (EORTC 22863),
5. internal mammary medial supraclavicular irradiation in stage I–III breast cancer (EORTC 22922),
6. conformal adjuvant RT ± CT for pancreas cancer (EORTC 22012),
7. pre-operative radiotherapy +/- concomitant and/or adjuvant chemotherapy in resectable rectal cancer (EORTC 22921).

The technology questionnaire for the prostate trial (EORTC 22991) confirmed that participating centres complied with the essential procedures to deliver conformal RT. The DR evaluation revealed an acceptable compliance to the protocol radiotherapy guidelines. The inaccuracies and deviations were interactively communicated with the participating centres to make the necessary adjustments. Consequently, the results of the ICR, carried out at the onset of the trial, documented only a limited number of minor deviations. The ICR of the adjuvant temozolamide trial (EORTC 22981) revealed strong inter-institutional consistency with a high rate of compliance with the protocol RT guidelines and dose volume recommendations. Comparison of the early with the late ICR of the ‘boost versus no boost’ trial for breast conserving therapy (EORTC 22881) showed an improvement in the second ICR, although continuous monitoring was judged to remain necessary. Evaluations of the CRF for late
toxicity in the EORTC trial 22863 revealed acceptable late toxicity rates with the addition of adjuvant hormonal therapy to definitive radiation in locally advanced prostate cancer. The analysis of the CRF and the questionnaire for the internal mammary chain (IMC) irradiation policy for the EORTC trial 22922 was in accordance with the protocol requirements for field borders, irradiation technique and dose prescription. Most of the centres optimized IMC RT by individualized planning with respect to depth and to a lesser extent to lateralization of the target volume. The CRF evaluation of the EORTC preoperative adjuvant rectum trial (EORTC 22921) revealed an excellent compliance and consistency between centres regarding RT parameters for field size, dose prescription and homogeneity. For the recent pancreas trial (EORTC 22012) a DR was set up and some protocol ambiguities were identified leading to relevant modifications in the protocol and the CRF in cooperation with the participating institutes, study coordinators and EORTC Data Centre team.

The ROG of the EORTC has and still is pioneering QA programmes for clinical trials involving radiotherapy. Compliance with protocol requirements is essential to achieve reliability and homogeneity in treatment execution and to validate the treatment outcomes, especially in multi-institutional trials involving many centres from several countries. The QA Committee of the ROG has become increasingly productive over the last years, supported by the EVDS fellowship programme. Their activities are widely adapted and supported and endorsed by the trial participants. In addition, several relevant aspects of the QA procedures have been consequently implemented into the daily clinical radiotherapy practice.

REFERENCES


Session 3b:  
*Radiation Imaging*  
X RAY COMPUTED TOMOGRAPHY  
QUALITY ASSURANCE
The impact of MDCT on optimization and QA of CT scanners

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Since its introduction into clinical practice in the early 1970s, CT has proved to be a valuable diagnostic tool. Advances in CT technology, particularly the introduction of helical scanning in the early 1990s, and subsequently multi-slice scanners in the late 1990s, have led to increased applications and greater use of CT. The ability to acquire currently up to 64 data slices simultaneously, as well as the increase in tube technology and data handling, have led to a large degree of flexibility in scanning parameters that can be used.

One of the costs of the high level of diagnostic information that can be obtained is radiation dose, and recent estimates have shown that the radiation dose from CT scanning can contribute almost 70% to the population dose from medical exposures. Dose reduction in CT is therefore an important issue, however this must not be achieved at a detriment to the diagnostic quality which is the primary aim of the CT scan. Quality assurance of the whole CT scanning procedure encompasses technical quality, as assessed by quality control procedures, as well as skilled and appropriate use of the scanner. Quality control procedures are important for ensuring the basic physical quality of the CT scanner, however in order to obtain optimum diagnostic quality images at a dose that is as low as is reasonably achievable (ALARA), a good understanding of the scanner and the effect of scan protocols is essential.

The first part of this presentation will outline some of the quality control procedures. An understanding of the influence of scanner parameters will be given. There are a number of resources that can be accessed to establish a quality control system on a CT scanner [1,2,3]. These cover issues such as ‘what to do and when’, ‘how to do it and why’, and ‘practical tips and pitfalls’. It is important to understand the difference between acceptance testing, commissioning and quality control. Many tests may be similar, however practical constraints, such as time available on the scanner, mean that some tests have to be adapted for the quality control procedures. Many of the tests that would be undertaken on a single slice scanner are similar to those carried out on multi-slice scanner. However there are five aspects to be considered when testing a multi-slice scanner: 1) Is the phantom or test object long enough to ensure that the wider beam and all the simultaneously acquired slices are tested? 2) Do you need to measure all of the extensive number of slices or configurations of slices that are available? 3) All the multi-slice scanners have narrower sub-millimetre slices. Can your test object measure down to that thickness? 4) Can you deal with the amount of data you will be generating by imaging many slices of data simultaneously. 5) At what stage, with scanners operating at larger numbers of simultaneously acquired data slices, do you abandon axial scanning and just test in helical mode? These aspect all have to be considered when establishing a quality control testing procedure.

The frequency of the tests has to be considered, as well as which personnel should be assigned the tasks. The UK Institute of Physics and Engineering in Medicine has produced a report Report, ‘Recommended standards for the routine performance testing of diagnostic X ray imaging systems’ [1] which gives guidance on this. It also provides guidance for ‘suppension’ and ‘remedial’ levels of parameters. Phantoms that are to be used consist of commercially available phantoms, such as the CATPHAN or RMI phantoms, those supplied by the scanner
manufacturer, and those made in-house. The scanner manufacturer’s phantoms are often easiest to use and may have quality control software available on the scanner which automatically scans and detects aspects of the scanner that are out of specification. However where a quality control system is to be applied across a number of different scanners external phantoms are preferable.

The second part will focus on the quality assurance of the whole CT scanning process, by looking at the more complex issues of optimization of CT scanning protocols. One important aspect is to define the diagnostic image quality for the particular clinical examination. To do this, the scan length, contrast requirements, patient motion constraints, size of structures imaged and contrast of these structures need to be considered.

It is well accepted as important to keep dose as low as reasonably acceptable or achievable – the ALARA principle. However what is relatively unknown, and poorly addressed until recently is the level of acceptable noise for specific clinical examinations. The ability of the human eye and brain to interpret diagnostic information is very important in establishing an appropriate image quality. A number of studies have been established which are investigating this. For example a study adding simulated noise to brain scans established that certain diagnoses could be still obtained at half the recommended mAs settings [3]. For high contrast imaging, such as lung studies, this could be a low as a tenth of the original dose. Some of the manufacturers have initiated work on this subject by making simulated noise programs available to certain test sites for full clinical studies. Scan parameters such as tube voltage, tube current, scan time, X ray beam collimation, pitch, imaged slice width and reconstruction algorithm will affect the image quality and dose. The setting of each of these parameters needs to be carefully considered to achieve the defined image quality whilst minimizing the radiation dose. For example low contrast resolution increases with narrower slices when the object is smaller than the slice thickness, however to keep image noise constant the dose has to be increased with narrower slices.

Finally, an understanding of tube current modulation software, how it works and its limitations, is essential for obtaining optimum image quality and appropriate dose.

Appropriate quality control testing, and a good understanding of the ability of the new technology in multi-slice scanners, enables good quality assurance systems to be established for the whole scanning process.

REFERENCES

A practical method to the users of radiation for the determination of patient doses in computed tomography

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Introduction

Radiation exposure of patients in CT examinations is best characterized by the weighted dose length product, DLP (in practice the DLPw) which is also directly proportional to the effective dose. The DLP is the most fundamental quantity for CT dose determination because it is the only quantity that can be directly measured. In principle, DLPw would be sufficient for the purpose of setting the diagnostic reference levels (DRLs) and for indicating the dose to the patient. However, for the comparison of different CT techniques and equipment, the weighted multiple scan average dose, MSADw, is also a useful quantity. Practical guidance to the users of radiation for the determination of patient doses in diagnostic radiology, for comparison with the given national DRLs, has been prepared in Finland by STUK.

A key aim of the study was to test a simple and quick integral dose assessment method, in which the patient couch and the measurement phantom are completely separated. An aim of this survey was also to provide updated national DRLs for CT for the purpose of improving the local practise in the pursuit of optimization of patient protection.

Methods of measuring the DLPw and the MSADw in CT

The DLPw-value for the whole examination can be easily measured directly by using a phantom and a radiation monitor (a pencil ionization chamber of 10 cm length) that is fixed at a static position during the whole scan series [1]. Because the phantom with the ionization chamber is hanging above the couch in the centre of the gantry opening, the feed of the couch does not disturb the measurement. The DLPw has been defined by

\[ DLP_{w,\text{tot}} = \int D_{\text{tot}}(z) \, dz \]

The multiple scan average dose, MSADw can be described with the quantity analogous to that for the CTDIvol (IEC 2001), but without the need to refer to the nominal slice thickness. MSADw can be defined as:

\[ MSAD_w = \frac{DLP_{w,\text{tot}}}{d} \]

where d is total axial length of the scanned volume.

Four types of examination were selected to cover a wide range of effective doses

- general abdomen (examinations for further control; optimization can affect doses received by a great number of patients)
- routine chest (important CT examination which can be used for many diseases)
- lumbar spine (high dose level, but the need of examination is often arguable)
- routine head (very common CT examination).
Two groups of scanners were focused on:

1. single slice scanners which have been used before 2000
2. multislice scanners.

The first group consisted of 19 units including all scanner types used in Finland. The multislice scanners consisted of 28 units, of which 19 were 2–10 slice scanners and nine (9) were 16–slice scanners.

Results and conclusions

The developed simple system (a “swing” system) for measuring directly the DLP\textsubscript{w} of the CT examination is quick and user friendly. The feasibility of the results was proved by comparison of the results with that obtained using the conventional method of IEC. Also, the CTDI\textsubscript{vol} was determined by making one scan (DLP\textsubscript{1}) and dividing it with a factor \( \Delta d/NT \) (IEC 2001). Results were equal to the MSAD\textsubscript{w} -value.

The DLP\textsubscript{w} -values (based on all types of scanners) are in general 17–64% lower than the DRLs in Finland. The current DRLs of MSAD\textsubscript{w} appear on one hand too low for chest and abdomen examinations but on the other hand too tight for head and lumbar spine examinations.

As a broad trend, the values of MSAD\textsubscript{w} and DLP\textsubscript{w} appear on the average to be lower for single scanners than for multislice scanners. In particular, the differences in dose between single and multislice scanners appear to be the greatest for examinations with helical scanning mode such as chest and abdomen. Similar trends for increased doses from multislice CT are apparent for head examinations using the axial scanning mode, although this trend is reversed for lumbar spine CT.

The range of CT doses in Finland is similar to that found in UK (NRPB 2005). The variation in dose between hospitals in Finland is a factor of five for chest and abdomen scans. The wide variations of the mean doses between hospitals indicate that the standardization of CT procedures could result in considerable reduction of population doses.

REFERENCES

Assessment and reduction of radiation dose in pediatric computed tomography

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Computed tomography (CT) examinations account for an increasingly large proportion of the population dose due to diagnostic radiology, and paediatric examinations form an important subset of these. Dose assessment and reduction is particularly important for paediatric patients as radiation risk factors are significantly raised compared to the average population. Assessment of dose is complicated by the wide range in patient sizes and there is little high quality data available.

A method has been developed to correlate the risk related quantity, effective dose, to the more simply derived quantity dose-length product (DLP) \cite{1}. This involved scanning a series of paediatric anthropomorphic phantoms, representing different ages, each containing thermoluminescent dosimeters (TLD) to measure effective dose for scans of various anatomic regions. The quantity effective dose per dose-length product was calculated and plotted as a function of patient size. This showed a simple exponential relationship, and equations of fit were derived to enable the calculation of effective dose for a child of any size. This work has been extended to assess the applicability of the conversion coefficients to new generation multislice CT scanners.

One of the issues highlighted by the conversion coefficients produced is the high effective dose per DLP for neonatal head examinations. This arises partly from the relatively high concentration of active red bone marrow in the paediatric skull, but also from the closer proximity of radiosensitive organs to the scan volume than for larger patients. Although the use of lead shielding for protection of sensitive organs and for limiting the radiation beam is strongly recommended in paediatric radiography \cite{2}, and is a reasonably common practice in most centres, its use during CT examination is less frequent. This is largely because scatter from a tightly collimated CT beam is usually assumed to propagate only internally to the patient. A study was thus designed to investigate whether lead shielding, wrapped around the body of a neonate or infant during CT of the head, could be used to significantly reduce the dose and radiation risk to the child.

Organ dose measurements were made using the neonate and one year old anthropomorphic phantoms loaded with TLD as before. The phantoms were scanned using a number of different protocols, and two different CT scanners. For each protocol the measurements were repeated using lead protection around the phantom. The change in effective dose, brought about by use of the lead shielding was determined for each of the experimental techniques used. The change in dose to thyroid and breast tissue was also determined.
The use of the lead shielding reduced the dose to both the neonate and one year old phantoms, for each of the parameters measured and calculated. The reduction in effective dose (Fig. 1) ranged from 5–33%, increasing with irradiated slice thickness, and being greater for the neonatal phantom. Thyroid dose (Fig. 2) was reduced by up to 30%, and breast dose by up to 70%.

The results demonstrate that a significant proportion of the scattered dose during CT impinges from outside the body, rather than being transmitted internally, and thus can be effectively shielded. A trial of routine shielding of babies presenting for head CT has been initiated at a local hospital, in order to assess the practicalities of the technique.

REFERENCES

Computed tomography quality control (QC) status in Sudan

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Quality control (QC) tests were performed to eleven computed tomography (CT) scanners in Khartoum, the capital of Sudan. The work was performed as part of the authorization procedure, which was requested on behalf of the Radiation Protection Technical Committee (RPTC), the regulatory authority in Sudan.

The purpose of the present study is to address malfunctioning of CT scanners and define its impact on image quality and state to which extent it can affect the diagnostic information gained from undergoing CT scanning. For the sake of achieving a thorough study of this issue, the relevant hospital staff – technologists, radiologists and medical engineers – were involved in this study through discussion and questionnaire.

The measurements were performed in accordance with IEC and ImPACT CT quality control protocols [1,2]. The following tests were involved: average CT number for water, CT number uniformity, noise, high contrast resolution, low contrast resolution, slice thickness, and CT number linearity. All scanners under study were tested, different performance phantoms were used as each manufacturer has its own phantom but all are testing same parameters, however each with its own method, e.g. for spatial resolution some using bar pattern while others using drilled holes, but both reflect the same result when expressed in terms of limited resolution in millimetres.

The primary analysis of collected data revealed that more than 60% of scanners under study were installed within the last three years. Nevertheless, the dominant feature among all scanners was the absence of quality assurance and quality control programmes – no acceptance testing is performed upon installation of the equipment, no designated personnel are available for quality control measurements, no preventive maintenance and regular calibration are being conducted. In some units, no performance phantoms were supplied with the scanner, and generally, the importance of quality control is not highly recognized by most of the hospital staff.

Regarding QC test results performed, only one scanner passed all the QC tests. The rest of the scanners were working below optimum. The results could be attributed to equipment miscalibration. Results are expressed as percentage of success, as follows: 62.5, 100, 87.5, 75, 62.5, 100, 100, 75, 75 and 75% for water average CT number, field uniformity, noise, low contrast resolution, high contrast resolution, slice thickness, linearity, table movement accuracy, scan indexing, light field accuracy, respectively.

As has been shown above, the percentage of average CT number for water and high contrast resolution was poor and this could be mainly due to the absence of calibration procedures particularly water calibration as well as software maintenance (algorithms).

Some test failures were selected to be as case studies: One unit, which was recently installed failed to pass light field and table travel accuracy. After investigation, we found that the light
field test failure was a result of failure of table travel. When table travel was 300 mm, the total movement was reduced by 3 mm. This makes the external light not to coincide with the internal light when the scanner moved to scan position. This unit was used for CT guided biopsy; consequently, it may lead to wrong tissue aspiration if the target area is very small.

Another scanner showed very high CT Number for water (135 CT Number), this scanner was not calibrated for seven months. The calibration service is assigned to a company dealer in the neighbouring country. It would cost too much to be calibrated regularly so the equipment owner delayed it until equipment failure take place. Also one of scanners show very poor low contrast resolution. To that extent, if there is focal lesion of 15 mm diameter in contrast, a 1% level from background can not be clearly identified; then possibility of misdiagnosis is high.

All of the above can lead to increased patient dose from CT examinations, which is among the highest in diagnostic radiology.

Recommendations were made to targeted hospitals to perform periodic calibrations for their facilities and to purchase quality control kits and ask for assistance for possible development of their own quality assurance programs and train their staff in CT equipment quality control.

In addition, effective regulatory control can contribute to improvement of CT QC status in Sudan. RPTC was advised to obligate equipment suppliers to provide calibration and maintenance service locally and train local staff in these issues in order to improve the situation.

\[\text{FIG. 1. QC tests results: Success versus failure of all scanners tested.}\]

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Evaluation of performance of computed tomography scanners in Tanzania

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The performance characteristics of CT scanners were evaluated from five large hospitals using the quality criteria proposed by the EC [1]. The performance characteristics evaluated in this study include dose related parameters, physical image quality parameters, diagnostic image criteria and patient doses. The dose related technical parameters employed by each scanner in this study were verified in terms of beam alignment, slice thickness accuracy, kV reproducibility and accuracy, output reproducibility and linearity, and half value layer (HVL) measurements. These parameters were verified using non-invasive X ray test device (Victoreen, model 4000+SI), a pencil ionization chamber (Diados, type M3009, PTW-Freiburg) coupled to electrometer (Diados, type 11003, PTW-Freiburg), and a CT performance phantom (Victoreen, model 76-410-4130) of 21.5 cm diameter. Methods for verifications of these parameters were based on those described in the AAPM Report #39 [2].

The physical image quality performance of a CT scanner from typical scanning techniques employed by each scanner was objectively evaluated in terms of CT number accuracy and linearity, CT image noise and uniformity, and subjectively evaluated in terms of high and low contrast resolution. The above tests were evaluated using CT performance phantom described above. Methods for evaluation of these tests were based on those described in the AAPM Report #39 [2]. The image quality evaluations were performed by utilizing the defined set of diagnostic image criteria proposed by EC guidelines for general CT examination of head, chest and abdomen [1]. Two experienced radiologists using criteria recommended by the EC subjectively evaluated the qualities of these images. Estimation of patient dose in terms of weighted CT dose index (CTDI\textsubscript{w}), and dose length product (DLP) were performed using ion chamber by employing standard phantoms and typical exposure parameters [1].

The results of dose related and physical image quality indicate that most of the CT facilities under study were within recommended tolerance limits, suggesting that maintenance of CT although irregular was adequate. The mean percentage image quality score for general CT examinations of head, chest and abdomen were 71\%, 68\% and 61\%, respectively. The mean values of CTDI\textsubscript{w} per examination for almost all hospitals were below the reference dose levels (RDLs), while the mean values of DLP per hospital for all except the head were above the proposed RDLs as shown in Fig. 1 [1]. The poor performance of CT scanners in terms of high values of DLP and image criteria score might be largely attributed to the lack of optimal use of CT due to inadequate skills and lack of in house quality assurance programs. It was therefore concluded that scanning parameters should be optimized and training programmes introduced for CT personnel.
FIG. 1 Dose length product (DLP) per hospital by examination type normalized to reference dose levels (RDLs).

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Doses in computed tomography

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Introduction

The decree on safe use of ionizing radiation in healthcare issued by the Polish Ministry of Health [1] provides a clear guidance on the doses in CT. Values of CTDIw and DLP should not exceed reference dose levels, which are set for several regions of the body. Polish reference dose levels have been adapted from guidelines published by the EC [2].

Materials and methods

In this study we investigated doses for a group of 484 patients who underwent an examination on a single slice GE HiSpeed CT scanner at the Centre of Oncology in Warsaw. Patients have been divided into 9 groups depending on the examined region of the body. Each group includes both diagnostic examinations and examinations for radiotherapy treatment planning. Measurements of CTDIw have been performed for selected examination protocols. We used a PTW Unidos dosimeter and ionization chamber PTW 77336 (calibrated at the SSDL Centre of Oncology in Warsaw). Measured doses have been compared with values displayed on the CT console. Problem of doses absorbed by patient during tomography used for therapy planning is usually ignored (doses in teleradiotherapy are much higher). It needs to be considered that during the therapy dose exposure is moderated to protect critical organs, but during tomography whole imaged slice is irradiated.

Results and discussion

The values of CTDIw displayed on the CT scanner console agree with results of the measurements within ±10% tolerance. Tab.1 presents observed values of CTDIw and DLP compared with the reference levels. The average doses (DLP) for diagnostic patient groups is 5–30% higher then for radiotherapy patient groups.

TABLE 1. SOME VALUES OF CTDIw FOR EACH REGION OF THE BODY

<table>
<thead>
<tr>
<th>Body region</th>
<th>Number of patients</th>
<th>CTDIw (mGy)</th>
<th>DLP (mGy × cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>57</td>
<td>5.3</td>
<td>26.8</td>
</tr>
<tr>
<td>Head/neck</td>
<td>47</td>
<td>6.9</td>
<td>28.5</td>
</tr>
<tr>
<td>Chest</td>
<td>107</td>
<td>4.4</td>
<td>14.4</td>
</tr>
<tr>
<td>Breast</td>
<td>43</td>
<td>4.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Abdomen</td>
<td>26</td>
<td>5.9</td>
<td>11</td>
</tr>
<tr>
<td>Stomach</td>
<td>14</td>
<td>4.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Pelvis</td>
<td>62</td>
<td>6.8</td>
<td>17.8</td>
</tr>
<tr>
<td>Prostate</td>
<td>113</td>
<td>7.1</td>
<td>9.5</td>
</tr>
</tbody>
</table>
Conclusions

Typical patient doses for a GE HiSpeed scanner at the Centre of Oncology in Warsaw do not exceed reference values. Reference dose levels are defined only for a standard size patients, therefore sometimes they are exceeded for properly done examinations. Polish reference dose levels are not based on up to date data, their revision should be considered. Doses for radiotherapy patients are less than for diagnostic patients.

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An action plan for dose reduction from computed tomography in Luxembourg

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Computed tomography (CT) is generally associated with high performance in radiological diagnostics, but also with high patient dose \cite{1}. The last developments towards faster CT scan systems (spiral, MSCT) and PACS archiving allow wide scan volumes and an increased passage of patients. Actual data from Luxembourg \cite{2} shows that CT contributed with 1 mSv 50% to the collective dose in 2002, comparable to the international trend of increased CT examinations frequency. Luxembourg has reached today with 157 exams per 1000 inhabitants one of the highest CT examination rate compared to other health care level I countries, which were reported by UNSCEAR with an average of 57 exams per 1000 inhabitants \cite{3}.

The European Directive 97/43/EURATOM \cite{4} has been implemented in the Grand Duchy of Luxembourg with the ordinance of March 16\textsuperscript{th} 2001 \cite{5}. This ordinance regulates the measures towards the radiation protection of patients, as well as the role of the medical physics experts in the realization of quality assurance controls. The Radiation Protection Department of the Ministry of Health has planned in cooperation with the Luxembourgish Association of Hospitals, which employs the medical physicists working in diagnostic radiology, actions in order to reduce the collective dose from computed tomography:

1. Carrying out a dose measurement survey using a CT-phantom and by evaluating a representative number of patient doses through a dedicated software \cite{6}.

2. Analysing the clinical protocols of the most common CT-examinations by a working group of specialists (physicians, radiographers and medical physicists) in order to optimize and if necessary standardize them.

3. Establishing lower national Diagnostic Reference Levels (DRL) compared to the European ones by taking into account the results of the dose survey as well as the optimization procedures of the protocols. Special DRLs will be defined for pediatric patients because of the higher radiation risk involved.

4. Developing an electronic X ray card for the population of Luxembourg using the records of the radiological information systems (RIS) of the hospitals and the HealthNet infrastructure (a national intranet). This project is embeded in the national e-health plan, having as main objective to avoid unnecessary repeated radiological examinations and to provide the health authorities with current frequency data for future collective dose calculations.

5. Improving the justification of radiological examinations by introducing referral guidelines for imaging focused on the CT in relation with other modalities like MRI and
ultrasound. As shown in Fig 1, the increment of MRI exams since 2002 in Luxembourg did not decrease the CT frequency as expected.

6. Providing regular feedback to all participants and partners involved in this work in order to show them the importance of their actions in dose reduction from computed tomography imaging.

The practical implementation of this action plan should show first results before the end of this year and could be part of international activities like the WHO CT Safety Project.

![Graph showing evolution of CT and MRI frequency in Luxembourg between 1994 and 2004](image)

**FIG. 1. Evolution of CT and MRI frequency in Luxembourg between 1994 and 2004.**

**REFERENCES**


Experience of Lithuania in creating quality systems in computed
tomography

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Quality assurance in radiological departments is an important tool for optimization of radiation protection of patients. Creation of quality systems is a complicated task which requires a high competence and broad experience of all the involved parties. In 2002–2005 the Radiation Protection Centre together with partners from the Netherlands pursued the MATRA project “Improvement of the Capacity of Services Essential for Radiation Protection in Medicine”. The main goal of this project was creation and implementation of quality assurance systems in pilot Lithuanian hospitals of different levels.

The first phase of the project was to select pilot hospitals and to form the team in each hospital. Hospitals of different levels have been selected. Two university hospitals, one large city hospital and one small regional hospital, were included. The team for creation and implementation of a quality assurance programme in the hospital was composed of a radiologist, a medical physicist (in non-university hospitals – technical maintenance staff) and a radiographer. Two week training courses on radiation protection, quality assurance and practical quality control measurements for these teams were organized. Lectures for short one day and two day training courses for hospital staff after training courses were prepared.

The plan for the creation and implementation of a quality assurance system was prepared. It contained five main steps. The first step was preparation. In this step quality assurance objectives, scope, identification of main and additional processes and determination of the Quality Manual structure were defined. The second step was preparation of the Quality Manual according to the local conditions of the hospital. Then such steps as description of main procedures and chains, identification of non-conformities and taking actions, creation of internal audit and quality assurance evaluation system in hospital followed.

One of the most difficult steps was preparation of the Quality Manual. The problem was to clearly identify and describe all points on which quality in radiology department depends. It should be described correctly and with enough details. The Quality Manual should be approved and confirmed by the head of the hospital. The hospital head should state a commitment to support and keep a quality assurance system on the appropriate level.

The task of the radiology departments was to bring in the main processes. The processes were divided into clinical procedures, processes related with staff, purchasing, maintenance, calibration and quality control of X ray equipment and accessories and the procedure for reviewing of the Quality Manual. For simplification of the description of these processes and procedures, they were grouped into main chains such as patients, staff, equipment and Quality Manual which were later analysed and described separately.

The “chain” of patients contains the following described elements: individual justification of examination, identification and information of patient, selecting of optimized parameters and correct positioning of patient, registration and form of registration of sufficient information...
about the examination and patient, exposure, evaluation of images, evaluation of diagnosis, archiving.

The chain of equipment refers to the “Life time cycle of X ray machine” and describes the elements like justification of need, equipment specification, tendering, contracting, installation, acceptance, status (commissioning) tests, training, clinical use, quality control testing and maintenance, alternative use, decommissioning of equipment.

After preparing the Quality Manuals and all the annexes, training courses for the hospital staff on radiation protection and quality assurance, and on quality control measurements and responsibilities were performed by members of the teams from pilot hospitals.

The appropriate practical recommendations for hospitals were created on the basis of quality manuals of pilot hospitals and subsequently published. All the measures helped to intensify creation and implementation of quality systems in radiology.

The experience gained in the creation of quality systems in conventional radiology was used for the same task in CT. It has been done also in cooperation with the Dutch exerts. In general the same approach was used. However, comparing with conventional radiology, the following differences should be cited:

− three pilot hospitals were selected for implementation of the project,
− teams from pilot hospitals were studying quality control tests to be carried out in CT,
− training material specific for CT was prepared and special training courses related with CT were held.

It became evident that structural approach might be used in achieving such complicated tasks as creation of quality systems in different areas of radiology, including CT. Many elements of quality control available in conventional radiology might be used for CT. It helps to increase efficiency of performance and make best use of available resources.
Quality control in computed tomography system

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Computed tomography (CT) is a technique providing excellent radiographic contrast between soft tissues and high quality clinical information for localized planes within the body. The widespread use of this technique has the potential to make the largest overall contribution to radiation dose to the patients from amongst all diagnostic medical X ray modalities. CT constitutes about 4\% of all examinations but contributes to about 40\% of the total patient dose from the use of medical X rays \cite{1}.

On the basis of the range of practice for ensuring better control of patient dose, safety and image quality in CT, it is necessary to perform a more systematic approach to the optimization of all exposure. So that the set of operations is intended to improve quality and should be carried out to the CT systems to optimum levels for all characteristics \cite{2}.

Quality control is an operational technique and activity that is used to fulfill requirements for quality. It involves techniques that monitor a process and eliminate causes of unsatisfactory performance at all stages of the quality loop \cite{3}. The objectives of quality control in CT are:

- Maximize of the diagnostic information (image quality).
- Maximize patient safety (no mechanical damage and minimum radiation dose).
- Minimizes operational cost.

Quality control tests were performed on a General Electric spiral single slice CT scanner in the Damansara Specialist Hospital. Test phantoms of a standardized human shape or test objects of a particular shape, size and structure (CATPHAN 500) are used for the purpose of calibration and evaluation of the performances of CT scanners. This type of phantom is used to test system performance including noise, CT number uniformity, CT number linearity, spatial resolution, low contrast resolution, z-sensitivity (imaged slice width), slice thickness, dose, etc. PTW DIADOS electrometer and CT chamber type 30009 are part of the computed tomography dose index (CTDI) set which makes CTDI and CTDIw determinations. Supporting envelope-wrapped X ray film at the gantry end of the patient table was used to assess the accuracy of gantry tilt and dose profiles (irradiated slice width).

Results show that the CT number calibration in water, air, CATPHAN phantom and its uniformity were less than 2.2 HU and comply with the standard limit and also have a linear relation to the attenuation coefficient.

The weighted computed tomography dose index (CTDI) for head is measured at 17.37 $\mu$Gy/slice and is three times that of the reference CDTI provided by the manufacturer, but it was constant for different settings in milliamperes (mA).
Low and high contrast resolution and measured slice thickness are placed within acceptable range and full width of half maximum (FWHM) decreased by increasing slice thickness, which means the resolution is decreased. All scan localization tests and X ray generator tests were within acceptable limits.

The radiation dose profile in all available slice thicknesses were wider in the middle part compared to the right and left sides, and also had a bigger penumbra in the middle part of the image. Variation of the noise was less than 6 HU for the body and less than 2.5 HU for the head phantom; algorithm consistency and gantry tilt corresponded with the limits.

Variation of kVp for all available range was less than 2.9 kVp and was acceptable. Percentages of variation of timer accuracy is measured less than 3.3 and is in acceptable range.

REFERENCES


The first experience of application spiral computer tomography (SCT) in oncology

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Clinical applications of spiral computer tomography (CT) scanning have augmented expansively over the past decade and continue to extend rapidly. Implementation of the three-dimensional (3D) reconstruction in CT technology has revolutionized medical imaging. This improvement has been possible due to the combination of spiral CT and various 3D reconstruction protocols which have permitted rapid and comprehensive examination of all regions of the body. Due to the efforts of the IAFA in the Republic of Moldova, the first SCT SOMATOM AR Star had been launched. This method has received a great deal of attention and at present includes numerous applications in oncology, especially for diagnosis, pre-operative management and planning in conventional radiotherapy treatment.

From January 2005, using SCT, we investigated 243 patients with tumours localized in different anatomic regions: 72 head and neck, 26 lungs and mediastinum, 21 liver, 18 pancreas, 26 kidney, 5 adrenal glands, 38 pelvic, 34 musculoskeletal, 3 non-organs retroperitoneal tumours; ranging from 5 to 72 years of age. In 56% of cases SCT was performed to stabilize diagnosis and preoperative management, and 44% of patients undergone radiotherapy.

The initial standard procedure was to perform a topogram. Using the protocol, axial CT data were obtained after 1 mm sections intervals without and after intravenous injection of contrast substance Urografin 76% by schedule. This yielded images which were then sent to a work station for 3D reconstruction which was done using: Multi Planar Reconstruction (MPR), Shaded Surface Display (SSD), Maximum Intensity Projection (MIP) algorithms.

The axial and 3D images of the patients under study were analysed and the virtual surgical procedures were designed, describing the tumour localization, the shape and the size, the numbers of tumour nodes, the tumour contour and the presence of capsule, the grade of tumour destruction, the topography of adjacent organs and the direction of dystopia, the structure density. Combining precise imaging techniques with radiation sources and high performance computing is improving our ability to shape radiation treatments to the tumour’s three-dimensional contours.

Pre-operative evaluation of three-dimensional tumour structure and volumetry using 3D SCT was for us more important especially in parenchymal organ establishments.

In cooperation with thoracic surgeons, we analysed 7 lung tumour patients in order to appreciate the three dimensional position of the tumour and adjacent structures, and to plan the virtual procedures for the operation. The 3D reconstruction permitted a better comprehension of the topography of organs, as well as helped stabilize access to perform thoracoscopy and thoracotomy which were essential especially in peripheral lung tumours. For the central lung tumours it was better to execute 3D reconstruction together with virtual bronchoscopy.
Operation planning in liver surgery depends on precise understanding of the 3D relation in the topography of liver tumours and major hepatic vessels. In three patients the tumours had to be assigned to a liver segment and subsequently drawn together with the operation proposal into a given liver model.

In radiation therapy the 3D SCT is important to determine the stereotactic coordinates of tumours and anatomic reference points in each tumour region. Together with radiotherapists, using 3D SCT, we investigated 107 patients to stabilize the optimal method for high dose radiation therapy and focus precision. Additionally, the same 3D SCT was used to establish the efficiency of acquired radiotherapy.

Using a CT scanner, an experienced radiologist can diagnose many pathological statements enabling faster treatment and often eliminating the need for additional, more invasive diagnostic procedures. Unlike other imaging methods, CT scanning offers detailed views of many types of tissue, including the lungs, bones, soft tissues and blood vessels. CT scanning is painless, non-invasive and accurate. Diagnosis made with the assistance of CT can eliminate the need for invasive exploratory surgery and surgical biopsy. CT scanning can identify normal and abnormal structures, making it a useful tool to guide radiotherapy, needle biopsies and other minimally invasive procedures.

Being able to distinguish between cancerous and normal tissue allows us to deliver treatments only to diseased tissues and in a minimally invasive way, and has the potential to minimize surgical trauma, shorten recovery time and reduce health costs.
Quality control of computed tomography systems in Bulgaria

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Computed tomography (CT) examinations are only 5% of the total diagnostic radiology procedures but give more than 40% of the total radiation dose. The number of CT units in Bulgaria increased rapidly in the last ten years, from 22 CT units in 1996 to over 110 in 2005. CT systems used in a clinical practice are of different generations and age that determine the differences in their characteristics causing variation in image quality and radiation dose. Objective quality criteria for performance assessment of X ray equipment were approved recently in Bulgaria with an Ordinance of the Ministry of Health for Protection of Individuals at Medical Exposure [1]. The present work provides a summary of the basic tests used to assess the performance of CT units and presents the first results of the pilot project on implementation of the developed QC protocol on ten CT units in the country.

QC tests cover testing of the X ray tube and generator performance, measurement of dose quantities computed tomography dose index (CTDI) for a single slice and dose length product (DLP) for the complete examination as well as some basic tests of image quality assessment [1,2,3].

Accuracy and reproducibility of the tube voltage were measured by the multifunctional instrument Barracuda (RTI, Sweden) with a detector, calibrated for tube voltages between 75 and 145 kV and for two type of filtration, 3 mm Al and 3 mm Al + 0,25 mm Cu. Half value layer (HVL) was measured with a dedicated CT ionization chamber with a length of 100 mm, type TW30009 connected to a dosimeter Unidos E type T10-009 (PTW Freiburg, Germany). The same chamber was used to measure CTDI free in air at the centre of rotation, as well as CTDI in a dedicated standard PMMA CT phantom. Measurements for the head and body regions were made with the corresponding part of the phantom, each comprising a central and four peripheral cylindrical holes for the chamber positioning. Geometrical parameters as the positioning and slice thickness were measured with a phantom and a film. Image quality was checked in a series of measurements of the noise, values of the CT numbers for water and tissue equivalent materials, CT number homogeneity and linearity, image low and high contrast resolution. Dedicated phantom was used for that purpose.

As a pilot project the developed protocol was tested for ten CT systems in clinical use at different hospitals: three Siemens systems, three GE systems, three Philips systems and one Shimadzu system.

Only for one of the tested systems that the tube voltage inaccuracy was found to be out of the level of acceptability. For all others, tube and generator performance, including tube voltage reproducibility and HVL were found to comply with the requirements. The maximum deviation of normalized $n_{CTDIAir}$ measured free in air from the nominal value was found to be 10.5%. The differences between the measured and nominal values for the weighted $n_{CTDIw}$ measured in the body phantom were less than 10%, but for the head phantom one of the scanners demonstrated 28% difference that can be explained by the difference between this unit and the prototype. Image quality assessment also demonstrated diversion from the
limiting value for some scanners. The most critical was found to be the calibration of the CT numbers for water where two of the systems demonstrated difference up to 6.9%.

This pilot survey demonstrated the important role of QC as an objective tool in finding the problems and in further improving the performance of the CT systems.

REFERENCES


Session 3c:
Radiation Imaging
IMPACT OF QUALITY MANAGEMENT ON CLINICAL NUCLEAR MEDICINE PRACTICE
Impact of quality management on clinical nuclear medicine practice

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In many countries, imaging facilities are simply not available or not functioning. In other areas, a large number of images are of poor quality and are of no diagnostic use. Many are also misread and this is frequent in developing as well as in developed countries. The main reason is the lack of adequately trained medical specialists, including radiologists, nuclear medicine physicians, physicists and technologists. Inadequate training means a lack of qualified personnel and improper use of equipment and incorrect interpretation of images. Lack of appropriate technology due to limited resources, poor maintenance of existing equipment due to a lack of available parts and inadequate training are also important factors affecting the clinical usefulness of imaging tests.

Recent reports of the European Commission and of the Italian Agency for Regional Health Services have documented that up to 30–50% of imaging tests are partially or totally inappropriate. Inappropriate selection of tests determines doubtful or inconclusive results which may request a further sequence of inappropriate tests. Wrong tests may produce wrong results and wrong diagnoses and, therefore, wrong and dangerous treatments. The most frequent causes are: 1) repeating investigations that have already been done, 2) investigation when results are unlikely to affect patient management, 3) investigating too often, 4) doing the wrong investigation, 5) failing to provide appropriate clinical information and questions that the imaging investigation should answer, (6) over investigating.

Clinicians, when considering the need of an imaging test, should first investigate themselves with a very simple question: what will I do after a positive or negative result? If the answer is “nothing in both cases” that means that the request is not justified.

The first step of quality control in clinical practice is the application of guidelines aimed to define useful application of imaging tests. Guidelines are systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances. Correct indications to imaging are furthermore mandatory when applying tests which imply radiation exposure. Radiation exposure of the general population for medical purposes has doubled in the last decade due to an intensive application of radiology and nuclear medicine studies. It is important to underline that an exposure to 10 mSievert corresponds to an increase of 15 year lethal cancer rate by 2–3 new cancers every 10 000 exposures.

When the decision of prescribing a nuclear medicine test is taken, the second step is the selection of labs practicing severe quality control procedures on imaging. A practical advice for lab selection is to verify if the report contains the following items:

- Clinical reason for performing the test
- Description of the adopted procedure
- Detailed descriptions of findings
- Clinical conclusions
- Presence of an interpretable hard copy of results.
All imaging tests are affected by artefacts causing false interpretations and determining a fall in specificity.

Specifically, nuclear imaging is affected by artefacts which can deteriorate image quality and limit interpretation of SPECT and PET results. Each organ or apparatus present specific problems. Imaging of the heart is a difficult task with all different technologies due to the asymmetrical shape and the asymmetrical position inside the thorax. Moreover the contractile function determines a variation of shape, geometry, position and density during the cardiac cycle. Similar problems affect tests evaluating lung anatomy and function when the time needed to complete test acquisition is too long to allow the completion of acquisition during apnoea or the patient cannot hold breath.

Conversely, imaging of brain needs an accurate patient positioning for symmetrical evaluation of both hemispheres, whose evaluation is usually due by comparison of symmetrical structures.

Artefacts in nuclear medicine can be categorized in four main subgroups:

1. mechanical and electronic
2. biological
3. patient-related
4. technical.

Biological and patient related artefacts cannot be avoided in many cases and they need a vast knowledge of physiopathological mechanisms producing artefacts. They usually require correction protocols, when available.

Artefacts are very common in nuclear cardiology. Myocardial hypertrophy often causes a transitory ischemic dilation after stress related to hypoperfusion of the subendocardial layer not necessarily related to lesions of epicardial coronaries.

Many papers document a high rate of false positive results in patients with left bundle branch block both in terms of fixed and reversible perfusion defects. A careful evaluation of extent and severity of defects may help to overcome the problem as well as gated-SPECT due to its ability to compare wall motion with perfusion and wall thickening. Gating offers also the possibility to recognize artefacts due to abnormal cardiac position within the thorax that frequently occurs after open-chest surgery.

In PET imaging a myriad of inflammatory diseases (including abdominal and pelvic abscesses, liver abscess, brain abscess, lung abscess, renal abscess, hepatic and renal cyst infection, salpingoophoritis and tubo-ovarian abscess, pneumonia, osteomyelitis, infected arthroplasty, tuberculosis, echinococcosis, aspergillosis, atypical mycobacterial infection, mastitis, enterocolitis, infectious mononucleosis, sinusitis, sarcoidosis, asthma, myositis, thyroiditis, mediastinitis, gastritis, pancreatitis) can mimic neoplasm uptake in patients affected by malignant diseases.

In conclusion, SPECT and PET imaging is a powerful tool for diagnosis, risk stratification, follow-up, and therapy management. Its effectiveness is sometimes limited by a loss of specificity due to image artefacts, thus significantly affecting patient management. Accurate patient selection and ability to recognize the sources of artefacts to avoid misinterpretations are the best option to improve imaging test specificity and effectiveness.
Influence of extracardiac activity and perfusion abnormalities on the results of myocardial gated SPECT with commercial software


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Introduction

Isotopic myocardial perfusion single photon emission computed tomography (SPECT) studies, gated with electrocardiogram signal, are currently used to assess coronary artery disease (CAD) patients. The excellent sensitivity of the technique for detecting ischemia or necrotic areas depends on different clinical and technical parameters, mainly, from strict quality control of the acquisition and processing. Extracardiac activity of the radiotracer (commonly in intestinal loops or liver) overlapping or adjacent to myocardium can affect the interpretation. Available software for gamma cameras includes automatic myocardial edging programs that allow manual intervention. Our interest was to assess the impact of the manual or automatic method in common clinical conditions observed using current myocardial perfusion protocols. The main hypotheses were: a) adjacent extracardiac activity affects significantly automatic edging, furthermore if perfusion abnormalities co-exist, b) interoperator reproducibility of the semiautomatic processing is also affected by these events.

Methods

From 350 myocardial SPECT perfusion tests performed in the last semester, we selected 100, (47 females, age: 63±14 years), 50 with and 50 without extracardiac activity. Each sub-group included 25 cases with perfusion abnormalities and 25 without them. Patients that moved during the test, miscorrected by motion-correction software were excluded. \(^{99m}\)Tc-Sestamibi was used in 77 cases (gated in both phases) and \(^{201}\)Thallium (gated only at rest) in 23 patients. Dipyridamol stress protocol was used in 82 cases, exercise stress in 13, and 1 case with viability protocol. A Dual Head Siemens ECAM 180 was used and an acquisition protocol was included: orbit 180°, collimators in 45°, gated: 8 frames. The post stress acquisition was performed within the hour post-injection. All cases were processed automatically and by four independent operators (physicians with different level of training in nuclear cardiology, rated accordingly 1 through 4, where Nº1 was the most experienced). They used the available software tools to mask and relocate the cardiac area when necessary. For the analysis, commercial software QGS and QPS (Cedars) was used. The software provides automatic functional and perfusion parameters. We analysed left diastolic and systolic ventricular volumes (EDV and ESV), left ventricular ejection fraction (LVEF) and reversibility perfusion score (SDS) as well as perfusion defect extension, at rest. Resulting data were compared using correlation Pearson test and student t test.

Results

A. Whole group. Automatic LVEF, volumes and perfusion parameters of ischemia and rest perfusion defects are shown in Table 1. Regarding functional parameters, the mean values
between processings were not statistically different for volumes and for LVEF, excluding operator 2 with 4 and automatic with operator 4 (p<0.01). The correlations between operators and automatic software for LVEF ranged between: 0.90–9.96, interoperator ranged between 0.90–0.96; for Volumes: 0.86–0.99 and 0.87–0.98; for SDS: 0.81–0.87 and 0.81–0.94; for Extension at rest: 0.74–0.88 and 0.74–0.99, respectively.

B. Comparative analysis in groups with and without extracardiac activity. The interoperator correlations were worse in patients with extracardiac activity compared with those without it, with a wider range of values: Average LVEF r: 0.95 vs 0.94 [range: 0.89–0.96 vs 0.90–0.95]; Average Volumes r: 0.91 vs 0.93 [range: 0.83–0.98 vs 0.91–0.98]; Average SDS r: 0.89 vs 0.92 [range: 0.85–0.92 vs 0.88–0.96]; Average Rest Extent r: 0.86 vs 0.99 [range: 0.73–0.98 vs 0.99–0.995]

C. Comparative analysis in groups with and without myocardial perfusion abnormalities. The interoperator correlations were not affected by the presence of perfusion defects versus those patients with normal radiotracer uptake, but a wider range was observed among the latter: Average LVEF r: 0.95 vs 0.89 [range: 0.93–0.98 vs 0.82–0.95]; Average Volumes r: 0.94 vs 0.85 [range: 0.92–0.99 vs 0.74–0.96]; Average SDS r: 0.88 vs 0.74 [range: 0.85–0.93 vs 0.48–0.88]; Average Rest Extent r: 0.99 vs 0.47 [range: 0.98–0.99 vs 0.79–0.98].

Conclusions

Our patient database included mostly Sestamibi as a radiotracer and Dipyridamol as pharmacological stress studies. These factors increase the presence of liver activity by biliar tracer excretion to intestines and splenic vasodilation, respectively. Accordingly, our incidence of extracardiac activity was higher than found in the exercise and Thallium protocols. Extracardiac activity affects the assessment of the automatic QGS software in a moderate degree, even when manual intervention is applied. The reproducibility of the results among different operators worsens when significant hepatic or intestinal activity close to the myocardium is present. The presence of perfusion abnormalities does not interfere with the reproducibility of the programme, and, surprisingly, a better correlation among operators was found in all functional and perfusion parameters studied, when they were present. Interoperator reproducibility was higher for functional than for perfusion parameters.

TABLE 1. PERFUSION AND FUNCTIONAL PARAMETERS IN THE WHOLE GROUP

<table>
<thead>
<tr>
<th></th>
<th>Automatic</th>
<th>Operator 1</th>
<th>Operator 2</th>
<th>Operator 3</th>
<th>Operator 4</th>
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<td>LVEF (%)</td>
<td>60.3±19.6</td>
<td>56.1±18.5</td>
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<td>Volumes (ml)</td>
<td>62.6±55.0</td>
<td>63.7±50.2</td>
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<td>SDS</td>
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<td>5.3±4.2</td>
<td>5.1±4.8</td>
<td>4.6±3.8</td>
<td>4.9±3.8</td>
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<tr>
<td>Rest extent (%)</td>
<td>9.2±14.6</td>
<td>6.3±11.5</td>
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Comparison of SPECT and Planar techniques in multigated equilibrium radioventriculography (MUGA): Analysis of ejection fraction and ventricular volumes


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Introduction

Clinically, planar radioventriculography (MUGA) is a well accepted technique for ejection fraction measurement, specially in left ventricle (LVEF) in coronary artery disease (CAD) and cardio-toxicity evaluation, due to its accuracy and reproducibility. Right ventricular ejection fraction (RVEF) has difficulties due to cavities superposition. Currently, an automatic program is available for single photon emission tomography (SPECT), offering fast information about biventricular parameters. It has been suggested that this method could replace planar images because it is able to separate cavities using edge detection analysis in a more effective way.

Aims

1. Correlate side by side planar with SPECT MUGA parameters in patients with different cavity size and wall motion abnormalities
2. Evaluate inter-operator reproducibility in both methods.

Methods

Population: 83 studies included prospectively corresponding to CAD, cardio-toxicity and other cardiopathies; their mean age was 56±14 years; 56% of them women. There were 34 patients with normal cardiac function (mainly corresponding to prechemotherapy women). Technique: MUGA was performed with in vivo red blood cells labeling with $^{99m}$Tc. A SPECT was acquired in a Dual Head Siemens ECAM 180. Orbit: 180° with collimators in 45° and immediately in the best septum image a planar study. The EKG gated was with 8 and 24 frames, respectively. Processing: Automatic program QBS (Cedars) was applied for SPECT and automatic and manual processing for planar studies. LVEF and RVEF as well as ventricular end-systolic and end-diastolic volumes (ESV and EDV) were obtained. Left ventricular volumes in planar images were calculated using a prior validated count-based method without blood sampling. For reproducibility we compared the initial routine processing of both acquisition with a 2° processing performed by a different observer with similar parameters. Motion correction was used for SPECT if it was necessary. Analysis: Mean differences were compared with student t test for paired samples and with Pearson correlation.

Results

1. Whole group

- Automatic planar LVEF could not be calculated by the program.
QBS program required manual adjustment of cardiac area in <10% of the processing, those cases presented more differences in LVEF second calculation.

Whole group ejection fractions and volumes showed no difference between the automatic-manual and manual-SPECT LVEF (p<0.05).

There was difference between automatic-SPECT LVEF with (p=0.0391) and in RVEF (p=0.018). Left ventricular volumes were also different (p<0.05).

Correlation between manual planar and SPECT in the whole group was better for LVEF (r:0.845) than for RVEF (r:0.688). Correlation between automatic LVEF and SPECT was adequate (r:0.8451). In the left ventricle, volume correlations were excellent (EDV r:0.927 and ESV r:0.939).

2. Normal function group

In the sub-group with normal function, left ventricular parameters were: LVEF manual planar: 55±11% and 54±6% for SPECT (p=ns); EDV: 86±37ml in planar and 66±36ml for SPECT (p=0.02); ESV were 37±18ml and 32±21ml, respectively (p=ns).

LVEF and all volume correlations were smaller in the group with normal ventricular function versus the dysfunctional ones (r:076 versus 0.92). Volumes and LVEF slopes in patients with normal function were also smaller – 0.68 and 0.89, respectively.

3. Interoperator reproductibility

Correlations between both operators, results for LVEF and RVEF planar MUGA were 0.933 and 0.821 and for LVEF and RVEF SPECT were 0.944 and 0.932, respectively.

There were no differences between means of data obtained for both operators (p=ns).

Conclusions

99mTc red blood cells MUGA is a reliable method for LVEF determination, with both planar and SPECT methods. In left ventricular volumes correlation of SPECT with counts-based method is also adequate. SPECT has a good yield in the presence of functional alterations, otherwise, as it was observed in clinical practice, in small hearts with normal function a worse correlation was found as well as underestimated volumes by SPECT.

Excellent interoperator correlation in SPECT and planar techniques confirm their high reproducibility.

BIBLIOGRAPHY


QA teaching needs for non-nuclear professionals using gamma probes


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Introduction

In Latin America, Gamma Probes (GP) for radioguided surgery are gaining popularity. This method is used for sentinel lymph node (SLN) detection, tumour localization and excision, as well as location of biopsy sites for tumours and orthopaedic infections. Gamma probes used in surgery are similar to conventional in vivo uptake probes and are very well known by nuclear professionals. Special tests have to be performed to accept them for routine work. In Latin America, non-nuclear professionals (surgeons) are generally the owners of this kind of equipment. They are not trained in nuclear counting techniques; therefore there is a deficiency in professional judgement and performance during the procedures. In addition, there is no law that regulates renting and/or buying of equipment. This lack of quality care and regulation may result in poor patient treatment.

Objectives

Our aim was to demonstrate that there is a need to develop teaching programmes for non-nuclear professionals in the handling of gamma probes techniques: selecting the appropriate gamma-probe, getting reliable surgical outcomes throughout instrumentation quality assurance (QA), quality control (QC) and correct application of the method.

Methodology

Six institutions comprising eleven surgical teams were evaluated since 1997. Six different GPs were used: 50% with INa crystal (IN-GP) and 50% with semiconductor crystal (SC-GP).

Pre-training data were collected during surgical procedures: QA/QC performance, technical procedure and management.

In a second stage, surgeons and operating theatre personnel were trained with theoretical and practical lectures.

Theoretical lectures: non-nuclear professionals were instructed on basic requisites for ionizing radiation management and instrumentation. They included radioactive decay, counting statistics, radiopharmaceutical biodistribution, instrumentation specifications, collimation, QA/QC, good radiation protection practice and probe handling. Concerning QA/QC, the parameters taught were: physical inspection, collimation (influence of background sources on activity determination), probe shielding, background measurement for some specific condition, ease of peaking in the surgery room, sensitivity in air and water at different distances (0 to 15 cm), field of view determination (area inside 20% isodose curves), spatial resolution (FWHM) in air and water at different depths, count rate linearity (linearity of activity response from 1 μCi to 2 mCi), angular sensitivity – changing the direction of the detector with respect to the source-detector axis (data normalized to 0º, calculation of isodose
curves), test of counting precision (Chi square test, maximum number of count, minimum reading time).

*Practical lectures:* two phantoms were developed: one for sentinel node (low activity line source with two hot point sources at each end) and another for parathyroid adenoma surgery (device filled with water simulating hot background and hot lesions of different contrast and sizes) for the evaluation of the influence of big hot sources on small lesion detection. After using the phantoms as a first approach, clinical cases were performed under the supervision of nuclear medicine professionals.

*Post training data* were also collected and used to compare the outcome of the technique before and after teaching implementation, evaluating the sensitivity and accuracy of the method.

**Results**

False positive signals are usually due to radioactive contamination. There is also interference with electrobistouries which produces stimulation of the GP when used near to it.

Previous to implementation of the training, surgical outcome was as follows: the number of false negatives (FN) = 31%. Success rate: 74% After the implementation, surgical outcome was: false negatives (FN) = 4%. Success rate: 99%

Through the analysis, factors depending and nondepending on non-nuclear professionals training, were described. *Factors depending on training:* performance of QA/QC parameters (due to instability QC is essential for IN-GP; among them energy calibration, linearity and spatial resolution are the most sensitive in performance), shielding, use of collimation, awareness of GP manipulation (interaction with electrobistoury, counting statistics). *Factors non-dependent on training:* radiopharmaceutical choice/labelling/injection, pre-surgical lymphography carried out, injection (site, method, contamination) and infiltrated lymph node (tumour, fat). *Other drawbacks:* 1) The procedure is not regulated by the government in most of Latin American countries (such as Argentina); 2) Surgeons are not likely to accept the intervention of external staff.

**Conclusions**

The success of radioguided surgery is operator and instrument performance dependent. A learning curve is associated with this technique and is very much tied to training. The later should be multidisciplinary to ensure the best result and should include QA/QC. Data should be collected on a regular basis so that QA can be performed.
Brain image fusion: Co-registration error

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Semi automatic and manually fused brain image registration using anatomical magnetic resonance (MR) and functional single photon emission tomography (SPECT) have been used to quantify the spatial registration error. An internal quality assurance protocol is employed to reject studies whose image quality was bad or the acquisition parameters were wrong.

At the beginning when this technique was started, a training programme was carried out using fiducial markers in phantom and patients to estimate the co-registration error.

The brain Hoffman phantom (Data Spectrum Model BR-3D-P), with 3 fiducial markers containing 2 $\mu$Ci $^{99m}$Tc $^{99m}$Tc as SPECT marker and Gadodiamide MR marker.

SPECT data were acquired with a dual head camera (ADAC) with ultra high resolution collimators and 128$\times$128 matrix size, 64 projections and post filter using iterative reconstruction method (number of iteration 12), with attenuation correction.

MR images were acquired using 1.5T GE SIGNA 3D spoiled-gradient sequence with 20 minimum TR, TE 6.24, matrix size 256$\times$256 and 124 axial slices separated by 1.6 mm.

The same acquisition protocol was used for the 13 patient studies. They have been injected with 740 MBq of $^{99m}$Tc-MIBI, radioisotope that provides functional information which can be used to detect tumour regrowth with higher specificity than post Gadolinium I.V administration imaging brain MR.

Woods’s Automatic Image Registration method [1] for intermodality rigid transformations has been used for fusion. Fine tuning of this transformation to achieve good fit converts the methodology in semi automatic. The algorithms could be classified as linear when alignment transformation (translation, rotation and scaling) is computed between both 3D volumes.

Manual fusion of both images was also accomplished without landmarks using anatomical structures as reference.

Using visualization techniques for both methods, it is possible to combine color and gray scale image for each pixel using 16 bits display. Such interleaved pixels appear as superimposition of color with gray scale, where the degree of transparency is proportional to the interleave step.

Slices localization differences (SLD) between semi automatic and manual methods allow to estimate the relative error.
Results

1. Phantom results show that the error (distance between markers) when the semi automatic method is used is 1.5 mm (size of one pixel).
2. Fig. 1 shows that the difference between the semi automatic and manual method values is always 0 or ±1.6 mm.

![FIG. 1. Phantom results showing semi automatic and manual method values.]

Since co-registered images are used in clinical applications, the physicians that use them act as external expert observers, and validate the co-registration.

The results for three dimensional display of SPECT and MR brain images show that this technique provides a potentially comprehensive and diagnostically valuable presentation about tumour extension in relation to the anatomy of the brain. Pre-operative image fusion techniques help to define specific pathological anatomic regions, distortion of normal neuroanatomy and assessment of the integrity of various functional pathways.

In countries where availability of more complicated softwares are limited, the use of the two most frequently applied methods for co-registration shows that due to the stability of the results this methodology can be trusted.

REFERENCE

Initial report back of the audit of nuclear medicine units in Africa

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The International Atomic Energy Agency (IAEA) is actively involved in all activities related to the peaceful applications of nuclear energy – in nuclear medicine (NM), amongst others. In Africa most of these activities are run under bilateral projects as well as the regional projects under the African Regional Cooperative Agreement (AFRA), mostly as RAF projects. The regional clinical project on nuclear medicine is called RAF/6/26. One of the important activities performed under RAF/6/26 is the auditing of all the nuclear medicine facilities in Africa. The decision to audit NM units has been taken at a project coordinators meeting in Harare, Zimbabwe in 1998.

The objectives for the audit missions were: 1) to carry out a technical and managerial audit of all aspects of nuclear medicine practice in the country; including infrastructure, clinical and managerial aspects of nuclear medicine practice using the AFRA format for auditing wherever possible; 2) to advise authorities on strengths and weaknesses in patient care related to nuclear medicine; 3) to recommend realistic and achievable improvements taking into consideration the country’s plans for future expansion.

Preparation for the audit visits. Units to be audited had to complete a questionnaire compiled by the IAEA, supplying information on all the activities of the unit. These included personnel details, and information regarding imaging, therapy and in vitro activities. These completed questionnaires were sent to the audit teams before the audit missions, to assist with preparation for the audit visits.

Audit teams. The audit teams were comprised of experts selected mostly from African countries although, in limited cases, experts from Europe were chosen. The initial teams consisted of a nuclear medicine physician (the team leader), a medical physicist and a technologist (radiographer). Later the teams consisted of two nuclear medicine physicians (one an expert in in vitro activities), and a medical physicist.

Procedures of the audits. Most audit visits were scheduled for one week. In the case of South Africa, with several nuclear medicine units, two periods of two weeks each were scheduled with visits of 2–3 days duration to each department. During the missions, nuclear medicine facilities including imaging, in vitro and therapeutic facilities were visited. In most cases, discussions also took place with the management of the hospital, the dean and other representatives of the related medical schools, officials of the radiation control authorities and other role players. The programme for the visits was compiled by the local counterpart, and on the first day adapted after discussion with the audit team. At the end of the visit a report back session with all the staff of the NM unit was also scheduled. A complete report by the
audit team, which included recommendations to the local unit, the government of the country and the IAEA, was afterwards sent to the IAEA. After some administrative and editing procedures in the IAEA, the audit report was sent to the National Liaison Officer in the audited country, for distribution to the unit(s).

**Results.** The first audit missions took place in 1999. Audit visits have been completed in 15 countries, and partially completed in one other country with several nuclear medicine facilities. South Africa, also with several departments, was audited during two two-week visits. Nuclear medicine facilities in six countries must still be audited. Even though several countries also have private NM facilities, only public units were audited.

Although nearly all the units had near adequate numbers of staff, the training of the different categories of staff was sub-optimal. Very few of the African countries had their own training programmes for NM, including the training of nuclear medicine physicians, technologists and medical physicists. Official training programmes were only available in South Africa and a number of the North African countries, including Algeria, Morocco and Tunisia. Radiopharmacists or radiochemists were employed only in two departments in Africa. Most of the units performed in vitro work, mostly radioimmunoassay work measuring hormones, such as T3, T4 and TSH and tumour markers. In most of the visited units the RIA units were the most active sections. Most audited units had gamma cameras, although some still used rectilinear scanners. In a number of facilities the gamma cameras were old or refurbished planar gamma cameras. Quite a number of gamma cameras were not functional during the visit of the audit team. Other equipment included dose calibrators, survey meters and gamma probes. Clinical studies done most frequently were thyroid, skeletal and renal scans. Nuclear cardiology is mainly practised in two or three countries. Nuclear medicine therapy is actively practised in North Africa where thyroid cancer is treated by nuclear medicine physicians. However, most of the countries treat on outpatient basis hyperthyroidism or toxic goiter. Radiation safety aspects were often sub-optimal. Written standard operating procedures existed in only a limited number of units. Quality assurance procedures were followed only in very few units.

The most evident feature is that nuclear medicine was practised in a significant number of African countries. However, the dependence of these units more or less on the support of the IAEA appears to be an important weakness or threat. In several countries, nuclear medicine was launched with the exclusive assistance of IAEA which has supplied all their equipment, as well as $^{99m}$Tc-Mo generators and some cold kits. The big challenge of these countries now is to sustain nuclear medicine activities with their own budget. The departments with their own budgets in most of the cases functioned more effectively, with a more regular supply of consummables.

**Conclusion.** Nuclear medicine is practised in numerous African countries and the most active sections of these units are most often the RIA sections. Imaging is often limited to the more basic types of investigations, namely thyroid, skeletal and renal imaging. Radioiodine therapy for thyroid cancer and hyperthyroidism is the most common nuclear medicine therapy procedure. An important recommendation to the different units is to convince the authorities to give them their own budget. This will enable more independent activities and further growth of such units. In some countries, level of practice of nuclear medicine is comparable to those of advanced countries. Such countries should share their experience with other countries.
Session 4a:
*Radiation Treatment*
CLINICAL IMPACT OF QUALITY ASSURANCE
Educational requirements and quality assurance in modern radiotherapy delivery

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The delivery of modern radiotherapy is a complex interactive process requiring coordination of many mutually dependent processes. It is essential therefore that it is seen to be delivered as a team process with co-dependent members trained in their specific areas of expertise recognizing the roles of different skills and their integration into the whole process. Mutual respect and understanding of each step in the process and the potential areas for error are a critical component in the education and training of members of the radiotherapy team. Few radiation errors are due to machine failure; the majority are due to human error. The weakest component of the quality assurance pathway is often the clinician. This must be addressed by rigorous attention to competency based training and the development of clear clinical guidelines and protocols.

The processes involved in the delivery of modern radiotherapy can be broken down into several steps each requiring different skills and levels of expertise and quality assurance.

1. **Cancer diagnosis, staging, patient selection and treatment intent.** The first step along the way to delivering radiotherapy is to ensure that it is an appropriate treatment for the patient. It is important that all members of the team share in this knowledge and can proceed with their tasks confident that their skills are being used for the correct treatment for a given patient. Thus the principles of cancer presentation and the diagnostic processes including staging investigations are an important part of the education of the radiotherapy team. All members should be aware of the basic principles of treatment intent, able to distinguish between radical and palliative treatments and their implications within the radiotherapy process. Clearly the level of understanding and decision making will vary across the team.

2. **Radiotherapy planning** for the specific site of tumour and treatment intent defined in the first step. This will rely primarily upon the expertise of radiation therapists (radiographers) and physicists supervised and directed by clinicians. All three groups need to have appropriate knowledge and understanding of the processes involved and their relevance to the ultimate treatment. The radiographer will require knowledge of the issues regarding patient position and immobilization whilst the clinician and physicist will need to focus on methods of tumour localization relevant to directing the radiation delivery. Part of the education process must involve mutual understanding of the relative importance of each component.

3. **Target localization.** This is a critical step since without accurate identification of the tumour and treatment volume any radiation delivery is going to be sub-optimal. The physician will have training in clinical examination and identification of malignant abnormalities together with an understanding of radiology using both plain X rays and 3D imaging, in particular for radiotherapy planning CT. Training in physics should include an appreciation of these aspects together with a deeper understanding of the interaction between diagnostic imaging and radiotherapy planning scans and their use in dosimetry. Integration of the information gained from diagnostic procedures into the radiotherapy planning process is an important role for all members of the team. Despite this, repeated studies have shown that this is the weakest point of the radiotherapy process and volume definition by different clinicians even when adhering to the same written protocol may vary considerably.
4. **Dosimetry.** Having identified the tumour volume to be treated the next step is to define the radiation modality and technical parameters for radiation delivery. For this part of the process the physicist will have the major responsibility but the radiographer will, with appropriate training, be able to undertake much of this process also. It is however critical that the clinician has an understanding of the principles of dosimetry, beam qualities and modifications to interact meaningfully with the dosimetrist. The physician therefore requires training in accurate interpretation of imaging modalities used in volume definition and the use of computer software to allow calculation of dose distributions within the defined area. Close interaction between the physician and physicist is required at this point with a mutual understanding of each other’s roles. The physicist will specifically have responsibility for defining the characteristics of the available radiation beams and inputting the data from these into the planning processes to allow their use in the dosimetry calculations required prior to implementation of the treatment plan. Often a compromise between tumour coverage and dose to critical organs will have to be discussed and a clinical decision as to justifiable risk then included in the final plan.

5. **Implementation of treatment** requires transfer of the planning processes and dosimetry to the treatment setting, often involving transfer of complex data from the planning calculations to the treatment machines. It is important that all members of the team have adequate training in the processes involved and potential areas for error so that they may be identified and avoided or corrected. A rigorous procedure for this is required and, typically, cross-checking of calculations and data movement will be introduced with at least two trained members of staff checking each step independently. Electronic transfer of data should always be preferred over manual transfer with less room for error. This is perhaps the most common source of major radiation errors, in particular when a wedge or other beam modifier is used. Treatment delivery will typically be in the hands of the radiographer who will have training in the technical aspects of the radiation beams and the machine characteristics and capabilities, including expertise in patient handling and beam set-up. This knowledge is also required by the physicist and physician particularly in more complex treatments and each should acknowledge the relative skills of the other in making joint decisions with regard to optimal treatment scheduling and set-ups, balancing simple pragmatic treatments with more complex procedures based on the relative advantages and treatment intent.

6. **Verification.** All radiation exposures should have a verification process associated with them. This may be a very simple visual check or use radiographic validation of the beam, position, size and shape. It may also use in vivo dosimetry. Again education and training of the radiographer to use this on a day-to-day basis, the physicist to oversee the procedures, troubleshoot and ensure the validation of the processes and the physician to interpret and make clinical judgements as to the impact of any variances in treatment delivery are all part of the integral process of radiotherapy delivery. Experience in clinical observation of acute radiation side effects is a further essential component of treatment delivery to identify extreme reactions and ensure they have a biological rather than physical basis. Throughout each of these processes the team should have sufficient familiarity and confidence with each step and process to be able to recognize major errors before they are implemented in treatment delivery. Ultimately the responsibility for the care of the patient will rest with the clinician who may have to tread a fine line between tumour cure and normal tissue damage; only with a thorough training in all aspects of the radiotherapy process can this be delivered in an optimal way.

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Treatment process - Clinical decision making

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Although many aspects of cancer treatment, especially the technical aspects of radiotherapy, are subject to rigorous quality assurance, the quality of actual clinical decision making is rarely scrutinized. There are several developments over the past 10 to 15 years that have driven forward attempts in the UK National Health Service (NHS) to bring such quality assurance into the clinic. This goes back to the work of Dr. Archie Cochrane in the 1970s and his views that clinical practice should be underpinned by research evidence and only treatments that have been shown to be effective should be used.

The term clinical effectiveness is now widely used. It refers to the amount by which any treatment actually affects outcomes for patients. For cancer patients this may mean ‘cure’, improving survival, local control, or symptoms, or minimizing toxicity – or indeed a combination of all of them.

But how do we know what is the most effective treatment for a particular patient? How do we assure the quality of the clinical decision? By going to the research evidence and asking questions about whether there is clear evidence which treatment is likely to give the best outcome for this patient. This is ‘evidence-based medicine’: the application of the best available evidence from clinical care research to the management of individual patients. However this is not just a blind application of this evidence and is not ‘cookbook medicine’. Other things need to be considered as well as the evidence, a clinical judgement about the applicability of any treatment to an individual patient and patient preference.

When confronted by a patient with a clinical problem, how do we find the ‘best’ evidence?

1. Refine the clinical question into a standard format: patient, intervention, comparison, and outcomes (PICO)
2. Search for relevant publications in electronic databases, such as Pubmed and Medline, and retrieve them
3. Critically read and appraise them: Are they relevant to this patient and problem? Are the research methods explicit and reliable? Are the results clear? Are the results applicable in this situation in my clinic?

What kind of publications should we looking for? Ideally we should look for randomized controlled trials or well conducted systematic reviews of such trials. Failing that we should try to find other controlled comparative studies and only if they are not available, should we be satisfied with cohort studies and other observational studies.

What are systematic reviews? They are reviews of the published evidence that try to identify all relevant publications, assess them for quality, extract and summarize all the relevant data. When well conducted they provide a more complete and objective summary of the research evidence than the more traditional narrative reviews. The Cochrane Collaboration is an international group of systematic reviewers that produce high quality reviews, publish them electronically in the Cochrane Library with regular updates. These then provide a high quality
source of relevant and up to date evidence on many clinical topics across the whole of healthcare.

Clinical guidelines are another possible source of good evidence. A high quality guideline will carry out systematic reviews of relevant topics and then use that information to make consensus based recommendations about best clinical practice. However clinical guidelines need to be treated with caution for two reasons:

1. The evidence reviews may not be very systematic and objective and rely too much on ‘informed’ opinion.
2. They are written for a specific healthcare system and so the recommendations may not be widely relevant because of different availability of resources and different culture and values.

So, having good access to research evidence and using that evidence to inform clinical decisions is essential to assure the quality of clinical decisions. But there is an ethical dimension to this. It is always important to remember to:

- do the best for the patient in front of you
- ensure that all your patients are treated equitably
- discharge your responsibility to society for the best use of scarce resources.

Certainty and complacency are the enemy of quality: in order to achieve high quality you must always be uncertain and questioning – never certain and complacent.

The second method for assuring the quality of clinical decision making is clinical audit. This is a method by which actual clinical practice is reviewed. Data on key process and outcome measures are collected either retrospectively or prospectively and key criteria of performance compared to some identified standard, preferably form published research. This then should mean that the following questions can be answered: ‘How good are your outcomes? How do you know? Show me’.

This then is another kind of evidence of quality – from your own practice.

This can be a time consuming and complex process. Ideally prospective systems for getting this information should be set up. It may be difficult to measure key outcomes in a timely fashion but there may be problems with using process measures as a surrogate. There may be important case-mix factors that need to be considered. Finally, if real problems or poor performance are identified it may be very difficult to carry out the changes in clinical practice necessary to generate improvement.

KEY MESSAGES

- Never be complacent.
- Always ask questions about what is the best for this patient and try to answer it from the published evidence.
- Always be sceptical of what you read.
- Use scarce resources to best effect.
- Audit the results of your own clinical practice.
- Be prepared to change and improve.
Developments in toxicity and QOL reporting in oncology clinical trials

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Toxicity reporting is a critical concern in the evaluation of oncology clinical trials. Historically, oncology development has been largely “efficacy driven”, with limited attention paid to the methods for evaluating risk and safety reporting. Thanks to a growing number of advances in surgical and combined modality therapies, cancer patients today may select from multiple treatment options with similar cure rates, but differing adverse effect profiles. For most treatments, our understanding of these profiles is incomplete. In this session we will describe the strengths and weaknesses of the current safety reporting process, including recent developments and initiatives in the quest for improved methods and standards for safety reporting. We will also discuss the added value of patient reported outcome (PRO) and quality of life (QOL) tools in increasing our understanding of adverse effects of treatment on health status.

Current deficiencies in safety reporting. A recent systematic review of phase III H&N trials has documented wide variations in the methods and completeness of reporting of adverse events (AEs), use of grading systems, methods of data display and overall data presentation [1]. These deficiencies raise significant questions about the reliability and completeness of safety data from multi-agent and multi-modality clinical trials, and suggests the need for adverse event reporting standards [2]. With the growing application of aggressive combined therapies as well as new technologies and interventions to reduce toxicity, we are in need of more accurate and more complete information about adverse event profiles and their associated health effects.

CTC: Evolution of a comprehensive dictionary for all modalities. The National Cancer Institute (NCI) Common Toxicity Criteria system (CTC v1.0) was first created in 1983 to aid in the definition, recognition and grading of adverse effects of chemotherapy. It was updated and expanded in 1998 (CTC v2.0), incorporating some radiation criteria, but remained focused on acute effects [3]. In June 2003, the NCI announced the third revision of the CTC, relabeled Common Terminology Criteria for Adverse Events (CTCAE) [4]. Compared with version 2.0, the principal changes are the inclusion of a full set of late effects criteria, expansion of criteria for surgical effects, and better anatomic site specificity [5]. CTCAE represents the first comprehensive multimodality grading system for reporting both acute and late effects in oncology. It is the recommended grading tool for all NCI funded clinical trials. CTCAE has also been widely adopted by the pharmaceutical industry for oncology trials, and has been mapped to function alongside other standard regulatory dictionaries (e.g. MEDRA). CTAE is much more comprehensive than previous systems, is more specific, and will potentially lead to much richer adverse event data.

Adverse events no longer pre-designated as “acute” or “late”. The previous rules requiring pre-designation of clinical trial events as “acute” or “late” are no longer used in CTCAE. The RTOG Late Morbidity Scoring tool has been eliminated from trials developed after 2003, and thus the ‘90 day rule’ has been dropped (but retained in “legacy” trials begun prior to 2003). Modern multimodality management involving the interactions of sequential and concurrent modalities makes it increasingly difficult to designate an effect as “acute,”
“subacute” or “late “. Designation of acute versus late is left to the investigator upon review and interpretation of the clinical trial AE data.

CTCAE recommended at the Technical Meeting of the IAEA on adverse events in radiotherapy trials. Recognizing the challenges of adverse events occurring from radiation therapy, radiation accidents, and terrorism, the International Atomic Energy Agency organized a technical meeting in Atlanta, on 2 October 2004 to discuss needs and developments. The experts at the IAEA Technical Meeting concluded that the development of international adverse event reporting standards is critical to improving the quality of clinical trial data and to facilitate comparison of acute and late safety profiles among international cooperative groups and clinical outcome studies. The experts recommended the use of CTCAE dictionary as the preferred terminology system for use in cancer treatment programmes [6]. The IAEA intends to play an ongoing role in the international development and dissemination of safety reporting standards via critical review, feedback, adoption, and recommendations.

New CTCAE web-based search tool: “Safety Profiler”. The NCI has developed a new web-based tool entitled “Safety Profiler Dictionary” to facilitate access and searching of the CTCAE dictionary for specific terminology and grading language. This can be found on the CTEP website at: http://safetyprofiler-ctep.nci.nih.gov/CTC/CTC.aspx [7]. CTCAE Safety Profiler contains both CTC v2.0 and CTCAE dictionaries.

Use of QOL and symptom tools in clinical trials. Quality of life (QOL) and symptom measures are increasingly used in clinical trials to better understand the impact of adverse effects on health status. The development, interpretation and utility of these tools continue to rapidly evolve. QOL and symptom tools are generally measured as patient self report (or patient reported outcomes – PROs), and capture information about patient symptoms and perceptions that traditional toxicity data may not, and so may be complimentary to CTC data. There are a number of generic, disease-specific, and symptom-specific questionnaires available to measure QOL and symptoms. Unlike the CTC, these instruments have been subjected to rigorous psychometric testing and have been found to meet standard criteria for incorporation into clinical trials. The FDA has recently issued draft guidance on the development and use of PROs in clinical trials. An update on PROs as key endpoints in clinical trials will be presented.

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Session 4b:
Radiation Imaging
MAMMOGRAPHY
National QA in BreastScreen Australia

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BreastScreen Australia was established in 1990 as a National Programme for the Early Detection of Breast Cancer, with the aim of reducing breast cancer mortality and morbidity [1]. The programme is offered free of charge to all women over 40 years of age but targets women aged 50 to 69 years, and covers mammography screening and multidisciplinary assessment up to tissue diagnosis. It is fully funded by the Australian Commonwealth, State and Territory governments. National Accreditation Guidelines were developed in 1991, as it was agreed from the start of the programme that, in order to achieve high quality outcomes, services operating within the programme would need to be accredited. Accreditation requirements have since undergone several revisions, and the current National Accreditation Standards cover all aspects of service operation necessary to achieve accreditation as part of BreastScreen Australia [2]. There have also been some changes to the accreditation process which is overseen by a multidisciplinary National Quality Management Committee (NQMC).

The service delivery model is that of multiple mammography screening units attached to a single or several multi-disciplinary assessment centres, forming a Screening and Assessment Service (SAS). Multiple SASs are linked under the relevant State/Territory Coordination Unit, and these form part of the national programme. As part of accreditation, the SASs are visited by teams which evaluate all facets of the service including facilities, equipment, staffing, clinical practice, data management and outcomes.

The current accreditation standards are clustered under 10 key outcome areas, considered equally important to achieve programme goals. These outcome areas are: cancer detection, participation, access, information, recall, assessment, counselling/support, data, timeliness and management. Quality assurance is both quantitative and qualitative. On the basis of the likelihood of not meeting a given standard and the consequences of not meeting that same standard, all standards have been ranked into 3 levels, with a resultant 14 level 1, 127 level 2 and 34 level 3. Tiered accreditation is as follows.

<table>
<thead>
<tr>
<th>Accreditation level</th>
<th>Achieved standard</th>
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<tbody>
<tr>
<td>Four year accreditation with commendation</td>
<td>Service performs highly against all standards in all clusters</td>
</tr>
<tr>
<td>Four year accreditation</td>
<td>Service performs well against most standards (89%), including all level 1 standards</td>
</tr>
<tr>
<td>Two year accreditation</td>
<td>Service meets all level 1 standards, but only a proportion of level 2 (80%) and 3 (70%) standards</td>
</tr>
<tr>
<td>Two year accreditation with high priority recommendations</td>
<td>Service meets the requirements of a two year accreditation term other than meeting a number of level 1 standards (up to 10%)</td>
</tr>
<tr>
<td>Provisional Accreditation</td>
<td>Eighteen months provisional accreditation for new services</td>
</tr>
<tr>
<td>Non-Accreditation</td>
<td>Service does not meet requirements for accreditation for 2 year accreditation with high priority recommendations</td>
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</tbody>
</table>
An illustrative example of a performance objective and associated standards is as follows.

**Performance objective 2.9:** The service ensures high quality of breast imaging systems.

**Standards for quality of imaging systems 2.9:**
- X-ray systems, premises and users meet radiation protection regulations
- Breast imaging quality control test equipment meets the minimum standards specified in Appendix L [3,4]
- Quality control procedures for mammography and ultrasound equipment that meet the standards in Appendices K are implemented [4,5]
- Breast imaging systems meet manufacturer’s specifications and performance standards as specified in appendices H [4,5]
- Acceptance and annual testing of mammography systems is performed by or under the close supervision of, suitably qualified and experienced persons as specified in Appendix J
- Preventive maintenance repair of imaging equipment meets manufacturer’s recommendations or other appropriate standards.

Accreditation standards are considered an essential platform for a quality improvement programme. The quality achievements of the BreastScreen Australia service are widely credited with having raised the quality of breast imaging services and of breast cancer treatment services outside of the national programme, leading to better care of women undergoing diagnostic investigations and cancer management.

Since the introduction of the BreastScreen Australia programme there has been a statistically significant improvement in mortality from breast cancer (comparison rates are for periods between 1994-1998 and 1999-2003), attributable to the earlier diagnosis and better management of early breast cancers [6]. This trend has closely followed the progressive introduction of the BreastScreen programme, with services continuously striving to achieve optimum outcomes.

**REFERENCES**


Evaluation of the population dose to the UK population from the national health service breast screening programme

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In the United Kingdom National Health Service Breast Screening Programme (NHSBSP), women aged between 50 and 70 years are invited for mammography every three years. Originally mammography comprised of a single view of the breast. Subsequently, women attending the programme for the first time have two views taken at their first visit. Since the beginning of 2004, it is NHSBSP’s policy for women to have two views at each screening round.

After the initial screening stage, some women are invited back for further mammography and possible other investigations. This is referred to as the assessment stage. Breast cancer may be detected at this stage, or women may be referred for a diagnostic surgical biopsy.

On an annual basis, the NHSBSP monitors the number of women who attend the breast screening programme, the number of women who are assessed, the number of fine needle aspiration cytology/small core biopsy examinations and the number of cancers detected. This information may be used to deduce the number of screening and assessment examinations women receive.

Screening histories for each woman, over four screening rounds, were analysed. Data from five screening programmes was used to select 54,610 women into the study. Women were selected using a standard report on the National Breast Screening Computer Systems held in each screening office, which was included in the study. Cases were selected on the basis of being between the ages of 50 and 53 at the start of the NHSBSP (i.e. between 1989 and 1992).

Assessment of the outcome for each screening round for each woman involved assigning a simple Outcome code. Each of the possible pathways through the four screening rounds was analysed. This comprises of 500 possible pathways. These data enabled the following information to be determined.

1) the number of times a woman attended the screening programme.
2) the number of women referred for assessment at each screening round.

This information may be used to deduce the population dose to this group of women averaged over four screening rounds. The patient dose to a typical woman attending the NHSBSP is routinely monitored as part of the quality assurance programme. Patient doses have been monitored since the programme’s inception and are typically 4.5 mGy for two view screening. It is possible to determine the mean glandular dose received by this cohort of women over four screening rounds by multiplying the number of examinations by the mean glandular dose.
for a typical woman. Allowance has to be made for the number of projections taken at each screening round.

Once a woman has been screened, she may be invited back for further assessment if an abnormality is found on her mammogram. A stereotactic attachment is used to determine where to place the biopsy device. Although the dose received during a normal screening mammogram is well known, the dose for a stereotactic procedure and other assessment procedures is less well known, partly because only a small part of the breast is directly irradiated during stereotaxis. However, the woman may have multiple exposures during this stage. A prospective survey of doses was completed to deduce the mean glandular dose at the first assessment stage and during stereotaxis.

Numbers of films, including magnification films taken at first stage assessment were established in the North East of England and Scotland by means of a postal survey. Average total mean glandular dose was deduced using previous survey data for the screening programme and a multiplying factor to allow for magnification film dose. On average, 1.6 full field and 0.15 collimated contact films are taken for each woman (with 2.25 mGy/film and 0.75 mGy/film), 1.0 full field and 0.9 collimated magnification views. The mean magnification film dose to the assessed breast was 5.0 mGy and 1.7 mGy for a collimated magnification film.

A survey of 134 women at screening centres in the North East of England was performed to deduce the mean glandular dose from digital stereotaxis which is almost universally used in breast screening. A typical woman received a dose to the assessed breast of 4.5 mGy with a range of 1.3 to 17 mGy.

These data may be used to deduce the total mean glandular dose over four screening rounds including the assessment stages. The estimated mean glandular dose to a typical woman invited to the screening programme is approximately 16 mGy, when allowance for attendance rate and assessment rate over each screening round is made. The mean glandular dose to the population is approximately 5,000 Sv/year.
Implementation of QA into daily practice of the mammography departments in Slovakia

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Because of the widespread use of mammography the implementation of optimization of image quality has been initiated in Slovakia. On the basis of EC Directive 97/43 the new Slovak legislation improved the national system of acceptability of radiological examinations by implementation of guidance levels, system of education and necessity of introduction of quality assurance (QA) and quality control (QC) programmes in radiological departments.

For the achievement of the good practice, experienced staff and close collaboration between radiologist, medical physicist and radiographers are required. For this reason the IAEA established during 1999 to 2001 a coordinated research programme (CRP) for optimization of image quality in mammography in some Eastern European countries. Our institute took part in this CRP with the aim to implement the European QA/QC protocol in a sample of mammography departments and to achieve improvement of the image quality and patient dose reduction.

In our contribution the results and experiences of a national mammography audit are presented. On the national level 42 mammography units were chosen in accordance with equipment performance for quality control programme at these departments, for two parts of the mammography audit in the years 2002–2005.

The obtained results indicate that the pilot mammography audit in Slovakia is a very important tool for correcting actions at the involved departments.

In the six month period, results of measurements were collected of:

1. object thickness compensation (measured weekly)
2. long time reproducibility (measured daily)
3. phantom image quality on the standard RMI 156 phantom (measured weekly)
4. ESD on phantom with TLD (once during the audit).

For the evaluation of the quality of clinical images each mammography department lent four images of ten patients (2 CC and 2 MLO). These images were evaluated by a group of independent experts nominated by the Slovak Health Ministry.

The results of the pilot mammography audit in Slovakia have shown that:

- important reduction in patient doses and remarkable improvements in image quality can be achieved by the practical application of the coordinated QC programme
- the measurements of ESD can be performed in the tolerance limit of 10%
- the regular measurement of performance indicators (AEC control) call attention to faults causing the deviations of acceptable tolerance levels
- clinical image evaluation of experts enables improvement of final diagnosis estimation.
The coordinated national mammography QA/QC programme was accepted by the Slovak Health Ministry as the basis for accreditation of mammography departments for preventive examinations and screening.

Meanwhile effective training of radiologist and radiographers help us to achieve the desired improvement of the current state of radiological practice in mammography.

FIG. 1. Long term reproducibility in mammography departments before and after QA implementation.

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Radiation risk in mammography examinations

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The application of X rays in mammography examinations requires not only constant control of physical and technical parameters of the equipment used, but also an evaluation of the radiation risk for patients, particularly in mammography screening programmes. There are a number of methods of dose evaluation in mammography. Some of them are included in the dosimetry protocols. The tolerances for measured values, limiting the dose to the patients have also been established. One of the methods, proposed by Dance, applies to establishing the doses to individual patients. It requires the knowledge of clinical and exposure parameters. Another method, recommended by the EC, requires establishing the phantom dose for reference exposure, as part of quality control tests. This approach is simpler but less precise, because at most mammography facilities, the conditions of reference exposure are different than those of routine clinical exposure, as was shown in an exercise of quality control tests in a group of 32 mammography facilities in Poland. The method proposed in this study is an intermediate solution recommending measurement of the phantom dose for routine clinical exposure.

The report contains the data of 230 exposures performed at six mammography facilities in Poland. These data were used to establish an individual dose for every patient undergoing mammography examination according to the method proposed by Dance [1].

For each mammography facility, the mean glandular dose (MGDF) was established for reference and routine exposures according to the EC Dosimetry Protocol. The limits for phantom dose were established, which, according to the EC protocol, depend on the optical density (over background) of the image of the PMMA phantom 4.5 cm thick.

The phantom doses determined for each mammography facility were below the limits. The lowest value of the mean dose received by patients in six facilities was 1.05 mGy, and the highest 3.03 mGy. The differences between these values among the six facilities are a result of different exposure parameters and different sensitivity of the image detectors. The differences between the values of weighed mean individual dose and phantom dose for routine exposure were in the range of 2.6%–15.4%. They are lower than differences between the values of weighted mean individual dose and phantom dose for reference exposure which were in the range of 8.4%–42.8%.

The parameters for reference and routine exposures for six facilities, the value of standard phantom dose (MGDF) for reference and routine exposures, average weighted individual dose values evaluated for various tissue compositions(MGD_{SR,1}) and for fat tissue component of 50% (MGD_{SR,1,50%}) are presented in Tables 1 and 2.

Individual doses, taking into account tissue composition of the breast for patients during mammography examination, are the best measure in evaluation of exposure to X ray radiation. A good approximation of the mean value of the dose received by patients is the phantom dose for routine exposure, and not for reference exposure. Therefore, the phantom dose for routine exposure may be used as the indicator of the radiation risk to the patients at a
particular mammography facility. The phantom dose for reference exposure may only be used for comparison of image detector sensitivity at different mammography facilities.

TABLE 1. INDIVIDUAL DOSES AND PHANTOM DOSES FOR FACILITIES NR 1, 2 AND 3

<table>
<thead>
<tr>
<th>Facility nr</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>ref.</td>
<td>rut.</td>
<td>ref.</td>
</tr>
<tr>
<td>Voltage [kV]</td>
<td>28</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>Tube loading [mAs]</td>
<td>54</td>
<td>152</td>
<td>43</td>
</tr>
<tr>
<td>Poziom zaczerńenia</td>
<td>-</td>
<td>10%</td>
<td>-</td>
</tr>
<tr>
<td>Half-value layer [mm Al]</td>
<td>0,38</td>
<td>0,34</td>
<td>0,38</td>
</tr>
<tr>
<td>Optical density</td>
<td>1,60</td>
<td>1,60</td>
<td>1,60</td>
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<tr>
<td>ESAK [mGy]</td>
<td>7,65</td>
<td>9,65</td>
<td>5,93</td>
</tr>
<tr>
<td>MGDₐ [mGy]</td>
<td>1,64</td>
<td>1,88</td>
<td>1,27</td>
</tr>
<tr>
<td>Tolerance for MGDₐ [mGy]</td>
<td>≤3,6</td>
<td>≤3,6</td>
<td>≤3,6</td>
</tr>
<tr>
<td>MGDₐ1.5% [mGy]</td>
<td>1,55</td>
<td>2,16</td>
<td>1,61</td>
</tr>
<tr>
<td>MGDₐ1 [mGy]</td>
<td>1,79</td>
<td>2,22</td>
<td>1,75</td>
</tr>
</tbody>
</table>

TABLE 2. INDIVIDUAL DOSES AND PHANTOM DOSES FOR FACILITIES NR 4, 5 AND 6

<table>
<thead>
<tr>
<th>Facility nr</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>ref.</td>
<td>rut.</td>
<td>ref.</td>
</tr>
<tr>
<td>Voltage [kV]</td>
<td>28</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>Tube loading [mAs]</td>
<td>113</td>
<td>195</td>
<td>42</td>
</tr>
<tr>
<td>Poziom zaczerńienia</td>
<td>-</td>
<td>+2</td>
<td>-</td>
</tr>
<tr>
<td>Half-value layer [mm Al]</td>
<td>0,40</td>
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<td>0,37</td>
</tr>
<tr>
<td>Optical density</td>
<td>1,60</td>
<td>1,53</td>
<td>1,62</td>
</tr>
<tr>
<td>ESAK [mGy]</td>
<td>10,51</td>
<td>13,73</td>
<td>5,79</td>
</tr>
<tr>
<td>MGDₐ [mGy]</td>
<td>2,34</td>
<td>2,95</td>
<td>1,22</td>
</tr>
<tr>
<td>Tolerance for MGDₐ [mGy]</td>
<td>≤3,6</td>
<td>≤3,5</td>
<td>≤3,6</td>
</tr>
<tr>
<td>MGDₐ1.5% [mGy]</td>
<td>2,83</td>
<td>1,40</td>
<td>0,95</td>
</tr>
<tr>
<td>MGDₐ1 [mGy]</td>
<td>3,03</td>
<td>1,43</td>
<td>1,05</td>
</tr>
</tbody>
</table>

REFERENCES


QA of mammography systems in Panama: Seven year experience

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Introduction. Mammography quality assurance is a programme established by the health care facility to ensure that mammography is being performed in compliance with minimum standards established by the national regulation. These standards include interacting with patients, testing of imaging equipment, evaluation of clinical films, and qualifications of personnel. The goal of the programme is to maintain optimum image quality standards using an appropriate but not excessive radiation dose. The three primary responsible persons for this program are the radiologist, mammography X ray technologist, and the medical physicist.

In Panama, mammography systems are submitted to QC tests on an annual basis. The national protocol for QC testing is based on the recommendations issued by the American College of Radiology [1] and the AAPM criteria.

When a new mammography system is installed or repaired, the Department of Radiological Health (DSR) must verify that the equipment parameters comply with the required acceptance criteria. If the equipment tests reveal any abnormality, the maintenance service company must perform the necessary repairs, correcting the anomalies outlined in the DSR report.

Methods. The results of all QC tests performed on mammography systems in Panama during the last seven years were reviewed. The annual tests performed basically consisted of:

1. **Mechanical**: compression strength (in Panama should be between 25–40 pounds), accuracy of angle indicator, accuracy of thickness indicator, thickness indicator reproducibility, radiation field definition, light/radiation coincidence, focal point size.

2. **Dosimetric**: tube potential accuracy, time/output linearity, HVL, mean glandular dose, automatic compensation with variable thickness and variable tube potential, output exposure, reproducibility of time, exposure and tube potential.

Image quality. Optical density, resolution, contrast, screen/film contact and evaluation of artefacts.

Results. There are 46 mammography apparatus in Panama. Nine belong to the Ministry of Health, one to the National Oncology Institute (ION), 20 to the Social Security Fund (CSS) and 16 operate in private clinics.

The QC tests performed during the last seven years in the Social Security Fund showed mechanical malfunctions in 33% of mammography systems tested, dosimetric deviations in 54%, 20% showed problems related to image quality (with some devices having more than one type of problem) and only 13% were found to comply with the acceptance criteria. Some tested devices showed more than one type of malfunction.

The most common mechanical malfunction was compression strength. In some devices the compression strength diminished with time. The most common dosimetric malfunctions were automatic exposure control and automatic compensation.
Problems with the image quality were mainly due to the fact that the Social Security Fund (being a government entity) must call for public bids for the purchase of consumables such as developer and fixer solutions, screens and films. This naturally leads to a great heterogeneity in the types and brands within this institution, which in turn reflects in difficulties when carrying out the QC tests.

Conclusions. Seven years of systematic QC tests of mammography systems in Panama have revealed the following sources of malfunctions:

<table>
<thead>
<tr>
<th>Type of malfunctions</th>
<th>% of the devices tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>33%</td>
</tr>
<tr>
<td>Dosimetric</td>
<td>54%</td>
</tr>
<tr>
<td>Quality of image</td>
<td>20%</td>
</tr>
<tr>
<td>Acceptable</td>
<td>13%</td>
</tr>
</tbody>
</table>

Note: The sum is more than 100% because each equipment can have several types of problems.

Our experience shows that mechanical malfunctions can usually be corrected by the local maintenance engineers, while dosimetric malfunctions tend to persist in subsequent evaluations. Radiology departments should perform compression tests themselves on a regular basis and not rely on the yearly tests performed by the DSR of Panama. We observed that maintenance companies have gained significant experience in the calibration of mammography units, thus correcting their equipment malfunctions in a shorter time.

The supplier or the biomedical engineering department should perform a comprehensive calibration of the mammography device (commissioning) taking into account not only the system characteristics but also the combination of screen, film, film processor, and developer and fixer solutions. It is not advisable to constantly change the type of developer and fixer solutions or the screen/film combination. Once this is done, all mammography services should have their own quality assurance programme to verify the stability of the initial conditions.

REFERENCES


A regional survey for mammographic systems

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Performance tests of 26 analog mammographic units manufactured by nine different companies were carried out. Measurement protocols and recommended limits were taken from different organizations [1,2,3]. Test of tube output (radiation output of the X ray tube, repeatability of output, variation of output with tube voltage, current and target/filter combination), check of kVp calibration, accuracy of beam alignment for different collimations, tests of automatic exposure control were made. ESAK values were measured for Perspex phantoms of different thickness in order to estimate the breast dose of any size. Tests for automatic film processors, dark rooms and film/screen combinations were carried out together with film sensitometry measurements. Qualitative and quantitative evaluations of image quality were performed using different phantoms.

Tube outputs of six (6) systems were in the desirable range (40–49 µGy/mAs). Outputs of 18 systems were within the 31–39 µGy/mAs, and there were two systems with the outputs of 28 and 30 µGy/mAs. Repeatability of all systems were within the normal limits. The calibration of kVp was tested mainly at 28 kVp and, with the exception of one system, maximum deviations for all the others remained within the 5%. HVL tests were carried out at 28 kVp and all the systems were found within the recommended limits. 2, 4, 6 cm of Perspex slabs were used for the performance measurement of automatic exposure control (AEC). The results of nine (9) systems were in acceptable limits, AEC of four (4) systems was not functioning and the results of the remaining 13 systems were not within the suggested limits. The ESAK values were measured for 2, 4 and 6 cm Perspex slabs, glandular doses were calculated for 4.5 cm breast thickness. The measured values were between 0.4 and 2.97 mGy with a mean of 1.46 mGy (Fig. 1).

X ray field/image receptor alignment tests were made both for 18×24 cm and 24×30 cm cassette sizes. X ray field/light field misalignment was found for 12 systems. There were eight systems that indicated alignment errors between the X ray field and exposed film area. The alignment of chest wall edge with the film area was not within the limits for three systems.

There were wide variations of film-screen combinations. The screens of Kodak MinR 2000, Kodak Min-R-2, Kodak Min R 2190, Agfa Mamoray HDS, Agfa Mamoray MR Detail, Konica MD100 were in use with the films from different manufacturers (Retina, Kodak Min R, Konica CM H, Agfa HDR, Primax RTG, Life Ray). Screen/film contact tests of 180 pairs were performed and 44 of them were found to be in poor condition.

The films from 18 centres were exposed with a sensitometer, and H-D curves were analysed. The mean and variations of base plus fog level and average gradient were 0.21 (0.16–0.28) O.D and 2.72 (1.19–3.2) O.D., respectively. Variation of relative speed was in the range of 1.41 and 2.03.

The measured range of developer temperatures of the automatic film processors were 28°-37°. The test of seventeen dark rooms were also performed using the films exposed with
sensitometers and considerable light leaks were inspected for nine of them. CIRS Model 11 A and GE MTM 100 phantoms were used for the test of image qualities. In addition to the visual evaluation of images, spatial resolutions parallel and perpendicular to anode-cathode axis were also measured with the line pair test pattern insert of CIRS phantom. The resolving power of four systems were not within the tolerances. The measured mean ESAK value was 9.91 mGy and the results were within 3.9 mGy and 14.9 mGy. Image qualities of 21 systems were also measured with a GE MTM 100 phantom which has a scoring feature. The range of scores was between the 4 and 48, and the score of 3 systems were lower then threshold value given by the phantom manufacturer. The mean ESAK value of 9.02 mGy was found for this phantom.

![Graph showing average glandular dose for 4.5 cm breast thickness (mGy)](image)

**FIG. 1. Average glandular dose for 4.5 cm breast thickness (mGy)**

**REFERENCES**


QA of all mammography facilities in Cyprus

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Introduction

The objective of this study was to investigate the quality status of all the mammography facilities in the Republic of Cyprus, in relation with the European guidelines for quality assurance in mammography screening [1], for the purpose of choosing a number of them to participate in a national screening programme for breast cancer.

Methods and materials

Processing and reading conditions, as well as image quality and patient dose were recorded at twenty seven (27) centres (23 private and 4 public) in the presence of the Radiologist in charge of each facility. Processing and reading conditions included the condition and performance of the: dark room, cassettes, processor, view box and reading area. From the mammography system, the Mean Glandular Dose (MGD), the Optical Density (OD), the contrast, the High and Low Contrast Resolution (HCR & LCR) and the number of microcalcification groups visible, were recorded. Quality Control checks were performed using a CIRS phantom, 4.5 cm compressed thickness with a 50/50 composition. Measurements of OD and luminance of view boxes were performed with calibrated instruments. It was also noted whether or not the facility was equipped with a phantom for quality assurance and a densitometer.

Results

Fig. 1 below shows a breakdown of the problems found at the 27 facilities inspected. Fifty five percent of the facilities were using view boxes that did not comply with the EC guidelines [1]. The next most frequent problem was the mammography unit itself. The main problems were with collimation mis-alignment, filtration and more than 10% difference between set and actual values. Fourteen percent of the darkrooms were not light proof, resulting in foggy images. Wrong developer temperature, wrong film speed or wrong chemical mixing caused 6% of the processors to need further attention. Finally 3% of the screens used in the cassettes examined, were not clean enough causing many artefacts visible on the mammogram. Results are summarized in Table 1, with the help of data collected with the phantom image shown in Fig. 2.

With reference to Fig. 2, the optical density was measured at a predefined part of the developed mammogram (centre circle), whereas the contrast was derived from the density difference between two points (most dark and most light square). The Groups as mentioned in the table refer to the amount of the micro-calcification groups visible (group of dots). Finally the low and high contrast resolution refers to the amount of circles and lp/mm seen. For better appreciation of the distribution of results, the standard deviation (SD), the minimum and maximum values and the first and third quartile ranges are calculated besides the mean value for each parameter recorded (Table 1).
TABLE 1. SUMMARY OF RESULTS OBTAINED FROM THE STUDY

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Q1</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGD in mGy</td>
<td>1.7</td>
<td>1.5</td>
<td>0.7</td>
<td>0.6</td>
<td>2.7</td>
<td>1.1</td>
<td>2.3</td>
</tr>
<tr>
<td>OD</td>
<td>1.4</td>
<td>1.4</td>
<td>0.4</td>
<td>0.9</td>
<td>2.7</td>
<td>1.2</td>
<td>1.4</td>
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<tr>
<td>Contrast</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Groups seen</td>
<td>6.2</td>
<td>7.0</td>
<td>1.8</td>
<td>0.0</td>
<td>8.0</td>
<td>5.0</td>
<td>7.0</td>
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<tr>
<td>LCR</td>
<td>3.4</td>
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<tr>
<td>HCR</td>
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<td>16.0</td>
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<td>8.0</td>
<td>9.0</td>
<td>15.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Conclusions

The quality of the mammograms developed and read from the majority of the centres, was not within the EC guidelines mainly due to trivial problems. Since the survey, all centres have been supplied with QC forms produced by the authors. These are filled in once a week from the data produced with the use of special mammography phantoms and densitometers now available at nearly all facilities. The results of Table 1 indicate that although the MGD was within specifications [1], there was a vast deviation of image quality parameters, resulting in poor images being produced in some facilities. Special care should be taken to reduce as much as possible the MGD, maintaining of course the requested Image Quality (IQ), since the lifetime risk of developing breast cancer, depends on the age and the dose received by the subject [2]. Having in mind that screening is mainly addressed towards a healthy group, limiting the MGD is of the utmost importance. More specifically, two facilities produced such poor images that none of the micro-calcifications and the low contrast circles could be seen. These centres have voluntarily withdrawn their interest to take part in the screening programme. The positive side of the survey is that all remaining centres have upgraded their facilities, follow a weekly QA programme in collaboration with the authors, and now are in line with the EC guidelines.

REFERENCES

The accuracy of retrospective dose estimation based on the mean glandular dose compressed breast thickness relationship

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Assessment of breast radiation dose for mammographic examinations is important, and alternative dose measurement methods considering the expertise of the user have been proposed [1]. Standard phantom measurements are easy to implement and useful for comparing doses between different mammographic systems, but they do not provide complete information about doses received by the patients. Determination of mean glandular dose (MGD) for patient breast is a well accepted dosimetric technique for mammography. However, for situations where dose measurements cannot be provided continuously in house, a previously created database relating the compressed breast thickness to MGD can be used for the estimation of breast doses retrospectively. The breast dose – thicknesses relationship is also useful for the presentation of screening results. Dose variations at each thickness should be minimum for the reliability of the results but high scattering of the data from the best fit are usually seen. Use of different beam qualities, variations on patient breast compositions at specific breast thickness, fluctuations of tube outputs, compression force uncertainties, and film processing conditions, problems in the performance of automatic exposure control (AEC) performance and in film/screen combinations could be the reasons for these uncertainties.

The main objective of this paper is to investigate the effect of breast composition and beam quality to the MGD versus thickness relationship both for patient examinations and phantom experiments. All measurements were obtained with a GE Senographe DMR mammography unit. The frequently used anode – filter combinations for this system are Mo-Mo, Mo-Rh, Rh-Rh. Although manual selection of kVp and target-filter is possible, the Automatic Optimization Parameter (AOP) mode of the system, together with the automatic exposure control (AEC), provides automatic selection of target material, filter, tube potential (kV) and mAs. This feature of the system enables the operator to make a selection of one of the modes of contrast, standard or dose modes. Gradual reduction of the breast dose is carried out from contrast to dose mode. In order to establish a database for our mammography department the post exposure mAs, compressed breast thicknesses, tube potential, target-filter combination and AEC settings were recorded for each exposure of patient studies. A total of 105 patients have been included in this investigation. Two different exposure techniques were used for the CC view of each breast; one breast was examined with the standard mode of automatic selection of the system which was also the routine technique of the Department. A manual technique, considering the approximate glandularity content of the breast and its compressed thickness was used for the examination of the second breast. In order to have an initial idea regarding to the glandularity content of the breast before the exposure, we tried to make a best guess of breast glandularity through the evaluation of X ray film of the other breast that was already examined by the automatic technique or from the previous films of the patient. Based upon this decision criteria, patient breasts were divided into three groups according to their glandularity content. Breasts with the glandularities of more than 75% and lower than 25% were categorized as dense and fatty breasts, respectively. All the breasts with glandularities between 25%–75% were collected in the third group. Beam qualities to be used for the manual exposure technique were selected according to these ratios and compressed breast
thickness; Mo-Mo combination with 27 and 28 kVs were used for breast thicknesses between 3–5 cm. In case of 5–7 cm thickness range, 28 kV with Mo-Mo and 26–28 kVs with Mo-Rh combinations were selected. The MGD was calculated according to a formula given by Dance [2].

MGD versus compressed breast thickness relationship for the 105 patients examined with manual technique and different target/filter combinations for each glandularity group are presented in Table 1. Less data scatter was noticed if these relationships were obtained specific to glandularity content and target/filter combination. Best correlation was found for Mo-Mo selection of fatty breast (R² = 0.73) and dense breast group (R² = 0.61). A low correlation (R² = 0.35) was found in case of mid glandularity group. The wide range of glandularities that were combined in this group was probably one of the major reasons for the high data scattering. Even the reduction of these data to specific beam qualities could not give a satisfactory correlation.

As a phantom experiment, tissue equivalent materials with a range of simulated relative glandular content (30%, 50% and 70%) and thicknesses (20–70mm) were exposed at dose, standard and contrast modes in order to better see the effect of beam quality to MGD versus thickness relationship. High data scattering was noticed at the 4–6 cm of breast thicknesses in these relationships due to the automatic change of target/filter combination.

If there is a need to generate a relationship between MGD and breast thickness relationship, the effect of all factors causing data scattering should be minimized.

**TABLE 1. CORRELATION COEFFICIENT (R²) VALUES FOR EACH MGD-THICKNESS RELATIONSHIP**

<table>
<thead>
<tr>
<th></th>
<th>All Groups</th>
<th>Fatty Breast</th>
<th>Medium Breast</th>
<th>Dense Breast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto. Manu.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.35 0.29</td>
<td>0.73 0.73</td>
<td>0.34 0.40</td>
<td>0.52 0.21</td>
<td>0.61 0.38</td>
</tr>
<tr>
<td>(105) (105)</td>
<td>(31) (31)</td>
<td>(53) (33)</td>
<td>(18) (21)</td>
<td>(13) (8)</td>
</tr>
</tbody>
</table>

*Patient number in each group is indicated in the parenthesis.*

**REFERENCES**


Session 4c:
Radiation Imaging
PATIENT SPECIFIC DOSIMETRY IN NUCLEAR MEDICINE
Radiation dose calculations are essential to the proper balancing of risks and benefits of radiotherapy with internal emitters.

This talk will first discuss fundamental concepts in the calculation of radiation dose and available models, methods, and available resources for dose calculations [1]. More accurate dose estimates than are available with current standardized models are needed to provide radiation dose estimates that are relevant to patient individualized therapy. Many new methods are currently under development that promise to provide detailed three dimensional representations of radiation dose distributions, which will permit plotting of complex dose distribution and dose-volume histograms, and ultimately improve dose-effect correlations in patients treated in radioimmunotherapy (RIT) and other applications [2,3,4].

A number of advances in single photon emission computed tomography (SPECT) instrumentation and reconstruction methods have occurred in recent years that dramatically increase the potential for more accurately estimating organ and sub-organ (voxel-level) radioactivity distributions [5]. This is particularly important for agents employed in radiation therapy such as in $^{90}$Y or $^{131}$I therapy of non-Hodgkin's lymphoma, in which severe bone marrow toxicity is to be avoided. It is critical to determine and deliver a tolerable and therapeutically effective treatment dose, if we are to treat patients and ensure good survival with tolerable side effects.

A facet of investigations into image based methods for dosimetry that has not been well treated to date is a characterization of the uncertainties and limitations of image quantification and dosimetry methods. Many nuclides pose difficult problems in absolute quantification in patients enrolled in clinical and research protocols.

In addition, this talk will discuss the validation of activity quantification methods in phantoms and animal studies and the sources of uncertainty in doses calculated using available methods. Progress with both calculation and interpretation of radiation dose estimates (i.e. in relation to predicting biological response) will be treated [6].

REFERENCES


Evaluation of red marrow absorbed dose in patients treated with $^{131}$I for differentiated thyroid cancer

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We present a patient-specific methodology for the estimation of red marrow absorbed dose ($D_{RM}$) in patients with Differentiated Thyroid Cancer (DCT) under radiiodine therapy that has been used within the framework of a clinical investigation on therapeutic internal dosimetry in Argentina.

The objectives of the investigation were to estimate a safe administrable activity in order to not exceed the empirical limit of 2 Gy in red marrow trying to avoid mielotoxicity and to compare the newly implemented methodology with a previous method we had in use.

The approximation, based on MIRD scheme, considers two source regions: red marrow itself for non-penetrating radiation and total body for penetrating radiation:

$$D_{RM} \approx \bar{A}_{RM} S^{op}(RM \leftarrow RM) + \bar{A}_{TB} S^{p}(RM \leftarrow TB)$$

Cumulated activity in total body ($\bar{A}_{TB}$) is obtained from measurements in a gamma camera (at 1, 24, 48, 72, 96 hours) and cumulated activity in red marrow ($\bar{A}_{RM}$) is derived from serial determinations of activity in blood, applying a red marrow/blood conversion factor ($RMBLR$) (at the same time samples). Based on the proposals of recognized authors [1], it becomes:

$$D_{RM} \approx RMBLR \left[ \frac{\Delta_{H^+}}{\rho_{H^+}} \Delta_{np} \phi_{np}(RM \leftarrow RM) + \bar{A}_{TB} \left( S_{ph\text{on}}(RM \leftarrow TB) \frac{m^{\text{phantom}}_{TB}}{m^{\text{patient}}_{TB}} - \frac{\Delta_{np} \phi_{np}(RM \leftarrow RM)}{m^{\text{patient}}_{TB}} \right) \right]$$

We had to adjust this formula to contemplate specific particularities of DCT therapy. First, INa is a simple, inorganic and small molecule, which could imply a remarkable accumulation of $^{131}$I in red marrow ($RMBLR$ between 0.62 and 1) [2]. So we supposed, as a first approximation, that:

$$RMBLR \equiv 0,55/(1 - HTO)$$

where

HTO is the patient hematocrit, and
0,55 is the assumed fraction of the distribution volume in red marrow.
Second, incidence of DCT is higher in women than in men, so male and female Eckerman-Stabin phantoms and red marrow model [3] were used to derive the corresponding absorbed fractions $\phi_{np} (RM \leftarrow RM)$, $S_{phantom} (RM \leftarrow TB)$ and phantom masses, that are all gender dependents. The electronic equilibrium constant was calculated to be $\Delta_{np} \approx 0.4105 \left[ \frac{g \text{cGy}}{\mu \text{Ci} \ h} \right]$. So, the formula incorporates specific patient information: whole-body mass ($m_{TB}^{\text{patient}}$) to adjust S phantom values, hematocrit, and actual kinetic information. In the female case:

$$D_{\text{fem}}^{\text{female}} = 1.98E - 4 \left[ \frac{l \text{cGy}}{\mu \text{Ci} \ h} \right] \text{RMBLR} \left[ \bar{A} \right]_{\text{bl}} + 0.515 \left[ \frac{g \text{cGy}}{\mu \text{Ci} \ h} \right] \frac{\bar{A}_{TB}}{m_{TB}}$$

Five non-osseum metastatic patients admitted in the programme and administered with an $^{131}$I tracer dose of 2–3 mCi, were evaluated. Dose coefficients and the maximum activity that could be administered were calculated. The formalism replaces the previous technique based on MIRD Report N° 5 we had in use, that only required total body activity measurements as entry parameters (estimations of maximum administrable activity between 453–807 mCi). The new estimations obtained from simulations and clinical data of patients (362–737 mCi maximum administrable activity with individual variation up to −32%) seems to be more restrictive in some cases, principally because the formalism considers the high non-penetrating red marrow self dose. Patient mass introduces variations between −8% and 28% in dose estimations, similar to the results reported by world reference centers.

This formalism contributes to the strengthening of radiopharmaceutical therapy complementing the empiric prescription protocols widely used in this practice and was selected because it can be implemented in an institution of median complexity with a gamma camera and a well counter.

**REFERENCES**


A software package for tridimensional patient-specific dosimetry in $^{188}$Re labelled h-R3 loco-regional RIT

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Internal radiation dosimetry calculations are essential to establish the safety of radioimmunoconjugates during the phase I–II clinical evaluation of these compounds [1,2]. A software package (TRIDOSE) for estimating three dimensional internal emitter radiation doses to the tissues of individual patients (patient-specific radiation dosimetry) has been developed. The software was focused for dose estimations in patients bearing brain tumours, who would be treated using locoregional radioimmunotherapy with the $^{188}$Re labeled humanized monoclonal antibody h-R3.

The Medical Internal Radiation Dosimetry (MIRD) formalism at voxel level was implemented. “S” values for $^{188}$Re at the required cubical geometries were estimated using two methods: (1) the MCNP-4C code for the simulation of radiation transport and energy deposition in the voxels of interest, and (2) integrating the dose point kernels for beta emissions reported by Cross, et al., plus the integration of the photon dose kernels reported by Furhang, et al., using an algorithm implemented in Borlan Delphi 7.0 [3–5].

Firstly, TRIDOSE reads the SPECT reconstructed slices and a set of additional parameters related to biological and calibration data in order to compute the volumetric cumulated activity. The accepted image formats are interfile, sopha files and raw data. The input parameters are the radioimmunoconjugate effective half-life in the brain tumour, voxel size, time between administration and SPECT acquisition, normalization factor during the SPECT reconstruction and tomographic sensibility. Calibration studies were required to calculate the voxel size, to estimate the attenuation correction coefficient and to assess the tomographic sensibility of the SPECT system. Sequential planar studies should be performed to compute the effective half-times in the regions of interest.

The absorbed doses are estimated voxel by voxel in the total volume after the “S” values data file reading. Computed tridimensional dose distributions are evaluated qualitatively using isodose curves at three predefined levels (25%, 50% and 75% of the maximum dose) or using interactive dose levels defined by the users. Simple or multiple profiles are also available to evaluate the computed doses.

Mean and maximum dose values are calculated for volumes of interest (VOIs), which are selected using regions of interest (ROIs) over the transversal dose slices or just using interactive isodose levels. Dose-volume histograms are also computed and shown for the selected VOIs corresponding either to the tumour or normal organs of interest.

An additional option was incorporated to perform quality control of the software. It allows generating software phantoms of spherical geometry with well known distributions of cumulated activity and computing the absorbed doses for these volumes. In order to test the
software, mean absorbed doses were calculated for four spheres of different diameters and the results were compared with the values estimated using the “nodule module” of the MIRDOSO software, for similar sphere diameters. The relative differences ranged from 0.09% to 1.10% (Table 1). These differences were due to the mismatch in the sphere diameters and also because of the discrete character of the spherical volume generated by TRIDOSE. Besides, the quality control option allows to test the calculation of the cumulated activity maps combining the generation of well known spherical distributions of count with pre-defined input values for the calibration and biological parameters.

TABLE 1. COMPARISON BETWEEN THE MEAN ABSORBED DOSES COMPUTED FOR SPHERICAL VOLUMES USING THE MIRDOSO AND TRIDOSE SOFTWARE

<table>
<thead>
<tr>
<th>Sphere diameter (mm)</th>
<th>MIRDOSO Mean Dose (mGy/MBq-s)</th>
<th>TRIDOSE Mean Dose (mGy/MBq-s)</th>
<th>Relative differences (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.8</td>
<td>0.0029100</td>
<td>0.0028782</td>
<td>1.10</td>
</tr>
<tr>
<td>81.9</td>
<td>0.0004040</td>
<td>0.0004043</td>
<td>0.09</td>
</tr>
<tr>
<td>122.0</td>
<td>0.0001230</td>
<td>0.0001241</td>
<td>0.87</td>
</tr>
<tr>
<td>176.0</td>
<td>0.0000421</td>
<td>0.0000420</td>
<td>0.18</td>
</tr>
</tbody>
</table>

The software was finally evaluated in one patient bearing glioma who underwent locoregional radioimmunotherapy with 15mCi of 188Re labelled Mab h-R3. The radioimmunoconjugate was administered through an Omaya catheter and a set of sequential planar data sets were acquired at 1 h, 3 h, 5 h, 24 h and 48 h, and SPECT studies were also performed at 3 h post injection. The mean and maximum absorbed doses were estimated as 3470 cGy and 6460 cGy, respectively, using the described methodology. These values are in the expected range.

The TRIDOSE software is being used for dosimetric calculations in a Phase I-II clinical trial for locoregional RIT of gliomas. It is expected to obtain a more accurate correlation of response and critical organ toxicity with computed absorbed doses. This software is also an important step to implement a planning system for this kind of therapy, such that computing glioma control probabilities and normal tissue complication probabilities become available.

REFERENCES

New specific absorbed fractions for annihilation radiation as a step towards a more individual dosimetry in nuclear diagnostics

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In order to establish a more individual dosimetry for treatments involving radiopharmaceuticals like nuclear diagnostics and targeted radionuclide therapy, this project aims to calculate Specific Absorbed Fractions (SAFs) for annihilation radiation over a broad range of physiognomies.

For the estimation of the SAFs varying with different physiognomic parameters, the study uses the Monte Carlo N-Particle Transport Code (MCNP) which during the last decades proved to be a powerful and reliable tool for dose calculations in human tissue. The human phantoms are generated from an additional software called The Body Builder which enables the user to generate a phantom according to his specifications. The phantoms generated by The Body Builder are based on the Christy/Eckermann phantoms \([1]\) with a first interpolation made on their coefficients and a subsequent transformation into the equivalent MCNP surface representation. The spectrum of age groups ranges from 1 to 21 years, covering both sexes. As source organs we chose the biokinetical compartments of \(^{18}\)F–fluorodeoxyglucose (FDG) used in the model of Hays and Segall \([2]\).

A homogeneous distribution of the activity within the source organ is assumed, which means that the annihilation photons of 511 keV are considered to be emitted from an isotropic and homogenous volume source. In order to get good statistics the number of photons simulated ranged between 2 and 20 million, depending on size and distance between source and target organs.

**Results**

Considering all possible combinations between source and target organs, representing 21 age groups of both sexes, one gets more than 30 000 SAFs. The work is still in progress during the preparation of this paper, but first results are already presented here.

The relative error of the Monte Carlo simulation for every SAF mentioned below does not exceed 1,1%. An additional uncertainty factor of approximately 0,5% is introduced by using the p-mode of MCNP. The results of the different age groups are compared with the SAFs from the Christy/Eckermann series. This is done by linear interpolation between the two closest age groups from the Christy/Eckermann series (e.g. 5 and 10 for an 8 year old), a procedure often applied in clinical practice. These values are then compared to the ones calculated in the simulations described above. One has to mention that the Christy/Eckermann values refer to the energy of 500 keV, a value of slightly difference to the actual value of the annihilation radiation.
Concentrating at the interesting age groups of 2–4, 6–9 and 10–14, where previously no explicit calculations existed one can now take a look at the different cases. For the cases where all the interpolated Christy/Eckermann values are higher and therefore represent a more conservative estimation in the sense of dose assessment, the new SAFs are smaller in a range from 1.5% to 8.9%, being 5% on the average. For the combinations where all the newly calculated SAFs are higher, the study so far bears an average increase of the SAF of 3.2% ranging from 0.5 to 6%. In total one can say that the new calculated SAFs differ from the interpolated Christy Eckermann values from -9% to +17%. However, 92% of the values lie between +/-9%. All data mentioned above result from combinations of source and target organs both lying in the trunk and therefore being very close to each other.

**FIG. 1.** The linearly interpolated SAFs from the Christy/Eckermann series compared with the newly simulated ones. Source organ is lung and target organ is small intestine.

### REFERENCES


Session 5:

*Plenary II*

QUALITY ASSURANCE PROGRAMMES AND COMPREHENSIVE AUDITS IN RADIATION MEDICINE
A continuum of quality in radiology

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International Radiology Quality Network,
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There is an increasing interest in the quality in radiology in recent years due to public awareness, concern with patient safety, malpractice indemnity cost and demand by payers on value and sustainability.

This paper firstly defines what quality in radiology is, followed by a discussion on the drivers for quality and the role of the stakeholders.

Quality in radiology may be defined in many ways and from different perspectives, one of these is: a timely access to and delivery of integrated and appropriate radiological studies and interventions in a safe and responsive facility and a prompt delivery of accurately interpreted reports by capable personnel in an efficient, effective and sustainable manner [1]. It is recognized that quality progresses from QC, and quality assurance to quality improvement.

There are four key stakeholders: consumers, referrers, providers and payers. The best outcome will be achieved if all stakeholders have a good understanding of their roles and responsibilities and are committed to deliver within the finite resources by: doing the right test for the right patient at the right time for the right reason and at the right cost.

The second part of the paper deals with the range of quality systems currently in place, covering individuals (e.g. certification, revalidation, CPD, etc.); practices (e.g. quality mapping, practice accreditation programs, etc.), and national and international programmes (e.g. appropriate utilization, system based quality improvement initiatives, national quality improvement programmes such as Medical Excellence in Diagnostic Imaging Campaign [2] Continuous Improvement in Radiology Information System [3] and Quality Use of Diagnostic Imaging (QUID) Programme [4], international standards [5], etc.). Quality systems are recognized as effective risk control measures.

Quality efforts are expensive in the short and medium term, especially if uncoordinated. However, they are inevitable and indispensable in the long term, forming an integral part of professionalism and risk minimization. It is useful for the profession to recognize the link between quality, economics and system sustainability. The long term objectives would be defined. Key stakeholders would be identified and engaged with a view to collaborate and to develop an integrated work plan. A multi-faceted approach would be adopted to promote quality and safety in practice. Finally, the role of professional organizations in promoting quality in radiology is discussed including the facilitating role of the International Radiology Quality Network [6].

The paper concludes that quality is a continuum, and quality improvement is perpetual. This on-going improvement process is applicable to all programmes and quality systems.
ACKNOWLEDGEMENT

A range of quality activities are referred to in this paper with which I am associated and I wish to acknowledge the contribution of many colleagues who have contributed to their success. These include the team members of:

– The Accreditation Guidelines and Quality Committee of the Royal Australian and New Zealand College of Radiologists
– The Medical Imaging Accreditation Advisory Committee of the Royal Australian and New Zealand College of Radiologists and National Association of Testing Authorities
– The Quality Use of Diagnostic Imaging Program
– The International Radiology Quality Network.

REFERENCES

QA team for radiation oncology (QUATRO)

J. Izewska\textsuperscript{a} P. Secllet\textsuperscript{b} V. Levin\textsuperscript{c} H. Järvinen\textsuperscript{c} E. Lartigau\textsuperscript{d} S. Thwaites\textsuperscript{e} R. Abratt\textsuperscript{d}, F. Aguirre\textsuperscript{g}, M. Coffey\textsuperscript{b}, J. Drew\textsuperscript{i}, B. El Gueddari\textsuperscript{l}, W. Hanson\textsuperscript{g}, K. Kiel\textsuperscript{k}, F. Leborgne\textsuperscript{l}, A. McKenzie\textsuperscript{m}, A. Poitevin\textsuperscript{n}, V. Smyth\textsuperscript{o}, H. Svensson\textsuperscript{p}, K.R. Shortt\textsuperscript{a}, B. Vikram\textsuperscript{a}, P. Andreo\textsuperscript{a}

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Independent external quality audits in radiotherapy, forming part of a comprehensive QA programme, are widely recognized as an effective method to verify the quality of radiotherapy practices. Quality audits include a wide range of types and levels of review, either of the entire radiotherapy process or of specific critical parts of it, such as radiotherapy dosimetry.

The IAEA has a long standing history of providing support for radiotherapy dosimetry audits, for educating and training radiotherapy professionals, and for reviewing the radiotherapy process in a variety of situations. Since 1969, and in collaboration with the World Health Organization (WHO), the IAEA has implemented a regular dosimetry audit service using mailed thermoluminescent dosimeters (TLD) to verify the calibration of radiotherapy beams in hospitals in Member States [1], which aims at improving the accuracy and consistency of clinical radiotherapy dosimetry worldwide. During the past 37 years, the service has verified the calibration of more than 6000 beams in approximately 1500 radiotherapy hospitals.
Detailed follow-up procedures have been implemented by the IAEA to effectively resolve incorrect beam calibrations. On-site visits by IAEA experts in radiotherapy physics have been organized to help identify and rectify dosimetry problems when errors could not be resolved remotely. The reasons for observed faulty calibrations were traced, explained, corrected and reported.

The IAEA has also been requested to organize expert missions in response to problems found during the radiotherapy treatment planning process. In addition to tracing, explaining, correcting and reporting the reasons for problems, assessment of the doses incurred by affected patients and their medical evaluation were undertaken when appropriate.

Though vital for radiotherapy process, accurate beam dosimetry and treatment planning do not guarantee a successful treatment of the patient, as QA of the entire radiotherapy process must be taken into account. A new approach has therefore been developed and named Quality Assurance Team for Radiation Oncology (QUATRO). The QUATRO methodology [2] was worked out in a series of consultants meetings organized by the IAEA in 2003–2005. The methodology was endorsed by EFOMP, ESTRO and IOMP in 2005.

The operations of QUATRO are based on the use of four different experts in the quality audit teams: a medical physicist, a radiotherapy clinician, a radiotherapy technologist and a radiation protection expert. The aim of QUATRO is to review the entire radiotherapy process, including the organization, infrastructure and clinical and medical physics aspects of the radiotherapy services. It also includes reviewing the department’s professional competence, with a view toward quality improvement.

In addition to pro-active audits such as comprehensive reviews of the radiotherapy practice, QUATRO involves reactive audits, i.e. focused investigations in response to the suspected or actual incidents in radiotherapy [3]. It includes a follow-up of inconsistent results detected with the IAEA/WHO TLD postal service. QUATRO helps Member States at a very early stage in the problem solving process focusing on prevention of incidents or accidents in radiotherapy.

A series of workshops on the QUATRO methodology were conducted in 2005 and 2006 by the IAEA for the audit teams and hospital staff prior to fielding the QUATRO missions. At present the methodology is used in several QUATRO missions taking place in Europe and Asia. Further missions are planned in Africa and Latin America.

REFERENCES


“QUANUM” – IAEA guidelines for comprehensive self appraisal of nuclear medicine practices

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The rapid development of nuclear medicine services, sophisticated equipment and radiopharmaceuticals has resulted in an enormous increase in costs and in the need to maintain quality. Quality management (QM) is fundamental for a safe and efficient practice of medicine. Although the focus has been on quantity and level of services in most developing countries, ample evidence suggests that quality of care must be central to any service. This does not only include quality control (QC) and standards of practice, but it is increasingly recognized that a sustainable holistic approach is vital.

Guidelines in Nuclear Medicine have been, and continue to be developed by a number of organizations throughout the world. On the international level the IAEA is keen to assist in coordinating the development of such guidelines, but recognizes the need for national guidelines whenever possible. National regulations on the administration of radioactive substances, differences in clinical practice and service delivery, etc. are understandably more meaningful locally.

The IAEA guidelines resulted from a consultants meeting that was organized by the IAEA in Vienna in January 2006 to:

– assess current and future considerations for establishing guidelines for a comprehensive audit of nuclear medicine practices,
– identify subtle national, regional and international variations in quality systems,
– create a self appraisal document to serve as a tool for quality improvement by drawing attention to any defaults that might be corrected ahead of any external peer review process,
– establish guidelines for an external peer review and any follow-up mechanisms,
– advise the IAEA on required systems for maintaining such a programme.

Following a review and discussion of the audit process in different regions of the world, it was concluded that, in general, quality systems are central to safe, efficacious and effective delivery of any service. Clinical audit of nuclear medicine services is likewise important. An organized peer review and follow-up of both the medical and scientific practices are essential, taking account the complexity of work undertaken in nuclear medicine as well as the multi-disciplinary input. Furthermore, comparing practice with predetermined standards such as the IAEA’s Nuclear Medicine Resources Manual is also necessary. The aim of any clinical audit is to achieve continuous improvement in all aspects of the nuclear medicine department and its services. This includes focus on patients, continuous evaluation leading to improvement in clinical effectiveness and involvement undertaken in multi-professional groups. Professional performance by individuals and department, and service as a whole, may be discovered through such a review.

The consultants concluded that an audit process can serve two purposes: 1) as an internal self assessment tool for individual departments, and 2) as an external peer-review. An audit
document was drafted that includes the following sections: Introduction, Overview of the process, Overview of departmental activities, Clinical audit, Radiopharmacy, Radiation protection, and Safety issues.

The IAEA programmes should aim to enhance cost effectiveness and appropriate use of nuclear medicine procedures in the diagnostic work — up through the harmonization of protocols, engendering evidence based medicine and development of standardization of new radiopharmaceuticals.

Under clinical audit analysis, three criteria were agreed on:

I. Conforming to written criteria
II. Acceptable but could be improved
III. Non-conforming.

The agreed timeframe permitted for follow-up actions should be restricted to three to six months, and four weeks for non-conformances (III). There was a need for immediate action as far as radionuclide therapy was concerned. All aspects of the audit should be discussed before the close of the audit mission. Any remedial action should also be considered during the feedback session so that there are no surprises later.

Setting standards and following the auditing cycle is a means to implement QM. Providing the correct framework and essential tools to Member States will help raise their standard of practice in health care delivery. There is a need for greater empowerment and an innovative approach in dealing with these problems, especially in many developing Member States of the IAEA. Therefore, self appraisals, together with externally audited programmes, are required for successful implementation of QM, and for proper pre-qualification and post implementation of IAEA technical cooperation projects.

The consultants discussed ways to ensure the successful running of the audit process and the resultant implementation of remedial/corrective actions. A properly trained and organized team in each region is essential for consistency. Timely delivery of the official report was considered a key point. Further, it was advised that the IAEA should consider translating the draft document into the six official UN languages to ensure maximum and effective dissemination of the final guidance document to the end-users through professional societies. The group strongly felt the need to have a process that strengthens and encourages wider use of internal audit procedures for a more sustainable development of nuclear medicine practice.

To ensure that the guidance document is effectively utilized, implementation of appropriate training and follow-up programmes would be considered. With the increasing sophistication and expanded use of nuclear medicine services it is now clear that professional training is a critical factor in its development. There is an urgent need to standardize training and target IAEA’s resources to educate a large number of nuclear medicine professionals in developing countries through the creation of centres of excellence, innovative teaching methodologies and effective application of various information and communication tools.

**Summary:** All-inclusive guidelines in the programme referred to as “QUANUM” will play a vital role for self appraisal and improvement of QA/QC in nuclear medicine clinics. The impact would be to improve standards of patient care offered by nuclear medicine services to an international level. It is hoped that it will also be an important tool for sustainable development of nuclear medicine services around the world.
Impact of clinical audit on the quality of radiological practices - Experiences from a national audit programme supported by a national steering committee

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Clinical audit is a systematic examination or review of medical radiological procedures against standards of good practices, with the aim to improve the quality and outcome of patient care. It is a cross cutting, multidisciplinary issue which can have a broad impact on quality of radiological practices.

Clinical audit, long applied in other fields of medicine, was introduced to medical radiological practices by an EC Directive (97/43/EURATOM). In Finland, the requirements on clinical audit were implemented by appropriate modifications of the radiation protection regulations. A special joint-stock company Qualisan Oy, supported by the major professional societies of Finland, has provided so far the necessary clinical audit services. About 150 auditors from volunteers among the major professional groups have been trained. By now, all radiological units in Finland, comprising about 450 health care units for diagnostic radiology, 30 units for nuclear medicine and 10 units for radiotherapy, have been audited by Qualisan for the first time.

In 2004, a national Steering Committee for the coordination, development and follow-up of the clinical audits was established by the Ministry of Social Affairs and Health. This is a multidisciplinary group of clinical experts, independent of Qualisan or other auditing organizations. The first results of the national audit programme, with the actions by the Steering Committee, are the subject of this paper.

Methods

At first, the national Steering Committee prepared guidelines on the detailed requirements of competence, experience and independence of the auditors. After about 25% of the units had been audited (excluding radiotherapy by that time), the committee carried out a comprehensive survey of the outcome of audits. Recently, the committee has organized meetings with other invited experts in order to supplement the audits by in-depth assessment of selected practices.
Results

According to Finnish regulation, clinical audits shall be carried out by competent and experienced auditors, who are independent of the organization to be audited. The Steering Committee has detailed this regulation among other things by recommending that (1) the auditors should have practical clinical experience in the field to be audited, (2) the lead auditors should have at least one week and the other auditors at least two days of specific training on the audit principles and techniques as well as on the objectives and criteria of the audit, (3) the composition of the audit team should generally include a physician (e.g., radiologist, oncologist, cardiologist or nuclear medicine specialist), a medical physicist and a radiation technologist.

The review on the outcome of clinical audits indicated that the health care units comply, on the average, rather well with the criteria of good practice deduced from the legislative requirements. There were no serious violations as for the radiation safety of the patients. In diagnostic radiology major findings concerned the lack of services by the medical physics expert, shortcomings of the referral practice, examination guidance and quality control programmes, insufficient evaluation of the results of examinations and insufficient recording of radiation protection training. The increase of communication between different professionals and speed-up of the development of documented Quality Management Systems, are significant supplementary benefits of the audits.

The results also revealed a risk of overlap with regulatory verifications or other quality assessments. For the former case, the Radiation and Nuclear safety Authority (STUK) and Qualisan have convened joint meetings in order to avoid unnecessary overlap between audits and regulatory inspections.

The results have also suggested the need to supplement the audits by more profound evaluation of selected practices. For diagnostic radiology, some areas to be focused on include self assessment of practices, paediatric X ray examinations, CT examinations and the implementation of digital techniques. For in-depth assessments, the criteria should be based on good practices convened by the special national expert groups. For nuclear medicine, areas of higher interest are bone scintigraphy, iodine-131 therapy, paediatric examinations, use of CT (PET-CT and SPET-CT) and the quality of reports. The criteria recommended by the EANM should be applied when available. For radiotherapy, standards of good practice seem more difficult to define. So far focus has been on important sub-routines like adequacy of the data for the justification of treatment (through a review for a sample of patients) or the follow-up practices (acute and late complications, recurrence).

Conclusions

The outcome of the first clinical audits in Finland have revealed a number of shortcomings where the quality of the practices can be improved. The results have also suggested that more detailed in-depth assessments of selected practices should be the goal of the next audit runs in order to increase the benefits to be derived.
Clinical audit guidelines in radiotherapy – Preliminary results of the ESTRO working group


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Radiotherapy is more strictly regulated than other medical disciplines since it uses ionizing radiation. The European Medical Exposure Directive (MED) 97/43/EURATOM became a fundamental legislation for Member States. However, in many EU states, detailed regulation has not yet been elaborated nor passed.

ESTRO decided to establish a working group on Clinical Audit Guidelines. During the first meeting, objectives, goals and methods of achieving them were discussed. Possible links and cooperation with other groups working on similar subjects, such as the International Atomic Energy Agency (IAEA), Union of European Medical Specialties (UEMS) and European Organization of Cancer Institutes (OECI) were also reviewed.

The crucial issue is that legislation is under continuous development and its changes concern both European and national levels. Science and technology in radiotherapy is developing rapidly and constantly offering new tools which modify implemented procedures. This has an impact on quality standards, making it difficult to establish uniform and detailed guidelines. The purpose of the Clinical Audit Guidelines is to help hospitals to improve their radiotherapy practice and quality.

Aim of this paper. To present the process of achieving consensus on a European level about the Clinical Audit Guidelines in Radiotherapy and the preliminary results from the working party.

Methodology of the project

Expected results. Results of the work will be shown in a publication including the following items: (1) Philosophy of clinical audit and the ESTRO objectives in clinical audits; (2) Definition of good practice (standards, protocols); (3) Review of present guidelines and legal status in different countries; (4) Relationship with MED 97/43; (5) checklist.
Steps
a. Conduct a survey on present status and expectations within the European states (in progress)
b. Present outlines of the project at a meeting with representatives from national radiotherapy societies (April 2006, Brussels)
c. Establish channels of communication with national societies to exchange data and consult outputs
d. Elaborate on the guidelines (first attempt made, first draft: July 2006)
e. Test guidelines in chosen European institutions and collect opinions
f. Obtain European consensus
g. Publish guidelines.

Preliminary results. A survey was sent in January 2006 to 67 national societies from 37 European countries. Twelve (12) responses were received by February 2006. The questions were aimed to reveal: (1) present status of legal environment concerning radiotherapy in European states, recommendations passed by other than state entities, i.e. scientific societies, academic bodies; (2) progress in implementation of MED 97/43 to national law; (3) organization and performance of clinical audits at the national level (4) access of national societies to participate in the ESTRO project.

The obtained data showed that conditions in which radiotherapy should be performed have just recently been regulated by national laws due to the implementation of the MED 97/43. The implementation process is currently in progress and it is mostly coordinated by governmental bodies such as the Ministry of Health or the National Atomic Energy Agency, which established working parties for this purpose. Although most countries have implemented the MED 97/43 regulation regarding the performance of clinical audit; including the steps of the audit, its comprehensiveness (i.e. assessment of medical records, treatment plans, dose distributions for random patients, dosimetry, equipment status and maintenance, personnel qualifications and residency programmes) and the composition of the auditing team (mostly experts in medical physics, radiation oncology and engineering from other radiotherapy institutions recommended and assigned for this task by official state bodies), in most countries it has not yet been put into practice. Most respondents confirmed that results of clinical audits do not determine eligibility of institutions to provide radiotherapy.

In some European countries (i.e. Poland, Czech Republic and Netherlands) lawful regulations have been also completed upon recommendation elaborated by scientific societies or universities. It was reported that hospitals rarely use their own written regulations regarding radiotherapy as they base their practice mostly on national laws and national society guidelines. However, majority of radiotherapy departments have already implemented quality assurance programs or quality management systems based on EN ISO Norm 9001:2000. Respondents were very open to the ESTRO initiative.

Methodology of data processing. The most debated issue is whether guidelines should cover only general good clinical practice or give specific examples on what is desirable according to established ESTRO standards or using benchmarking. It is a very complex task as our goal is to elaborate guidelines which will (a) encourage national bodies to establish their own regulations/recommendations; (b) help to fulfill regulations of the incoming EU Bokkestein Directive; (c) provide tools to institutions with less resources helping them to obtain funds from their authorities for the quality improvement and (d) maintain the existing quality level of well equipped and technologically developed institutions by avoiding recommendation of standards below their expectations and needs.
Guidelines of the Italian National Institute of Health on QA in interoperative radiotherapy

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The Italian National Institute of Health (ISS in Italian) is designated as a consultant body for public health protection in relation to the production and application of energy for diagnostic and therapeutic purposes. In this framework, activities related to quality assurance (QA) in radiotherapy, mainly devoted to the elaboration of guidelines, have started on this subject.

Activities aimed at the improvement of quality does not assure per se the optimal implementation of health standards, but allows the Institution to demonstrate that it works according to rules of good practice, reducing the potential risks connected to the implementation of complex clinic procedures.

Within this context, the ISS has established an Interdisciplinary Study Group on QA in radiotherapy, which, on the basis of the input from Italian centres working in this sector, has felt it necessary to elaborate guidelines for the application to radiotherapy of new technologies, such as those employed in the Intra Operative Radiation Therapy (IORT).

IORT is a treatment which requires multidisciplinary collaboration among radiation oncologists and other medical specialists, surgeons and anaesthetists, and with other professionals, i.e. medical physicists, radiation technologists and nursing personnel. Due to the involvement of large staff and to the complexity of the treatment, it is recommended that IORT relies on the collaboration between two distinct groups for effective implementation: an operational group which carries out the treatment and a group to monitor quality:

- The operational group includes all the operators (health personal, technical and administrative personnel) involved in the execution of the IORT treatment, who have been trained to follow the indications of the quality assurance programme prepared in each Centre.
- The quality group is composed of the person responsible for the programme of QA and of representatives from all the sanitary operators involved in the IORT treatment, each of them nominated by the Director of the Department or affiliated service.

Modern intra-operative radiotherapy is carried out with electron beams produced by a linear non dedicated accelerator generally used for radiotherapy with external beam, by transporting the patient, in the course of the surgical intervention, to the shielded radiotherapy facility and re-transporting him to the operating theatre after the irradiation. Recently dedicated accelerators producing only electron beams of a maximum energy of 9–12 MeV have been designed. They can be introduced directly into an operating theatre without particular needs for special fixed shielding barriers. The use of this type of equipment avoids the transport of patients outside the operating theatre, but presents more complex problems in terms of dosimetry.

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1 On behalf of the ISS Working group on QA for IORT.
IORT requires special dosimetric determinations, which are sometimes different in comparison to those associated with conventional external-beam radiotherapy. The main reason stems from the fact that a single high dose of radiation is delivered to a selectively defined volume of tissue, with extension and depth that are directly determined in the operating theatre. It is also in the operating theatre that the IORT team selects the shape and diameter of the applicator, energy and isodose of reference more suitable for assuring the therapeutic prescription.

In addition, in the case of IORT treatments performed in a unshielded operating theatre, some interventions are necessary due to the presence of a field of radiation stemming from four main sources:

- leakage radiation from the accelerator head
- leakage electrons from the walls of the applicators
- radiation produced in the patient by the braking of the electron beam (*bremsstrahlung* radiation)
- neutron radiation if electron beams of energy superior above 10 MeVs are used.

A suitable programme of follow-up is necessary to be able to define the control of the evolution of the neoplasm and the possible medium and long term side effects of the multimodal treatments that include IORT as one element of the therapeutic strategy. It is useful that the late side effects on healthy tissues and/or organs at risk are reported and classified according to the international systems (SOMA LENT and RTOG EORTC scales) pointing out, if possible, the spatial and time relationship between these and the treatment. Finally, the possible onset of new tumours, with particular information of the localization of the tumour in relation to the irradiated volume, should be reported.
QA in conformal radiotherapy

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The demand of measuring hospital performances to improve health Service quality has recently required to apply, also in this field, quality assurance guidelines and survey systems currently employed in the industrial framework for the performance measurement of productive structures.

An activity in the field of quality assurance in radiotherapy has started in Italy since ten years under the coordination of the Italian national institute of health-Istituto Superiore di Sanità (ISS). Groups consisting of a number of operators of different professional categories (radiation oncologists, medical physicists and radiation technologists) from radiotherapy Centres and from medical physics Services have been formed under the coordination of experts in health technology assessment from the ISS. Objective of the groups was the elaboration of guidelines, in different fields of radiotherapy, and of indicators able to monitor performances and the quality level of a radiotherapy centre.

Conformal radiotherapy has recently widely diffused in Italy, becoming, for many Centres of radiotherapy, the standard treatment for some pathologies. Furthermore, IMRT is being presently implemented in many Italian Centres. For this reason, we have considered the need of elaborate basic indications for quality assurance in conformal radiotherapy and in IMRT as well as to elaborate indicators to survey their application. Recommendations for conformal radiotherapy have been elaborated following the indications of the document consensus DYNARAD

The 3D CRT, represents a radical change in the clinical practice and in the treatment planning as it favour the optimization of the single treatment. Consequently, much larger experience is requested to the radiation oncologist in defining the target and the organ at risk, as well as to the medical physicist to assure higher accuracy in planning doses and to the technician in performing the patient set up. Italian guidelines have considered procedures for all the treatment steps and therefore precise indications have been given about patient selection, patient set up, anatomical data acquisition, volume contouring, planning of the treatment, treatment optimization, treatment execution, treatment verifications and toxicity monitoring.

Special attention has been devoted to the need of human and technological resources. For the radiation oncologist, 3D treatments are more demanding for the target definition, choice of margins, discussion of protocols for dose escalation and precise toxicity monitoring. Conformal radiotherapy implies additional workload also to the medical physicist not only for the study of the plan and the employment of new technologies for dose conformation to the target and for the verification of the beams, but also for setting procedures such as those connected to the use of multileaf collimator and portal verifications of treatment plan systems.

¹ On behalf of the Working Group on Quality Assurance in Radiotherapy and of the Working group on Quality Indicators for Selected Pathologies in Radiotherapy.
On the other hand, technicians are more strongly involved in the preparation of the patient for the treatment and in the execution of a larger number of quality controls.

As first system of survey on the status of implementation of 3D conformal treatments, a questionnaire aimed at surveying the implementation of conformal radiotherapy in Italy was elaborated. Each addressed people was asked to provide data on the status of 3D conformal radiotherapy in his Centre. The questionnaire consisted of one specific session on equipment and one on clinical and physical-dosimetric procedures. A question on the existence of standardized protocols for each of the main procedures of the 3D conformal radiotherapy treatment and on their application was included into the questionnaire as general item.

Indication on the need of performing clinical audit are contained in the EU MED directive, although more precise indications on how to perform clinical audit have not yet been given. Therefore, quality indicators have been elaborated for selected pathologies that may much benefit from a 3D conformal treatment. Among these, 3D conformal treatment of the prostate is the most applied. Seven indicators have been developed: an indicator at the same time structural and process that monitors the presence in the Centre of structural and procedural features necessary for 3D treatment; 5 process indicator: an indicator aimed at monitoring the pre-treatment clinical data present in the Centre; an indicator aimed at monitoring how are defined the clinical volumes; an indicator aimed at monitoring set up errors; an indicator aimed at monitoring how the follow up is performed; finally, an outcome indicator aimed at monitoring rectal toxicity.

An analogous activity has started very recently for the IMRT.

REFERENCE

Components of quality assurance of radiotherapy process - Setup in the Czech Republic

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Quality assurance (QA) of radiotherapy process consists of many components. It includes a system of internal tests of radiotherapy equipment (acceptance tests, status tests, constancy tests), external tests of radiotherapy equipment (on site audits, TLD postal audits), clinical audits, and inspections. Definitions of these items are presented, as well as description of their aim, content, range, methodology, facture (who performs, how often, budget), acquisition, impact on practice, implementation, etc. Advantages and disadvantages, and related difficulties are described and compared.

Legislation, guidelines, recommendations, and standards (international, European, national, ESTRO, IAEA) serve as the bases for QA implementation. According to these documents workplaces introduce QA system, set up QA manual, quality control (QC) procedures, local standards for radiotherapy procedures, and other documents. Particular QA system implementation depends on the national procedures.

Actual situation and impact of QA implementation on radiotherapy in the Czech Republic is described as an example. Comparison of all on-site audits of teleradiotherapy equipment performed in 1996–2000 and after 2000 is presented.

Selected results of audits of linear accelerators with MLC used for IMRT are given. Experiences from clinical audits of radiotherapy workplaces in the Czech Republic – pilot study – are discussed.
REFERENCES


Implementation of QA in medical radiological practices: A national cooperation model

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Introduction

According to the EC Medical Exposure Directive (MED) the Member States shall ensure that appropriate QA programmes, including quality control measures and assessments of patient dose or administered activity, are implemented by the holder of the radiological installation. The importance of these programmes is emphasized, in particular, for clinical application of new techniques when the relevant radiation protection requirements and guidance have to be laid out. An optimal use of all possible resources for these efforts requires good co-operation between authorities and radiation users.

Methods for the cooperation

To contribute to the excellence in QA and to ensure that appropriate QA programmes are implemented in medical radiological practices, the Radiation and Nuclear Safety Authority (STUK) in Finland has used a six step model:

1. Introducing regulations for the use of radiation
2. Undertaking research to support the regulations
3. Organizing discussions and meetings on QA with different specialists and organizations
4. Preparing guidelines for radiation users together with specialists
5. Educating and training a number of advisors who can distribute information among other specialists
6. Making verifications of the present situation and improving the process.

Practical examples

In the field of QA of radiation therapy STUK has convened annual meetings with radiotherapy physicists for more than twenty years, focused on QA issues. In the first meetings the basic questions of QA were discussed and a schematic model for a quality control programme was created. Later on, a number of more specific questions have been addressed such as the QA of treatment planning systems and the calibration of brachytherapy sources. The latest major issue was the change in the basic dosimetry when the IAEA TRS-398 was implemented. The fundamental change from air kerma to absorbed dose to water based dose determination was carefully planned with medical physicists resulting in a national consensus. STUK undertook also research on the sequences of the change before it was finally accepted. The responsible physicists for radiation therapy dosimetry in hospitals were educated and trained on site to calibrate their beams in accordance with the new approach. Finally, STUK prepared a national code of practice (in Finnish) based on the IAEA TRS-398 [1,2]. Implementation of the code was done in 2003 and verification was carried out in connection with the regular site visits of STUK.
In the field of *nuclear medicine* the QA of imaging equipment has been in STUK’s interest during the last few years. Three national meetings for NM were organized biennially by STUK. In the first meeting regulations were introduced and QA was discussed. In the second meeting, a joint working group of medical physicists and STUK was established to prepare national guidelines for users, and to assist STUK to renew the acceptance criteria for gamma and PET cameras. Also a survey of QC of imaging equipment was presented, which was carried out by STUK [3]. In the third meeting, in 2005, the results of this work were discussed. Finalization of the guidelines is currently in progress.

In *diagnostic radiology*, like in radiotherapy, there has been a long tradition in the cooperation on QC issues between STUK and the users. New techniques have challenged STUK to update the requirements and guidance. A guide to determine patient exposure was published in 2004 [4]. Updated regulation for X ray practices was issued in 2006. In 2005 a small group of experts was convened by STUK in order to prepare national guidelines on the QC of digital imaging by the end of the year 2006.

**Conclusions**

Up to date regulatory control for QA in medical radiological practices will benefit from efficient cooperation between the authorities and users. This cooperation can be established through the six step model used by STUK, where purely regulatory actions are supplemented by a number of research, training and advisory efforts.

**REFERENCES**


Comprehensive QA for IMRT: The role of internal and external audits

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Intensity modulated radiation therapy (IMRT) is becoming a routine practice at many modern radiation oncology facilities. The treatment planning and beam delivery processes in IMRT can be very complex and require special attention with regard to quality assurance (QA). At our institution, a commercially available inverse planning system is used together with dynamic multileaf collimation (DMLC) to plan and deliver IMRT. In this work we describe the overall implementation of a comprehensive QA programme for the clinical implementation of IMRT with emphasis on QA auditing. The QA programme covers four major areas: delivery hardware QA, treatment plan specific measurements, internal annual audit of IMRT cases, and participation in clinical trials requiring an external audit of procedures leading to institutional credentialing. The four main aspects of the programme are outlined below.

**Delivery hardware QA** refers to the procedures designed to test the performance of the DMLC treatment delivery, in terms of MLC leaf position, leaf acceleration and speed, and MLC position reproducibility. The procedures are usually carried out in solid phantoms using radiographic film.

**Treatment plan specific measurements** must be performed for every treatment plan. The complex nature of dynamically delivered IMRT beams makes it impossible to verify monitor unit calculations and field portal geometry in a simple fashion. A dose distribution based on the patient’s beam intensities and treatment geometry is calculated on a QA phantom and measurements with an ionization chamber at one or more points in the phantom are made and compared with the calculated values. A planar distribution is measured with film and also compared to calculated values.

The **annual internal audit** is a complete review of thirty IMRT cases from the previous calendar year, and is comprised of three components: an assessment of the treatment plan with respect to plan evaluation parameters, verification of the patient’s daily treatment record, and a review of the physics QA tests and documentation for each patient. Quantitative acceptability criteria, based on relevant endpoints, are formulated for each parameter investigated. For each patient, up to 21 parameters are evaluated and a score of 1 is assigned for compliance or 0 for non-compliance with the acceptability criteria. A total score is calculated for each patient, and an overall score is computed for the entire data set.

Participation in **multi-institutional collaborative trials and protocols** such as those endorsed by the Radiation Therapy Oncology Group (RTOG) may require credentialing of the entire IMRT planning, treatment, and QA process by an external agency such as the Radiological Physics Center (RPC) or the Quality Assurance Review center (QARC). The credentialing process may include the completion of a facility questionnaire, submission of “dry run” plans,
approval of the institution’s QA process, and a phantom experiment requiring CT scanning, planning, and delivery of an IMRT treatment on a phantom containing dose measuring devices. Additionally, once credentialed for protocol participation, all patients enrolled in the study have every aspect of their treatment scrutinized by an external agency.

In summary, a comprehensive quality assurance programme specific to IMRT is a necessity. The programme should include components addressing the delivery hardware and plan specific dosimetric measurements. Auditing should also play a key role in the implementation of IMRT. Internal departmental audits are a valuable tool for retrospective analysis of patient cases and QA procedures. External audits are important because they are usually conducted by an unbiased observer objectively, and ensure that the institution is complying with international standards. Moreover, even more importantly, participation in these trials and credentialing processes ensures an appropriate standard of practice for all participating institutions.
Emerging Canadian QA standards for radiation therapy

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Canada operates a publicly funded health care system in which 70% of health care costs are paid by some level of government. Radiotherapy, indeed most cancer management, falls within the publicly funded realm of Canada’s health care system. National legislation (the Canada Health Act) guarantees access to cancer services for all Canadians. However, the financial responsibility for these services is borne by the provinces. Most Canadian provinces manage the cancer management problem through central cancer agencies.

In the past few decades, these provincial cancer agencies have formed the Canadian Association of Provincial Cancer Agencies (CAPCA). This association has adopted a broad mandate for cancer management in Canada (see www.capca.ca). Included in this mandate is the adoption of standards and guidelines for all aspects of cancer control.

The complexity of radiation therapy has long underscored the need for cooperation at the international and national levels in defining programmes and standards [1]. In recent decades formal quality assurance programme recommendations have emerged in the United States [2,3], Europe [4] and Great Britain [5].

When defining quality assurance programs, Canadian radiation treatment centres have referenced U.S. and other program standards since they have been available. Recently, under the leadership of the Canadian Association of Provincial Cancer Agencies (CAPCA), Canadian national quality assurance program recommendations are emerging.

A CAPCA sponsored project to harmonize Canadian quality assurance processes has resulted in a draft document entitled “Standards for Quality Assurance at Canadian Radiation Treatment Centres.” This document provides recommendations for the broad framework of radiation therapy quality assurance programs. In addition, detailed work is currently underway regarding equipment quality control procedures.

This paper explores the historical and political landscape in which the quality assurance problem has evolved in Canada, summarizes progress to date and examines future opportunities for Canadian quality assurance standardization.
REFERENCES

Development of cancer care and use of radiotherapy equipment in a small country - The Finnish model

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This presentation describes the development of cancer care in Finland focusing on development in the use of radiotherapy and comprehensive QA systems. Finland is a small country in Northern Europe, where health care system has been actively developed to current equal and cost free or low cost treatment for all inhabitants. Radiotherapy, cancer care organizations, screening and awareness of cancer have been systematically developed in Finland since the 1960s. Five university hospitals are responsible for development of diagnostics, treatment and research; The Finnish Cancer Registry is responsible for reliable national statistics on cancer, and through collaboration with other statistical centers for epidemiological and follow up research; The National Radiation and Nuclear Safety Authority (STUK) regulates the use of radiation in Finland. The hospitals must have responsible physicists to maintain suitable instruments and skills to perform high standard quality assurance for the equipment. The Finnish Cancer Society is working on people’s awareness and fund raising to support research and rehabilitation.

The source for cancer statistics is the population based cancer registry (FCR), which was started in Finland in 1952. The registration of all cancer cases has been mandatory in Finland since the 1960s. Therefore, the currently available data are considered reliable in providing the data on cancer incidences and trends in Finland (Table 1). Furthermore, the follow up data on treatments, survival and occurrence of new cancer cases among the patients is invaluable for assessing the long term effects of different treatment systems. The Mass Screening Registry is part of the FCR, screening of cervical cancer for 30 to 60 year old women was commenced in the mid 1960s, for 50–59 year old women of breast cancer in the mid 1980s, and screening of colorectal cancer with occult faecal blood tests for 60–69 year old subjects in 2004. Some centres have participated in studies for screening prostate cancer.

Radiotherapy is currently given in five university hospitals in Helsinki, Turku, Tampere, Kuopio and Oulu and in six municipal hospitals. The trend in the 21\textsuperscript{st} century is to start new centres allowing people to have treatment closer to home. Treatment intention is recorded at FCR, with 98\% of patients having information on treatment intention (curative/palliative). In the 1960s mainly curative indications in the use of radiotherapy were reported to FCR, 90\% as curative vs. 10\% palliative. In the 1980s 50\% of recorded treatment intentions were given as curative and the same number as palliative, while in the 2000s 74\% of patients were treated with curative intent. This can be interpreted as increasing need for curative RT in breast and prostate cancers, which are the most common cancers in Finland.
TABLE 1. SIZE OF POPULATION AND GROSS NATIONAL PRODUCT (GNP) USED IN HEALTH CARE ACCORDING TO OECD ESTIMATION IN FINLAND FROM 1960 TO 2000, RELATED TO TELEThERAPy EQUIPMENT AND NUMBER OF CANCER CASES [1,2,3]

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (Million)</th>
<th>GNP %</th>
<th>Linacs</th>
<th>Co-60</th>
<th>Superficial X rays</th>
<th>Orthovoltage X rays</th>
<th>Betatron</th>
<th>New cancer cases</th>
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<td>1</td>
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<td>0</td>
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</table>

Clinical audits in radiotherapy have been commenced according to European Union directive Euratom 97/43 and national guidelines since 2005. Three day audit visits are to be conducted five times yearly. With all these elements, cancer patients have priority access to needed care, outcome of patients in international comparison is good, and internationally important research is increasingly conducted in collaboration with other centers and industry. The five year survival rate for male cancer patients in Finland was 56%, for females it was 65% and for children with cancer the 10 year survival was 75% in 2003.

REFERENCES

Session 6a:  
*Radiation Treatment*  
QUALITY ASSURANCE  
FOR EMERGING TECHNOLOGIES
Image-guided radiotherapy (IGRT) and four dimensional radiotherapy (4DRT)

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Since the development of conformation radiotherapy in the 1960s by Takahashi, et al., diagnostic and localization accuracy have been the main concerns. With increasing improvement in imaging techniques and multileaf collimators, three dimensional conformal radiotherapy (3D CRT) and intensity modulated radiotherapy (IMRT) have prevailed to produce highly conformal dose distribution. Image guided radiotherapy (IGRT), in which diagnostic imaging techniques are equipped in the treatment room, has been paid more attention than before to increase localization accuracy in the use of complex fields in clinical radiotherapy. Setup error has been shown to be reduced by using stereotactic frames for intracranial diseases, diagnostic X ray imagers, ultrasound, or computed tomography in the treatment room for relatively static organs. Planning target volume (PTV) margin for the clinical target volume (CTV) can be reduced by using these IGRT techniques.

However, for mobile tumours such as those in the liver or lung, it is still difficult to use a “tight” margin because of difficulty focusing radiation beams exactly on the moving tumour. Planning target volume for these mobile or moving tumours has generally been determined with a large PTV margin in the direction of tumour movement. A respiration gated radiotherapy system was developed in an attempt to reduce the PTV margin. However, it remained impossible to neglect the possibility that the tumour might be dislocated by depth of breath or setup error. A more accurate method is required to determine the 3D coordinates of a moving tumour during radiotherapy. The relative relationship between the tumour and the surrounding normal structure may change due to tumour mobility, thus a more accurate treatment planning method is also required accounting for temporal changes of anatomy.

We have developed a linear accelerator synchronized with a fluoroscopic real time tumour tracking radiotherapy system (RTRT) by which the 3D location of a metallic marker in the tumour can be determined with an accuracy of 1 mm every 0.033 second during radiotherapy. This dramatic improvement in the localization of moving tumours has made it possible to irradiate the tumour at a favourable phase of respiration. We have improved the 3D radiotherapy planning system (3D RTP) to incorporate the time factor into the treatment planning and called it four dimensional (4D) treatment planning. More than two hundred patients with lung, liver, and prostate cancers were treated using the RTRT system. Internal tumour motion was investigated using the fiducial markers. It revealed that inter-fractional and intra-fractional changes of amplitude and speed of the tumour motion were larger than we expected.

Correction of target localization by using the RTRT system at the start of radiotherapy everyday is useful to reduce inter-fractional setup error for brain, spinal cord, head and neck, esophagus, prostate, and uterus tumours. For reducing intra-fractional error due to organ motion, the RTRT system was also shown to be useful for lung, liver, pancreas, and adrenal tumours with a little exposure of diagnostic X ray. Clinical benefits of these techniques have been suggested for many organs to reduce normal tissue complications. Migration of the
marker, shrinkage and deformation of the tumour during radiotherapy are the subjects to be carefully controlled during the radiotherapy.

FIG: 1. The motion-gated linear accelerator system and fluoroscopic real time tumour tracking system. Three of the four fluoroscopic systems are shown.

REFERENCES


Helical tomotherapy: A review of early experience at the London Regional Cancer Programme, London, Canada

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Helical tomotherapy (HT) is a recently developed form of image guided radiation therapy (IGRT) that combines features of a linear accelerator and a helical computed tomography (CT) scanner. In treatment mode, the 6 MV X-ray fan beam is intensity-modulated by a binary multileaf collimator and is delivered from a rotating gantry while the patient is moving through the gantry aperture. Megavoltage CT (MVCT) images are obtained in a similar manner using a narrow fan beam (5 mm at isocentre) of 3.5 MV X-rays. MVCT data allow verification and correction of patient setup on the treatment couch by comparison and image registration with the planning kV CT images. This presentation summarizes our experience with IGRT for patients treated with HT since its first clinical use at our centre in September 2004. Special consideration is given to quality assurance (QA) activities.

Prior to actual clinical treatments on the HiART 2 system, we had one of the first three prototype HT machines (HiART 1) installed at the London Regional Cancer Program (LRCP). To gain a fundamental understanding of this new treatment technology, a number of planning studies were developed and published [1–8]. Relevant research [9–13] and special QA activities have also been addressed [14].

Initially, two clinical protocols were opened for patient accrual: a radical protocol using a prescription of 50–70 Gy in 25–35 fractions and a palliative protocol using a prescription of 30 Gy in 10 fractions. An accrual of 36 patients on each protocol was planned, with the primary endpoints being reliability and safety of the unit. Secondary endpoints were patient and staff satisfaction, dosimetric comparisons between HT and 3D conformal plans, measurement of setup variance and accuracy of MVCT image registration. The results of these studies will be summarized. In-phantom verification of plan dosimetry has been successful for all patients planned for HT and in all cases the HT plan was equivalent or superior to a comparative 3D conformal plan. Co-registration of a tomotherapy MVCT and planning kV CT allowed optimization of patient position prior to treatment for all fractions delivered with tomotherapy. Fig. 1 summarizes the results of average interfraction shifts and the corresponding standard deviations. In summary, our experience has shown that HT is proving to be a very viable, advanced and superior form of IGRT.
FIG. 1. Average inter-fraction shifts, $<R>$, and their standard deviations, SD, for different disease sites: a) prostate, b) head & neck, brain, c) spine, abdomen, rib, d) thorax, e) breast.

REFERENCES


Cobalt-60 based IMRT with image guidance: Is it possible?

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Modern radiation therapy is moving to advanced conformal techniques such as intensity modulated radiation therapy (IMRT) in conjunction with image guidance to ensure appropriate patient treatment (see Fig. 1). This work has been limited almost exclusively to linear accelerators. Investigations of conformal Cobalt-60 (Co-60) radiation therapy have been sparse, in part because of ill conceived notions that Co-60 is not suitable for precise dose delivery [1]. This presentation will review the results of investigations of the potential for Co-60 based tomotherapy, a rotational implementation of IMRT using the modulation of a fan beam of radiation as the source revolves about a patient [2,3]. The discussion will also include a summary of investigations of Co-60 megavoltage computed tomography (MVCT) for image guidance [3,4].

The tomotherapy dose delivery system consists of a benchtop motion stage that provides rotation and translation through the radiation beam from a clinical Co-60 MDS Nordion T-780 unit. Film and polymer-gel dosimetry have validated the tomotherapy irradiations planning using an in-house, inverse treatment planning algorithm. EGS Monte Carlo simulation has been used to model different beam delivery approaches for clinical implementation, such as source design for increased radiation output. CT imaging is provided by 1st and 3rd generation CT geometries using a Sun Nuclear ISORAD diode detector or a Varian PortalVision LC250 EPID and in-house image reconstruction software. EGS Monte Carlo simulation is also used to model different beam delivery approaches for clinical implementation, such as source design for increased radiation output.

The findings from the work to date have clearly confirmed the viability Co-60 based tomotherapy. Film and gel dosimetry measurements validate that Co-60 tomotherapy provides the delivery required of modern IMRT techniques. Delivered doses are within 3% of plans in homogeneous regions; in high gradient regions the distance to agreement is typically less than

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**FIG. 1.** A flow chart demonstrating how image guidance provides feedback into the radiation delivery that ensures optimal patient treatment.
FIG. 2. Comparison of treatment plans for a conformal avoidance delivery with tomotherapy with radiation from a Co-60 source or a 6 MV linear accelerator. The planned doses are displayed as a quantized grey wash (the scale is in Gy). Apart from modest increases in the surface dose, there are no significant differences in the plans – either in the coverage of the PTV or in the sparring of the critical organs at risk.

FIG. 3. CT images of an anthropomorphic head phantom: left, conventional diagnostic kVp image; right, Co-60 MVCT image. Three metal pins were inserted in the phantom to illustrate some advantages of MVCT imaging.

2 mm. Computer simulations show Co-60 dose delivery compares well with that from a 6 MV linear accelerator (see Fig. 2). The Monte Carlo results show that it is possible to improve source design for a dedicated Co-60 tomotherapy unit; for example radiation output can be increased by about 40% through the redesign of the standard commercial radiation source shape. MVCT imaging has been demonstrated using a variety of phantoms. Co-60 CT provides sufficient contrast and resolution for image guidance and the EPID based Co-60 MVCT shows great promise (Fig. 3). The results have provided the impetus to modify a clinical Co-60 treatment unit into a tomotherapy capable system at the Cancer Centre of Southeastern Ontario.

ACKNOWLEDGEMENTS

This work was funded through the Canadian Institutes of Health Research and the Ontario Consortium for Image Guided Surgery and Therapy government/industry research collaboration, with in-kind support from MDS Nordion and Varian Medical Systems. The loan of the MIMiC multileaf collimator from NOMOS is greatly appreciated.

REFERENCES

On board imaging and cone beam computed tomography: QA procedures

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\textsuperscript{b}Duke University Medical Center, Durham, North Carolina, USA

The newly installed On Board Imager (OBI) system uses two retractable arms that deploy on either side of the treatment couch in addition to the portal vision MV imager (MVD). The source arm holds a KV X-ray tube (KVS) and the detector arm holds a high performance Kilo-voltage amorphous silicon detector (KVD) \cite{1}. These devices are linked to the OBI workstation which provides a platform for acquisition/analysis of images and auto couch motion for repositioning the patient.

As OBI becomes a routine clinical modality, we propose a quality program QA for OBI and CBCT. The suggested QA procedure was based on the OBI/CBCT customer acceptance procedure \cite{1,2} and additional tests assuring proper performance of the system. Our QA program addresses safety of patients and staff, geometric calibration, image performance, database and software integrity.

Safety and functionality QA. The items to be tested for safety are door interlock, warning lights and alarm, collision detection and interlock, and hand pendant motion enable bars. All tests could be quickly performed during tube warm-up that will not only prevent X-ray tube damage but also verify functionality of the system and network connection among the record-and-verifying system server, the treatment workstation, and the OBI system. We suggest most safety QA testes to be performed daily during the tube warm-up.

Geometrical accuracy QA. 1) Mechanical accuracy: Mechanical arm positioning accuracy and arm travel accuracy should be checked for the source (KVS) and detector (KVD). The discrepancy between the calibrated position and the measured position should be within 2 mm. We suggest this test to be performed monthly. 2) OBI isocenter accuracy: This QA could be performed with a phantom that contains a small positioning marker visible in OBI images. This test should be performed with calibrated room lasers, linear accelerator (Linac) crosshair, and optical distance indicator (ODI). The disagreement between the Linac isocenter and the digital graticule in the OBI application should be less than 2 mm (Fig. 2). We suggest this test to be performed daily. 3) OBI isocenter consistency over Gantry rotation: This QA is continuous from the isocenter accuracy but monitors the detector sagging over gantry rotation. Cube phantom or marker phantom is placed at the isocenter and images are taken at the gantry 0°, 90°, 180° and 270°. Each image should be evaluated independently. The disagreement between the center marker (or BB) and the digital graticule should be less than 2 mm in all directions. Fig. 1 shows the cube phantom with 1.5 mm diameter BBs and images taken at gantry rotation. 2D matching should be performed to place the digital graticule at one of the off-centered BBs or disks. The measured couch shift is applied and the couch is shifted remotely. The disagreement between the measured and the expected couch shifts should be less than 2 mm (Fig. 3). The couch position should be verified in the room. We suggest this test to be performed daily. 4) OBI matching and couch shift accuracy: The cube phantom should have two off-centered BBs placed at known positions. After acquiring two orthogonal OBI images, 2D 2D matching should be performed to place the digital graticule at one of the off-centered BBs or disks. The measured couch shift is applied and the couch is shifted remotely. The disagreement between the measured and the expected couch shifts should be less than 2 mm (Fig. 3). The couch position should be verified in the room. We suggest this test to be performed daily. 5) CBCT matching and couch shift accuracy: This test is similar to OBI matching and couch shift accuracy test. Any phantom with BBs at known positions could be
used. A phantom is placed at the couch intentionally off with a known shift from the position where the planning CT has been prepared. After CBCT image is acquired, the couch shift parameters are analyzed to place the phantom as prepared in the planning CT. The disagreement between the measured shift and the expected shift should be less than 2 mm. We suggest this test to be performed monthly.

![Figure 1](image1.png)

**FIG. 1.** Cube phantom with 1.5 mm diameter BBs and images taken at gantry at 270°, 0°, 90° and 180°.

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**Image quality. QA.** 1) OBI resolution and sensitivity: Leeds Phantom -TOR 18FG has bar patterns for resolution (high contrast) test and disks with different depths for sensitivity (low contrast) test. We suggest this test to be performed monthly. 2) CBCT image quality QA: HU values, spatial linearity, high contrast resolution, low contrast resolution [3], and uniformity are monitored in this test. We suggest this test to be performed monthly or quarterly.

We have developed a practical yet comprehensive set of QA tests for the OBI/CBCT system. The Performance of these tests over extended period shows that the OBI system has good mechanical reliability and stable image quality. It is important in the clinic to establish a specific QA protocol to monitor the performance of the OBI/CBCT system.

**REFERENCES**

A QA programme for a radiographic image-guidance system

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Princess Margaret Hospital, Toronto, Canada

As image guided systems become routinely available, we propose a comprehensive acceptance protocol and quality assurance (QA) programme. Since image guidance is likely to transform the practice and process of radiation medicine, image guided systems can be thought of as a QA tool for the delivery of radiation medicine.

The image guided system under study consists of a radiographic imaging system combined with a linear accelerator (Synergy, Elekta Oncology Systems, Crawley, UK). The imaging system consists of a retractable conventional X ray tube and a $41 \times 41 \text{ cm}^2$ amorphous silicon flat panel detector. This assembly is mounted at 90 degrees from the treatment beam central axis and shares the accelerator isocentre. The radiographic system can acquire radiographic images, perform fluoroscopic imaging, or reconstruct cone-beam computed tomographic (CBCT) images. During installation, users verify the electrical and mechanical safety, geometric reproducibility and calibration, radiographic, fluoroscopic, and megavoltage image quality, the reconstructed CBCT image quality, database and data transfer safety and integrity, and the accuracy of the intended clinical process. To maintain the image guided system performance, we have designed a QA programme with specified test frequencies and tolerances. As several aspects of acceptance and QA testing are extensively covered in the literature, [1–4] we focus on those tests germane to CBCT, including geometric calibration, image quality, and accuracy of clinical processes.

Since the kilovoltage beam does not coincide with the treatment beam, the kilovoltage system geometry must be calibrated such that the three dimensional imaging matrix represents accurately to the treatment beam geometry. Geometric calibration involves measurement of the voxel size and scale, the alignment of the kilovoltage and megavoltage beam axes, and compensation for component flex as the accelerator gantry rotates around its axis. This is achieved by taking radiographs of a ball bearing placed at the isocentre through a complete gantry rotation. The travel of the ball bearing with respect to the image matrix [longitudinal (v) and medial (u) axes] is plotted as a function of gantry angle defining a “flexmap”. The stability and reproducibility of these calibration flexmaps has been assessed on one unit over nine months. The relative flex motions are within 1.5 mm, and are reproducible, within 0.5 mm (Fig. 1).

The second part of the QA programme focuses on the stability and reproducibility of the technical components of the system. First, the programme verifies that the X ray generator settings ($kV_p$, HVL, mA, ms) are accurate and linear. Second, the properties of the flat panels are refreshed such that variation in individual dark pixel performance, pixel gains and defects are accounted for to ensure optimal image quality. Tracking these parameters may indicate when a panel is nearing the end of its useful life.

Image quality is assessed using phantoms commonly encountered in diagnostic CT imaging (CatPhan, the Phantom Laboratories, Salem, NY) to compare image artefacts, noise, and high-contrast and low-contrast resolutions with baseline values. A single imaging session can assess simultaneously image quality, pixel size, and scale.
Radiographic image guidance has the potential to profoundly affect radiotherapy practice and processes by reducing or eliminating geometric variations from radiation medicine. For example, our radiographic guidance system has been used to assess the accuracy of target position for our hypofractionated, stereotactic radiotherapy lung program. For our first ten patients, displacements of 4.7±5.3 mm, 7.3±9.4 mm, and 5.6±4.8 mm were required to move the target to the machine isocentre, in the medio-lateral, anterior-posterior, and cranio-caudal directions, respectively. After setup correction, the accuracy of image guidance reduced to 2.0±1.8 mm, 2.7±2.2 mm, and 2.1±2.3 mm in the corresponding directions.

A quality assurance programme for radiographic image guidance periodically assesses the stability and accuracy of its components. In turn, a reliable image-guidance system can be a powerful tool to assure the quality of external beam radiation medicine.

\[ \text{FIG. 1. Plots of the flexmap in the medial (}u\text{ offset) and longitudinal (}v\text{ offset) directions. Flexmaps were acquired after repeatedly deploying the imaging components, over nine months.} \]

REFERENCES


Neutron and proton therapy QA at iThemba Labs


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iThemba Lab offers both neutron and proton therapy at the same location. The main accelerator is a variable energy separated-sector cyclotron. The proton vault makes use of a 200 MeV horizontal beam, whilst the isocentric neutron therapy unit makes use of 66 Mev protons which bombard a beryllium target to produce a neutron beam referred to as p(66)Be. Patients undergoing proton therapy are treated two fractions per week on Mondays and Fridays, whilst patients undergoing neutron therapy are treated on Tuesdays, Wednesdays and Thursdays. Neutron therapy uses a gantry that has a multiblade trimmer attached to it. This beam-shaping device is attached to the end of the existing variable neutron therapy collimator. The device permits for the treatment of irregular shaped beam portals. This allows more sophisticated treatments, better dose conformation to the tumour, and results in less normal tissue irradiation. The proton therapy beam (191 MeV) has a residual range of 24.00±0.3 cm in water; treatment makes use of a shoot through beam or spread out Bragg peak. Proton therapy uses a patient support and positioning system that was designed at iThemba. This system makes use of real time digital stereophotogrammetry (SPG) techniques and is linked to the patient support system, which is a computerized adjustable chair with 5 degrees of freedom. When a patient undergoes proton treatment, a custom made plastic mask is fitted over the patient's head. The mask has small retroreflective markers that are affixed precisely on it. The mask is fixed to a fully adjustable chair headrest. During the patient positioning stage charge coupled device TV cameras capture video images of the retroreflective markers on the patient mask. A computer analyses these images, and using the motorized chair the patient is then moved into the required treatment position.

The goal of radiotherapy is to cure or control disease while minimizing morbidity. In order to meet this goal a comprehensive quality assurance (QA) programme is in place. The QA programme entails quality control tests and procedures for both neutron and proton therapy. These radiation and non-radiation tests are done routinely on a daily, quarterly or annual basis. The non-radiation tests are conducted in the absence of a radiation beam, while the radiation tests require a beam. Daily radiation tests for neutron therapy include checking the area radiation monitoring system, the proton beam alignment with the beryllium target, the dose monitoring system and dosimetry. As part of the proton checks, a multi-wire ionization chamber and a segmented ionization chamber monitor the position and alignment of the beam in real time. The chambers are connected in a feedback loop to sets of steering magnets to ensure that the beam is kept properly aligned and symmetrical. These online measurements are checked against a set of perpendicular transverse scans and a depth-dose scan in a 3D scanning water phantom. The beam profile is checked by examining a depth-dose curve and checking that the range, entrance dose, and the full width at half maximum of the Bragg peak are within prescribed limits. The transverse profiles are checked for symmetry and flatness to ensure that the beam is properly aligned. The scans are analysed and checked for compliance with set limits. If the scans are beyond the tolerance limits the beam is adjusted until it is within acceptable limits. A multi-layer Faraday cup and a set of stacked ionization chambers are used offline to check the energy and the energy distribution of the beam. The non-radiation tests include checking the room clearance system and room lasers for both proton
and neutron therapy; checking the couch, gantry, collimator and retractable floor movements for neutron therapy; and calibrating the (SPG) system for proton therapy. The SPG system is checked by using a test patient that consists of a small steel frame, with retroreflective markers on it as well as simulated lesion and entry points. The positions of all of these points have been accurately surveyed. This frame is attached to the treatment chair and positioned by the SPG system simulate the patient’s head. The final positions of the lesion centre and entry point are then measured by theodolite to check that they are within limits. If there any discrepancies, a large steel frame is used to calibrate the system.

The procedures for these tests are well documented as part of the Medical Radiation Group Quality Management System. This management system is part of iThemba Labs’ quality systems policy currently being prepared for compliance with ISO 9001. Internal Quality Management Audits are conducted annually to check for adherence to these policies and procedures. The poster presentation gives an overview of the QA programme for both neutron and proton therapy, and insight into how the various procedures are implemented.

Below is a worksheet for some of the proton daily checks:

**WORKSHEET FOR DAILY CHECKS**

<table>
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<th>Checked</th>
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<tr>
<td>1.1 Final collimator alignment</td>
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<td></td>
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<tr>
<td>1.2 Patient positioning system</td>
<td></td>
<td></td>
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<tr>
<td>1.3 Room lasers</td>
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<tr>
<td>1.4 Room interlock</td>
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<tr>
<td>1.5 Room communication</td>
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<tr>
<td><strong>2 Radiation checks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Radiation monitoring system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 Proton beam alignment – feedback system</td>
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<tr>
<td>2.3 Energy distribution</td>
<td></td>
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<tr>
<td>2.4 Beam characteristics: range, Bragg peak width, entrance dose</td>
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<td></td>
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<tr>
<td>2.5 Beam characteristics: flatness and symmetry</td>
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<tr>
<td>2.6 Double wedge</td>
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<tr>
<td>2.7 Relative beam output check and DMC calibration</td>
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<tr>
<td>2.8 Enter Cvolts for the day into the supervisory system</td>
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<tr>
<td>2.9 Switch over the intercom to the treatment control room, and place the key on the treatment console.</td>
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Application of novel thermoluminescence foils (2D) for QA of proton eye radiotherapy beams

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In modern radiation therapy such as intensity modulation radiation therapy, image-guided brachytherapy or proton therapy through improved dose conformation, one is able to better match the target volume and to spare the surrounding healthy tissue. The high dose gradients and complicated patterns of dynamically varying dose distribution require two dimensional (2D) dosimetry, with spatial resolution better than 1 mm, preferably with real-time readout. In clinical dosimetry, thermoluminescence detectors are routinely applied as point detectors in the form of chips, rods or microcubes for in-phantom measurements of dose distribution. Among the many TLD materials available, LiF:Mg,Ti (TLD-100 or MTS-N) is most frequently applied in clinical dosimetry. 2D or 3D dosimetry can be performed in anthropomorphic phantoms using several TLDs suitably placed in the phantom and exposed simultaneously or sequentially. The spatial resolution of dose measurements is limited to the physical dimensions of the TL detectors and ranges between some 6 mm (rods) to approximately 1 mm (micro-cubes). Alternatively, sheets of X ray photographic emulsion or Gafchromic® films have been used for 2D passive dosimetry in medical physics. The disadvantages of these film techniques are not entirely flat energy response of X ray films but rather low sensitivity of the Gafchromic® films, as well as fading. Many 2D dosimetry systems, typically with surface deposited TLD powder heated with a scanning laser beam, have been tested in the last two decades but such systems were never commercialized [1]. Application of sensitive coupled charge device (CCD) cameras used for readout of 2D TLD detectors opened new possibilities for 2D dosimetry. The currently available CCD cameras have sufficient sensitivity to record the weak TL signal and visualize its emission source – the irradiated and heated TL detector – as a two dimensional digital image array. A prototype planar TL reader with a sensitive CCD was developed at the Institute of Nuclear Physics in Kraków (Polish acronym IFJ) in cooperation with the Mikrolab company. We present the dosimetric properties of our recently developed two dimensional (2D) thermoluminescence (TL) dosimetry system, consisting of 2D TLD foil and planar TLD reader with 78 mm heater.
and 12-bit CCD PCO camera with a resolution of 640×480 pixels. The image manipulation may be performed with specially dedicated reading and analysing software, which allows for quantitative analysis of the 2D pictures. The TLD foil, of thickness 0.3 mm and different diameter (up to 70 mm), was developed as a mixture of highly sensitive LiF:Mg,Cu,P powder and ETFE polymer.

The new 2D TLD system has been applied for studies, which may contribute to the improvement of quality assurance for proton radiotherapy of eye melanoma. A special eye phantom has been developed, in which several TLD foils or Gafchromic foils can be installed to verify 2D distribution of dose. The measurements have been performed at 60Co beam and 60 MeV proton beams at AIC-144 cyclotron in Krakow and at INFN, Catania. The used detectors have a spatial resolution better than 0.5 mm and a measurable dose range typical for radiotherapy. The beam profiles for different configurations of the beam preparation system have been tested. The results obtained from these measurements were compared with these measured with ionization chambers and profiles calculated using “Eclipse Ocular Proton Planning” showing good consistency, with discrepancies up to 0.5mm.

We believe that our 2D thermoluminescence technique will become a promising tool for quality assurance tests in radiotherapy, particularly proton radiotherapy, and in the assessment of dose delivered to patients undergoing radiotherapy. The potential advantages of the 2D TLD technique, as compared to silver-halide X ray films and radiochromic films, are the flat energy response of lithium fluoride and the re-usability of the 2D TLD sheets. Radiochromic film also provides a flat energy response and high spatial resolution but due to its much lower sensitivity, doses above approximately 3 Gy are required to provide accurate dosimetry. Moreover, radiochromic films are not re-usable and their readout is preceded by several hours of waiting for “dye coloration”.

Several problems must be solved before the 2D TLD technique can be introduced as a routine method in radiotherapy dosimetry. Some limitations are inherently connected with the properties of the thermoluminescence technique such as fading, sublinear (or supralinear) dose response at doses exceeding about 1 Gy, or variable energy/LET response. Based on experience gained from applying TLDs in the dosimetry of radiotherapy beams, e.g. in the mailed dosimetry audits of radiotherapy units where TLD point detectors in the form of chips, pellets or encapsulated LiF powder are used, to reach an overall uncertainty better than 2–3% is quite difficult. Such low uncertainty can be obtained only in an experienced laboratory after reproducible preparation and annealing of TLD material and suitably correcting for energy response, dose response, fading, instability of TLD reader, etc. In 2D TLD dosimetry many additional problems are encountered, such as a distribution of sensitivity of the individual pixels in the CCD camera, optical distortion of the camera lenses and the non-homogeneously sensitive TLD sheet. We have demonstrated that it is possible to provide individual sensitivity corrections for individual fragments of the sheet, but such a procedure should be coupled with advanced software able to identify fiducial markers on the detector and able to suitably re-evaluate the TL signal read from individual pixels or from groups of pixels.

REFERENCE

Tolerance limits of leaf accuracy positioning for a micro-multileaf collimation system used for 3D conformal radiosurgery


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A method is proposed to analyse the effects of leaf positioning uncertainties to the 3D dose distribution in conformal stereotactic radiosurgery (3D CSR). According to Ezzel, et al. [1] leaf positioning uncertainties of 1 mm or even 2 mm do not affect the output due to the fact that field sizes used in radiotherapy are larger than these uncertainties. However, these uncertainties could represent about 7% of the field sizes used in conformal radiosurgery with micro-multileaf systems. For that reason, it is necessary to assess the error carried out by the systematic offsets that leaf positioning uncertainty introduces in the 3D dose distribution.

The micro MLC collimation system studied in this work was m3-mMLC (BrainLab, Inc., Germany), this system has 26 rounded tungsten pairs leaves with leaf widths: 14 leaves of 3 mm 6 pairs of 4.5 and 6 pairs of 5.5 mm at isocenter. The analysis method consisted in selecting arbitrarily a leaf within all the beams of a 3D CRS treatment. The position of the selected leaf can be manipulated arbitrarily using the treatment planning software (BrainScan v. 5.31). A systematic offset of 2.0, 1.0, 0.5, 0.1, 0.0 mm were selected in order to simulate the positioning error commonly found in QA routines of the MLC. For simplicity the 3D dose distribution obtained were exported using an axial slice at isocenter plane. The data were analysed using DoseLab v. 4.0 [2]; relative differences, and dose difference histograms were used when comparing dose distributions relative to the 0.0 mm offset dose distribution (without error). In order to trust in the calculations of the treatment planning software a detailed validation of the algorithm in homogeneous media and depths commonly used in 3D CRS was performed using film and ionization chamber measurements.

Differences were found differences between the measurements and the calculations of the order of the uncertainty of the ionization chamber and film calibrations (±2%) for isodose curves of 100 to 20%.

The offsets different to 2.0 mm included in this study pass the criteria of 5%/3 mm of difference between the dose and distance of isodose lines. The 99.6% of the points of 2.0 mm offset dose distribution are bellow the 5%/3 mm criteria, and it is considered that the 0.4% of difference is not significant. This shows that even for small size targets a 1.0 mm offset in a leaf does not affect the calculated dose distribution. However, a typical dose of conformal radiosurgery lies in the range of 15.0 to 24.0 Gy, a 5% of dose difference represents an absolute error of ± 1.2 Gy. This discrepancy could be critical if it is planned to protect some radiosensitive structure. For that reason, we decrease the tolerance to 3%/3 mm; in this case the treatment plan with offsets of 1.0 to 0.1 mm pass the criteria, too. The 2.0 mm offset increases the amount of points that do not pass the criteria up to 3.5% with absolute dose difference up to ± 1.5 Gy. This maximum discrepancy could be significant if it is close to an organ at risk (see Fig. 1).

This study shows that for 3D CRS even a systematic offset of 1.0 mm in leaf positioning does not modify the output of a treatment plan according to 3.0%/3.0 mm criteria. Thus, a leaf tolerance of 1.0 mm in QA routine MLC is adequate for this kind of procedures. However,
these results do not take into account the fact that there exists others source of error in dose delivery, like dose rate stability, and mainly mechanical uncertainties intrinsic to the linear accelerator and patient positioning. If these kinds of uncertainties could be measured separately, the 3.0%/3.0 mm criteria could not be enough to guarantee quality of the treatment.

FIG. 1. (a) Percentage difference between the 0.0 mm offset image and the 2.0 mm offset image (take negatively), the errors in the shades zones are in the range -1.0 to -7.5%. (b) The dose histogram distribution for the same situation shows a narrow distribution within the 3%/3 mm criteria.

REFERENCES


A method for quick alignment check of MLC leaves in tomotherapy Hi-Art II for QA

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The alignment of MLC leaves with the beam defining jaws and the plane of rotation of the megavoltage X-ray beam are done with film measurements and data from the xenon detectors of the Tomotherapy Hi-Art II machine during commissioning [1]. The film analysis tools and the xenon detector data analysis tools are not readily available for the user.

In order to verify alignment of MLC leaves, a simple and accurate method based on our previous experience with sequential tomotherapy using a MiMIC delivery system has been utilized.

An EDR film is sandwiched between two 4 cm slabs of plastic water. The film is held vertically on the couch with its plane parallel to the horizontal green laser and laterally offset by 20 cm from the isocenter. Two procedures are created for static gantry positions of 90 and 270 degrees beam delivery with a sinogram which opens only the middle thirty two leaves for a 5 cm beam. The film is exposed in turn from the two static gantry angles and developed. The double exposed film shows a smaller rectangular field within a larger rectangular field. If the alignment is perfect, then the smaller rectangular field is symmetrically situated within the larger field (see Fig. 1). Also, all the sides of the smaller rectangle are parallel to the corresponding sides of the larger rectangle. Any twist between the MLC and the movable jaws can be observed from the lack of parallelism between the sides.

A second EDR film sandwiched between two plastic water slabs is now placed similarly but this time at the isocenter with the horizontal green laser in the plane of the film. Two more procedures are created for static gantry angles of 90 and 270 degrees beam delivery with a sinogram which opens only the even numbered leaves for a 5 cm beam. The film is double exposed from 90 and 270 degrees with a 2 cm Y-direction displacement of the couch between the exposures. The alternate unexposed strips of the film from the 90 degree exposure are filled by the exposure from the 270 degree exposure, thus creating a uniform pattern of leaves separated by a thin gap between the adjacent leaves (see Fig. 2). If the alignment of the leaves is not perfect, then the leaf images will be overlapping. A visual check of the leaf image pattern will indicate whether or not the MLC is aligned properly.

This simple check can be performed in the clinic at some regular frequency for quality assurance. Also, whenever a target or linac is replaced, this test can be performed for a quick alignment check.

This check is also performed in a similar way for the other two cardinal gantry angles, i.e., 0 and 180 degrees. In this case, the film sandwiched between the two slabs is kept horizontally on the couch.

A quantitative analysis of the intensity pattern has also been done with a film analyser, but this method is a quick and simple visual check for alignment.
FIG. 1. Rectangular field within a field at 90 and 270 degree exposures.

FIG. 2. Even number leaves at 90 and 270 degree exposures.

REFERENCE

Impact of emerging technologies on stereotactic techniques

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Stereotactic Radiosurgery (SRS) is a single high dose of radiation given in one treatment with the patient in a neurosurgical stereotactic frame whereas stereotactic radiotherapy (SRT) refers to multiple daily fractions of radiation with the patient in a modified relocatable frame. Both these modalities have been around for many years and quality assurance (QA) procedures have been established for the many vendors that have existed in the market. However, many of these QA standards can still be considered “traditional” and were perhaps formatted when even electronic portal imaging was not to be routinely found. Several technological advancements have taken place in the last few years and it has become necessary to critically examine the existing QA standards when applied to stereotactic technology. As an example, the following provides the various options currently available in the Radionics’ XKnifeRT stereotactic system and the links that may be established on a Varian linear accelerator that has a 120-leaf MLC:

If a clinic, such as ours, has the complete solution as outlined above, several questions arise as far as the QA in each of the possible branches is concerned. Should we be imposing additional QA steps or should we in fact be dropping many of the steps that have been in place for many years now? The following detailed analysis might perhaps assist in the discussion:
1) Stereotactic Radiosurgery

By definition, the patient is in a *neurosurgical* frame and the goal would be to accomplish the entire process from start to finish as quickly and efficiently as possible. The lesions are small and, therefore, IMRT together with its QA process is clearly not justified. Using IMRT for radiosurgery also implies that proper checks be done on the MLC prior to the treatment delivery. The risk of mechanical (MLC) failure are increased during this dynamic treatment delivery especially as the linac (and hence the MLC) ages. However, using the circular cones/arc, the pressure on the Physicist to accomplish the various QA procedures in a matter of a few hours is absent and yet does not compromise the conformity of the dose distribution.

When setting up the patient at the linac, all the QA procedures are required to be followed. Portal imaging is not practical due to the small cone sizes used in radiosurgery. Even otherwise it does not provide adequate image quality to assess the accuracy of the isocenter. IGRT continues to evolve and therefore is prone to technical problems. Hence it should be used as an additional QA tool only so that all the steps outlined for a radiosurgery setup must be followed.

2) Stereotactic Radiotherapy

a) Cranial: A similar process is generally followed as in the case of an SRS. It should be noted that the hardware allows for setting up the actual isocenter and the patient position is verified using a depth helmet and nearly 20 readings to the scalp. Since portal imaging is not realistic, two individuals must independently verify the isocenter coordinates.

b) Extracranial: It is no longer possible to set up the stereotactic coordinates at the isocenter. Instead, the treatment planning system prints “setup” sheets with isocenter marked on them. The paper printouts are then attached onto plastic sheets that in turn fall in place in a box that must be placed onto the frame. The couch is then adjusted so that the two lateral and one vertical laser match exactly the isocenter markings on the printouts. Clearly, the accuracy of the isocenter is considerably reduced and there is a need for additional QA to ensure proper patient setup. This may be provided through portal imaging or Image Guided Radiotherapy (IGRT). In addition, many extracranial treatments require the use of intensity modulated radiotherapy (IMRT) which must have its own QA process for the Physicist prior to the first treatment.

The ever increasing complexities and applications in SRS/SRT imply that QA procedures are likely to increase until adequate experience and a comfort level have been obtained. It also places an increased responsibility on the Physicist to ensure not only stringent standards of safety but act as an educator for the various professions such as Radiation Oncologists, Radiation Therapists and Nursing.

Many ideas are now in place that look at the importance of various emerging technologies being combined into SRS/SRT and the resulting impact on the QA procedures. An exhaustive document will be published that merge these procedures which, at the same time, do not compromise any of the standards. A cranial SRS and an extracranial SRT (spinal) case will be used as examples to outline the various QA procedures that must be followed.
Performance evaluation of indigenous telecobalt machine
Bhabhatron-I at ACTREC, Mumbai, India

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Introduction

To meet the growing need of teletherapy machines in the country, BARC has taken up the development of Cobalt teletherapy machines. Isocentrically mounted, 80 cm SSD telecobalt machine having fully electronic operations and computerized control console was designed by the Division of Remote Handling and Robotics (DRHR), BARC. The Tata Memorial Centre has been in the Task Group and provided expertise on many clinical and technical aspects. For commercial manufacturing, the know-how was passed on to M/s Panacea Medical Technology, Bangalore.

The first machine Bhabhatron-I produced by them was installed for clinical evaluation at Advanced Centre for Treatment Research and Education in Cancer (ACTREC), Tata Memorial Centre (TMC), Mumbai.

Acceptance tests

Quality assurance tests for the acceptance of the machine were carried out by scientists from RP&AD, BARC and physicists from TMC.

All safety features like door interlock, emergency stop and other functional safety interlocks are available and working properly. Optical and collimator axis coincidence, orthogonality and parallelism of jaws, accuracy of collimator and gantry scale are well within specified limits. Shift in isocentre due to collimator, couch and gantry rotation are well within BARC specified limit (≤ 4mm dia Sphere). This needs to be improved as many other commercial telecobalt machines in market have this parameter within ≤ 2mm diameter sphere. Optical field size accuracy for field ≤ 10×10 cm\textsuperscript{2} and ≥ 10×10 cm\textsuperscript{2} is well within specified limit.

Optical and radiation field congruence are within acceptable limit. Timer reproducibility is acceptable. All the radiation leakage levels Such as head leakage (source on and off condition) and collimator transmission are well within limit. The profiles for smaller field sizes (5×5 and less) showed lot of coning effect. This was later improved after necessary modifications. Another important safety features of Bhabhatron-I is whenever there is any emergency situation or any interlocks are activated, the jaws will close to 0×0 cm. It will minimize the radiation level in the room if the source is struck, and RSO has to go to push the source to the safe position with T rod.
Beam data generation

Measurement of beam data was carried out using Radiation Field Analyser PTW-MP3S System. Percentage Depth Doses (PDD) were taken for field sizes 5×5 cm, 10×10 cm, 15×15 cm, 20×20 cm, 25×25 cm and 30×30 cm. The value of PDD for standard 10×10 cm at depth of 10 cm were found to be 56.2%, which is in agreement with standard cobalt PDD value (56.4%) quoted by BJR 25 within 0.3%. X and Y profiles for all above fields were taken for 5 standard depths. Analysis of profiles showed flatness of 14% and symmetry of 8% for field size of 10×10 cm and above. This was later improved to 5% and 2% respectively. Penumbra for 10×10 cm was found to be about 12 mm. The data was also verified using Linear Diode profiler and values were matching with RFA measurements.

The absolute output measurement for various field sizes was carried out using 0.6cc (FC65-G) chamber and Dose-1 Electrometer (Scanditronix Wellhofer). Output of the machine for 170 RMM source at 80.5 cm for standard 10×10 cm field was 235 cGy/ min.

Technical improvements

During and after commissioning, there have been several design modifications leading to improvements in the technical beam parameters. Software upgrades have made the control console more user friendly and easy to handle. The machine beam data has been configured into the Treatment Planning System and data on beam modifiers (wedges) has been generated. Wedge filters of standard angles (15, 30, 45 and 60) for varying field sizes have made using high density lead alloy. The beam profiles for wedges were generated for different wedge angles and field sizes. Wedge angles are verified by generating isodose charts. Wedge factors are measured at two different field sizes and two different depths. Dependence of wedge factors on field sizes and depths are studied. Before using clinically, wedge factors are verified by comparing the dose calculated and dose measured at 5 cm depth using 0.6cc (FC65-G) chamber and Dose-1 Electrometer (Scanditronix Wellhofer) and solid water phantom. They were found to be satisfactory and have been implemented in clinical use.

Several software upgrades have been provided which have made the control console remarkably user friendly. Database of the patient treatment can be stored in the computer. Patient setup notes can be written which will appear on the monitor in the treatment room along with the treatment parameters for the patient to be set up. Treatment record is maintained for the future verification.

Around 125 patients of various anatomic sites, mostly head and neck, cervix and chest wall irradiation have been treated on the machine on clinical trials since the commissioning of the unit. Currently 30–40 patients are being treated daily with multi field treatments.

Conclusions

Indigenously developed telecobalt machine Bhabhatron-I satisfies all the required specifications needed for clinical acceptance. Continuous interactions between BARC scientists and manufacturer and clinical inputs from the Tata Memorial Centre have resulted in the development of a very good, user friendly and cheaper telecobalt unit in India.
Development and pre-clinical evaluation of a real time monitoring and feedback system for deep inspiration breath hold for stereotactic body radiotherapy


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Background

Respiration can cause tumour movements in the thoracic region up to 3 cm. Currently, there are several approaches under development and/or evaluation to minimize the internal margin which is generally applied to account for motion effects. One approach is the deep inspiration breath hold (DIBH) technique to immobilize the target and to deliver a beam during breath hold. Such an approach has the additional advantage of an increased lung volume with decreased lung density. However, the application of respiration-controlled delivery in stereotactic body radiotherapy (SBRT) still remains a challenge and the treatment technique for the optimal therapeutic benefit (TCP/NTCP) is still under evaluation.

Material and methods

The BrainLAB ExacTrac system was used to monitor deep inspiration for patients immobilized in a stereotactic bodyframe. As in the standard procedure for patient positioning using ExacTrac, several markers are placed on the patient’s skin, preferably close to the target position and on the sternum. During training sessions the dominant direction of marker movement was determined. Using an in-house developed interface, online information about respiration movements of the thorax (determined form ExacTrack marker) was displayed. Additionally, a patient feedback system was developed to visualize the respiration cycle to the patient and thus to utilize his/her ability for cooperation. The feedback system was tested with 35 patients undergoing SBRT. In a multislice CT study, the underlying hypothesis that targets can be immobilized with high accuracy with a DIBH maneuver and that ExacTrac marker can be used as surrogate was verified for 16 patients. The DIBH reproducibility and stability were determined from multislice CT studies with multiple (4–5) DIBH maneuvers and from various training sessions with patients.

In a subsequent treatment planning study, 13 patients with lung lesion undergoing SBRT treatment underwent additional multi-slice CT studies besides the regular planning CT. The multislice CT studies were performed under shallow breathing (SB), deep inspiration and expiration breath hold (DIBH, DEBH). For each CT set the lung and the CTV were delineated. For each patient six different conformal treatment plans were designed for the various respiration conditions and standard (7/7/10 mm in AP/lat/CC) versus reduced margins (5/5/5 mm). We combined 6–7 coplanar or noncoplanar 6 MV or 15 MV photon beams with individually shaped MLC fields. The dose distribution was calculated with an inhomogeneity correction using a superposition algorithm. The percentage of lung volume receiving ≥12Gy, ≥15Gy and ≥18Gy in 3 fractions, mean lung dose D\text{mean}, NTCP and the total monitor units (MU) were evaluated. The SB plan with standard margins was used as a reference.
Results

The relative reproducibility of DIBH maneuvers was improved with the feedback device (74.5% ± 17.1% without versus 93.0% ± 4.4% with feedback). The correlation between tumour and marker was good (Pearson correlation coefficient 0.83 ± 0.17). The regression slopes showed great inter-subject variability but on average the internal margin in a DIBH treatment situation could be theoretically reduced by 3 mm with the feedback device. The intra-breath hold stability was within 0.4 mm for all individuals. The respiratory signal from the marker can be easily used to gate the linac for a computer controlled gated DIBH (GDIBH) technique.

With DIBH it was possible to reduce all lung dose parameters by about 20%. Applying reduced margins in DIBH, this reduction was even increased to about 40%. The standard technique (SB + abdominal compression) with individual margins showed similar results as DIBH with standard margins. DEBH showed some improvement over FB only when reduced margins were applied. Only for 3/13 patients NTCP values>1% were obtained. For these patients a significant NTCP reduction was achieved with DIBH techniques. There was a small difference in the total MU only between plans with and without margin reduction (+3% for DIBH, +5% for DEBH).

Conclusion

The best sparing effect of healthy lung tissue for SBRT could be achieved with DIBH and applying reduced margins. For the realization of this technique a breathing control system is required. DIBH monitoring can be realized through external marker tracking in a non-invasive manner. DIBH thus enables to reduce margins for the treatment of lung patients. However, for a successful application of such a DIBH technique, the identification of suitable patients and training sessions are necessary.
A QA phantom for motion adaptive radiation therapy

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Modern radiation therapy uses advanced technological procedures to minimize the dose to critical normal tissues in the vicinity of the tumour in such a way that tumour doses can be increased compared to more conventional treatment procedures. As a result of breathing, conventional treatments for lung tumours have included a large margin around the clinical target volume (CTV) to generate a planning target volume (PTV) which ensures adequate tumour coverage. This increased treatment volume has the potential of compromising the radiation effects on normal lung tissue. To allow for a decrease of the PTV, various techniques have been developed to reduce the effect of motion of the tumour in the thorax while the beam is on. One approach takes advantage of the correlation between the tumour position and the phase of the breathing cycle. Using a Real-time Position Management\textsuperscript{®} (RPM) system developed by Varian\textsuperscript{®}, the patient is allowed to breathe freely while monitoring the height of the chest wall and delivering dose only when the tumour is in a specific location. Such sophisticated technologies require specialized quality control (QC) tools that will test treatment methods which account for breathing motion. The goal of this paper is to describe a phantom that will address QC issues associated with respiratory gating.

Fig. 1 shows the moving phantom that was designed by us and constructed by Modus Medical Devices, Inc., London, Ontario, Canada. It is capable of using MOSFETs and film as dosimeters. The concept of the QC test is to place five radiation detectors (MOSFETs) in the penumbra region of a square field and to compare the expected readings of these detectors in both a moving phantom without beam gating and a moving phantom with beam gating. A mathematical model of the phantom motion and the effect of motion on dose profiles was written in MATLAB. The modeling accounted for uncertainties associated with the MOSFET readings. Fig. 2 shows an example set of results of dose profiles as seen by the detectors in a moving phantom for both non-gated and gated irradiations. It is the comparison of the predicted ratio to the measured ratio of the gated moving phantom readings versus non-gated moving phantom readings that determines the criterion of acceptability. Monte Carlo techniques were used to obtain an assessment of the probability of being able to detect a specified level of discrepancy in the gating. Phantom irradiations were performed using the RPM system with a 6 MV beam, a $10 \times 10$ cm\textsuperscript{2} field, and a superior-inferior tumour motion of 20 mm. Experimental tests were set up for a number of gating duty cycles to test what level of error in the gating procedure was detectable and how that compared with the Monte Carlo predictions. The design and utility of the phantom are described and experimental measurements are compared to predicted values. The results indicate that a $4\%$ error in duty cycle can be detected with an $85\%$ confidence level. The phantom should prove to be a useful tool for assessing treatments using Varian’s RPM gating technology.
FIG. 1. Picture of quality control phantom used to assess the gating system on a linear accelerator
A. Vertical moving platform on which the RPM block with infrared reflectors is placed
B. Plate which moves horizontally representing thoracic breathing motion
C. Wooden insert in body phantom which is magnetically attached to B. and represents a moving lung. Radiation dosimeters such as MOSFETS can be placed in the hole in the wooden insert
D. QUASAR® acrylic body phantom
E. Electronic controls which allow variation in both period and amplitude of motion of part C.

FIG. 2. Calculated cross-beam dose profiles at the depth of the MOSFETS. Only data near the edge of the beam are shown. Both profiles are for the moving phantom. The lower profile represents doses without gating while the upper profile is obtained using beam gating with a 40% duty cycle. Vertical lines show where the MOSFETS are located and the dose ratios one would expect by dividing the dose at each MOSFET location for the gated procedure by the dose for the non-gated procedure.
Five year results of an IMRT QA programme

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Introduction

Intensity modulated radiation therapy (IMRT) is a treatment technique that delivers non-uniform fluences for each radiation portal with the aim of shaping the dose distribution in the patient. These IMRT fluences are usually created by using a multi-leaf collimator (MLC) that moves during the radiation delivery either continuously or in a “step and shoot” fashion. This complex beam delivery relies heavily upon the linac’s ability to move the MLC accurately and on the treatment planning system’s ability to calculate the required number of monitor units to deliver a given patient dose correctly. At the McGill University Health Centre we have implemented a quality assurance (QA) programme for IMRT to address both of these issues. As of December 2005, approximately 300 patients have undergone IMRT treatments at our centre. This work summarizes our five year QA results and discusses some of the difficulties encountered during that period and presents our current IMRT QA guidelines.

Methods and materials

MLC mechanical QA is carried out at quarterly and annual intervals. Quarterly tests involve delivering a series of static and dynamic MLC test patterns to Kodak X-Omat V films placed at the isocentre under full buildup conditions. Specific test patterns are used to assess leaf positioning accuracy, leaf acceleration and deceleration, and in-plane and cross-plane skew. Annual tests include MLC centering with collimator rotation, head sag, measuring inter-leaf, intra-leaf and abutting transmissions.

The patient specific IMRT QA programme aims to verify that the treatment plan can be delivered accurately and that the calculated number of monitor units will result in the calculated dose. Due to the difficulties of in vivo dosimetry methods, measurements are carried out in solid water phantoms using the actual beam fluences destined for the patient treatment. A single point measurement is carried out using cylindrical Farmer type ionization chambers. A planar dose map is obtained using Kodak EDR2 film. The ionization chamber measurement point is selected to be in a low gradient region of the dose distribution. The measurements are compared with the results of a treatment plan generated by applying the patient beam fluences to a solid water phantom. The equipment used (Farmer chambers, rectangular solid water phantoms, and radiographic film) is the same equipment that is used routinely for other dosimetric uses in our department.

Results

The results of mechanical QA tests are assessed qualitatively. Additionally, log files that record MLC motions during beam delivery are verified to determine leaf position accuracy in any situation requiring further investigation. To date, no significant deviations have been observed on any of these tests on four linacs used for IMRT.
Our patient-specific ionization chamber QA results suggest that 95% of our measurements are within ±4% of the pre-calculated values. Additionally, the standard deviation of the difference between ionization chamber measurements and calculated values has decreased with experience. Several factors have contributed to this improvement. Specifically, we now account for daily linac output variations (less than ±2%) and have on several occasions adjusted the treatment planning calibration factor, a user determined parameter accounting for differences between planning and treatment delivery. Our current ionization chamber QA guidelines are:

- Absolute point dose measurements must be within 5% of the planned values otherwise the QA procedure is repeated or redone selecting a more suitable point of measurement. If the subsequent QA measurement also reveals a difference greater than 5%, the patient is re-planned in order to achieve a more deliverable set of fluences.
- Ionization chamber QA data are reviewed once a year.
- The treatment planning calibration factor is adjusted if the mean discrepancy changes by more than 1%.

The results of our film dosimetry QA are also evaluated qualitatively (isodose shape) and quantitatively (distance to agreement [DTA]). Our film QA policy is to accept a 3 mm DTA or ±5% dose difference in the high dose region and 5 mm DTA or ±10% dose difference in the low dose region.

**Conclusions**

A QA programme for IMRT delivery can be implemented using fairly common tools available to the medical physicist (radiographic film, Farmer type ionization chambers, solid phantoms). Together with appropriate methodology, this can lead to acceptable results. However, a continued review of QA results with time is essential.
Session 6b:  
*Radiation Imaging*  
X RAY DIGITAL IMAGING
Development of a QC programme for digital mammography

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Digital mammography has recently been demonstrated to be equal in accuracy to film mammography for screening women over a wide range of ages and superior in accuracy for women with dense breasts and those under 50 years of age [1].

But, in order to achieve the benefits in accuracy, it is necessary that the imaging be performed in an optimal manner. Among other things, this implies that an effective quality control programme be in place.

Digital mammography is similar to film mammography in some aspects like the basic operation of the X ray equipment and the need for appropriate beam quality geometrical alignment of components and beam restriction. It differs from film mammography in that there is more variety in the types of image acquisition technology used, chemical processing is not normally involved, and images are generally read from a display monitor or from laser printed, dry processed film. For this reason some of the traditional mammography quality control tests are less important with digital mammography while it is necessary to implement special tests for the digital X ray detectors and for the softcopy image viewing systems.

It is also important that quality control testing be practical and address areas where problems have a reasonable probability of occurring [2,3].

A quality control programme should also be efficient, employ objective testing methods wherever possible and capitalize on the fact that images are in digital form.

Finally a quality control programme in which a consistent set of tests can be applied to different types of digital mammography equipment is highly desirable.

In this presentation, work on developing such a quality control programme will be described.

In addition, some thoughts on the optimization of digital mammography will be discussed.
REFERENCES


Real time patient dose and QC in digital radiology using DICOM headers

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The present work describes an online quality control system for digital radiology, including patient dose audit. The system allows controlling different parameters depending on contents of the DICOM (Digital Imaging and Communications in Medicine) header. A previous positive experience in our Centre for computed radiography (CR) [1] suggested processing further information from the DICOM header, which currently is not restricted to only doses. Now, data on relevant parameters of the diagnostic or interventional procedures are also provided. Quality of the clinical images can also be audited in real time — to accomplish a whole quality control (QC) process for different X ray systems, for groups of patients (e.g. paediatrics), for the type of examination and also, on an individual basis.

The system has been implemented in a university hospital with a full digital radiology department with 350,000 examinations per year [2]. Five CR, two Digital Radiography (DR) and four Interventional Radiology/Cardiology modalities connected to a PACS are being audited. CT will be the next modality to be included in the “QCONLINE” system.

Images from each examination are sent to the PACS. From there, they are sent to a working station based on a PC, at the Medical Physics Service. An in-house software using Microsoft Visual Basic 6.0 receives the images, extracts the DICOM header and adds it to a database. Upon reception, the software calculates the patient entrance surface dose (air kerma at the entrance of the patient with backscatter) (ESD) for some modalities. For the DR systems (a chest and a mammography unit), ESD is calculated using the radiographic parameters from the exposures (kV, mAs) and distances contained in the DICOM header. The X ray tube output curves measured during periodic quality control (QC) checks allow to apply the appropriate correction factors to the dose values transferred by the X ray system to the DICOM header of the images. For interventional radiology, more data are transferred to the database: dose area product per series, cumulative dose per series, number of frames per series and per procedure, angle of the C-arm for the different series, format of the image intensifier or flat panel detector, collimation, added filtration in the X ray beam, etc.

At the workstation, a survey of relevant parameters is performed by comparing their current mean values (or individual values) for a given imaging procedure with values considered suitable, such as diagnostic reference levels (DRLs) in the case of dosimetric data or trigger levels defined by the user (e.g. compression in mammography, the use of the appropriate automatic exposure sensor in chest imaging, etc.). A warning message is presented on the screen for parameters out of range, thus corrective action can be undertaken if required.
By default, images received are presented on the QC workstation screen, for basic image quality inspection in real time. By software, images giving rise to a warning are stored in the workstation to enable further inspection, with the alarm source recorded in a private field at its DICOM header.

Statistical data are also provided for evolution follow-up and local reference value (LRV) assessment for continuous updating. Each individual dose value is used to calculate the varying average of ESD from a selectable number of the most recent patients (now fixed at 30). Plots from doses, kVp values or other parameters for the last exposures of a given type are easily obtained, to help a deeper investigation of particular cases.

The system allows an on line quality control with four levels of audit:

- ESD as described
- Equipment parameters: flat panel temperature in DR, exposure level and number of uses of the plate in CR, added filters, collimation, etc.
- Radiological procedures: kVp, exposure time, mA, automatic exposure control mode, ionization chamber selected and number of images in the study in DR, and additionally compression force, anode and filter material for mammography
- Image quality: selection of possible repeated images for rejection rate analysis is possible by consulting the database, clinical image quality evaluation of images with alarms can be performed and also can be used in training sessions.

A specific module for interventional radiology/cardiology modalities is being implemented that allows evaluation (and specific trigger levels) of number of frames per series, series per study and total number of frames per study. As in DICOM header of these modalities C-arm angle is also available, an estimation of patient skin dose distribution could be achieved.

This new version of the QCONLINE system, based on DICOM header, has been in service during more than 30 months. During this time, a part of the procedures has been audited, as a pilot action, using mammograms from over 20,000 patients, over 50,000 from chest, 80,000 for CR and 300 cardiology procedures. Owing to the QA running program, very few alarm signals were generated on mean values out of range. For chest examinations, for example, only three cases of mean values above 0.3 mGy for PA projection were observed during the initial 18 month period. For IR, alarms were mainly related to procedures exceeding 2500 frames. LRVs are between 30 and 60% lower than the ESD European reported RVs, while showing good image quality.

This work has been in funded by the European Commission (SENTINEL programme), and the Autonomous Community of Madrid (project GR/SAL/0272/2004).

REFERENCES


Comparative study of image quality and imparted dose with SF, CR and DR for mammography systems

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In this article we perform a comparison, in terms of contrast-detail curves, of image quality in a conventional screen-film (SF: GE Senographe DMR with Kodak Min-R S screen and Kodak Min-R 2000 film) system, two computed radiography (CR1: GE Senographe DMR with Fuji FCR Profect CS image plate, and CR2: Siemens Mammmomat UC with Fuji FCR 5000 MA Plus image plate) systems, and two direct digital radiography (DR1: GE Senographe 2000D and DR2: Agfa Embrace DM1000) systems. Two series of measurements have been taken: the first one using a standard exposure with routine working techniques and the second one at an exposure to approximately the same imparted dose.

The contrast-detail curves [1] were obtained using the CDMAM phantom (version 3.4). Six phantom images have been made for each setting, and they were reviewed on hardcopy by three different medical physicists who are experienced with the use of this phantom. Each observer evaluated two images with standardized viewing conditions, including equal background lighting and light box settings, and the average of the six threshold thicknesses was recorded for each diameter. A magnification glass was used.

In order to compare the imparted doses, the SF system working with routine technique (Mo/Mo target-filter combination, 28 kV, AEC at central position) was taken as reference. This technique implies a mean glandular dose of 1.2 mSv in a 45 mm thick breast.

With regard to digital systems (CR and DR), two series of measurements were taken: the first one using routine technique exposures; the second one with manual technique, selecting parameters in order to obtain similar doses to that of the SF routine series, setting up the exposure charge so that the effects of different tube output and focus-detector distance were compensated. A strict equality was not achieved due to non continuous steps between selector positions.

In Fig. 1 we present the contrast-detail curves at conditions of routine technique. For an easier evaluation of image quality, we have shaded in the zone between the lines which are designated as “acceptable” and “achievable” in the Addendum on Digital Mammography [2].

In this figure we notice that the SF system fulfils the acceptance criteria of the Addendum (as expected of 90% of the film based systems [2]). It is also shown that, at much lower doses (49% and 55%) than that of the SF system, the image quality of CR systems is at the limit of acceptance; while DR systems, with 75% and 88% dose levels with respect to SF, present an excellent image quality, and in this way they would allow a greater dose reduction.
FIG. 1. Comparison of contrast-detail curves of SF with CR (left) and of CR with DR (right), using routine technique. Legend percentages refer to the dose with respect to the reference one.

In Fig. 2 it is shown that, at equal imparted doses, both DR systems present much better image quality than the CR, and that the CR system performs better than SF. In fact, the image quality in DR systems is superior to what is called “achievable” in the Addendum. That allows us to state that, at these dose levels, SF systems cannot achieve the image quality of DR.

FIG. 2. Comparison of contrast-detail curves of SF with CR (left) and of CR with DR (right), at equal doses. Legend percentages refer to the dose with respect to the reference one.

We also conclude that the dose-image quality relationship at routine exposure is not optimized for CR1 and CR2 systems. From the above figures, we observe that it is possible to improve CR image quality by increasing doses but even maintaining them under SF dose levels. So, both CR systems fulfil the Addendum criteria, and they are valid in mammographic screening programmes according to the European Protocol.

REFERENCES


Acceptance testing of CR and DR systems

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Introduction. Computed and digital radiography (CR and DR) are replacing traditional film screen radiography as hospitals move towards digital imaging and PACS. Recently published IPEM guidelines [1] and protocols developed by KCARE [2] set out quality assurance and acceptance testing methods which rely on a mix of objective and subjective tests for assessing performance. Increasing interest is being shown in quantitative metrics such as detective quantum efficiency (DQE) and noise power spectrum (NPS) [3–5] but due to measurement complexities these still have not become part of routine field testing. In this paper we present results from DR and CR Acceptance Testing.

Materials and methods. It is intended to assess and compare performance of twenty CR and DR systems. Seven different manufacturers are included. Dose to the detector plate under AEC, with varying generator and detector conditions, is measured. The patient is simulated using a range of thicknesses of tissue equivalent material. Image quality assessment divides into (a) objective measures (performance assessed through pixel values) including signal to noise ratio (SNR), dark noise, uniformity, image retention (ghosting) and scaling and (b) subjective assessment using standard Leeds Test Objects.

Results and discussion. Initial results show dose variance of >10% for most AEC tests. Further work is underway to assess SNR variation under the same AEC conditions. Controlling SNR in response to changing conditions (which is similar to ensuring that film optical density remains constant) will provide a consistent image, but is one step away from controlling dose to the patient. At present, acceptance thresholds are fairly wide (baseline +/- 30% [1]). Collating results from numerous systems will help refine limits and produce realistic performance thresholds that balance image quality and dose.

Indicated exposure values and displayed mAs were assessed as means of monitoring dose. Fig. 1 depicts the relationship between indicated exposure value on two CR systems and dose. There is increased need to monitor dose as the wider dynamic range of CR and DR means that systematic overexposures may not be evident from image quality.

![FIG. 1. Linear and system transfer properties for two Kodak CR systems.](image)

Clinicians report considerable improvements in image quality with CR and DR. Image quality assessment largely bears out this assessment: objective measures taken to date all perform
well and in subjective assessment of test objects indicating contrast performance (Leeds TO10/TO20) shows considerable improvement over that measured on film.

In order to capture the range of clinical requirements for image display, scoring of test objects was performed on review stations and printed film as well as diagnostic monitors. All review monitors performed poorly for limiting spatial resolution and, on diagnostic monitors, acceptance thresholds were not met in some clinical protocol. Sample results comparing review monitor and printed film results for the Huttner test object are shown in Table 1. Film scores better than review monitors and artefacts are more evident in soft copy display especially when the phantom is orientated at 0° and 180°.

**TABLE 1. LIMITING SPATIAL RESOLUTION FOR THREE DR SYSTEMS, VARYING PHANTOM ANGLE**

<table>
<thead>
<tr>
<th>Phantom angle</th>
<th>Limiting spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Monitor</td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td>2.37</td>
</tr>
<tr>
<td>0°</td>
<td>2</td>
</tr>
<tr>
<td>180°</td>
<td>224</td>
</tr>
<tr>
<td>Film</td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td>2.8</td>
</tr>
<tr>
<td>0°</td>
<td>3.15</td>
</tr>
<tr>
<td>180°</td>
<td>3.15</td>
</tr>
</tbody>
</table>

Conclusions. As the technology is relatively new there is still limited experience with acceptance testing of CR and DR systems. In this paper we report test results on a broad range of CR and DR systems. We review dose control under AEC, and image quality performance. Comparisons between different technologies and models are reported. Collation of data will help refine acceptance thresholds and contribute to optimizing dose and image quality, as well as streamlining performance of QA measures.

Acknowledgment. This work was conducted partially within the frame of the European Commission 6th Framework Programme SENTINEL Contract No FP6 - 012909.

REFERENCES


A mechanical method to remove Moire patterns of an X ray antiscatter grid with a fixed type of grid in digital radiography

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A Moiré pattern caused by an X ray antiscatter grid in digital radiography (DR) was investigated, and we proposed a new mechanical alignment method to remove the pattern.

A carbon-interspaced grid, which has a superior grid line uniformity to those of conventional lead strip grids, was processed to have the line frequency of 185 lp/inch, a little bit higher than the DR sampling frequency. Grid images were obtained from the DR detector made of an amorphous selenium with the pixel pitch of 139 $\mu$m.

The detector underneath the X ray grid was translated and rotated with the help of a micro-controlled jig. The height of the grid from the detector was adjusted by four (4) micrometers to magnify the shadows of the grid lines at the detector and, hence, to exactly match with the sampling frequency of the detector.

The angular displacement of the detector caused a frequency difference to represent a higher frequency of moiré [1].

The horizontal translation did not change the moiré frequency but only phases. As the frequency difference between the grid and DR was decreased, the low-frequency moiré patterns were found and finally disappeared at the complete matching as shown in Fig. 1.

High straightness and uniformity of grid lines of the carbon-interspaced grid and the micro-controlled alignment method enable matching the frequencies to remove moiré patterns without a software filtering and a moving grid.

Further research will be performed on dose reduction effect in an amorphous silicon (a-Si) DR, which is expected if the grid shadows were located accurately on the X ray insensitive regions in each of the a-Si pixel detector.
FIG. 1. Moire pattern acquired in DR (pixel pitch: 139 µm) with the grid of line frequency 185 lp/inch with varying the distances from the grid to the detector surface.

REFERENCE

QC of direct radiography and computed radiography mammography systems: Image quality and average glandular dose

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\textsuperscript{b}University Malaya Medical Centre, Kuala Lumpur, Malaysia

Today, two technologies have emerged in digital mammography: direct radiology (DR) and computed radiology (CR). The introduction of these technologies leads to different measures and limitations in the quality control (QC) of these mammography systems. The objective of this work was to carry out QC tests on DR and CR mammography systems using the EUREF protocol [1,2,3] about image quality and average glandular dose (AGD).

These evaluations were made using the same test tools for both SIEMENS DR and CR mammography systems. Image quality was compared in terms of low contrast detectability, exposure time, and ghost factors. Exposure factors were selected clinically. Entrance surface air kerma (ESAK) was calculated from the measured output for PMMA thickness of 2, 3, 4, 5, 6, and 7 cm. The AGD was determined from ESAK and the measured half-value layer (HVL), and the respective conversion factors were obtained from the protocol.

Test results indicated that DR mammography system selected a longer exposure time and a higher ghost image factor. CR mammography system yielded mean contrast-detail score higher than that of the DR system, for smaller details. The contrast-detail curves of both systems are shown in Fig. 1. They indicate that the DR system has better low contrast detectability than the CR system, as seen from the contrast-detail curve that extends further to the left toward small detail.

![FIG. 1. Contrast-detail curves of computed radiography (CR) and direct radiography (DR) mammography systems.](image-url)
HVL of DR mammography system is higher than that of CR system. Table 1 shows the entrance surface air kerma and average glandular dose of both systems: direct radiography and computed radiography. For both systems, AGD decreases as PMMA thickness increases; AGD for DR is higher.

TABLE 1. ESAK AND AGD OF BOTH SYSTEMS: DR - DIRECT RADIOGRAPHY AND CR - COMPUTED RADIOGRAPHY

<table>
<thead>
<tr>
<th>PMMA thickness (cm)</th>
<th>Technique and average glandular dose</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DR</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>ESAK (mGy) AGD (mGy)</td>
<td>ESAK (mGy) AGD (mGy)</td>
</tr>
<tr>
<td>2</td>
<td>7.23 2.89</td>
<td>6.47 2.54</td>
</tr>
<tr>
<td>3</td>
<td>7.47 2.21</td>
<td>6.72 1.95</td>
</tr>
<tr>
<td>4</td>
<td>7.74 1.79</td>
<td>6.96 1.58</td>
</tr>
<tr>
<td>5</td>
<td>7.94 1.52</td>
<td>7.24 1.35</td>
</tr>
<tr>
<td>6</td>
<td>8.33 1.34</td>
<td>7.52 1.18</td>
</tr>
<tr>
<td>7</td>
<td>8.61 1.17</td>
<td>7.86 1.05</td>
</tr>
</tbody>
</table>

To conclude, both DR and CR mammography systems performed well within the stated values of the EUREF protocol. However, we found that the DR mammography system operated with higher beam quality that resulted in higher dose and better low contrast detectability. Therefore, DR should not be considered equal to CR mammography system.

REFERENCES

Optimization of the image receptor dose of digital radiographic units in clinical practice

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The potential for reducing the radiation dose to which the population is exposed during medical X-ray examinations has not yet been fully taken into account with regard to digital imaging systems designed to substantially decrease patient dose while retaining adequate image quality. Switzerland's Federal Office of Public Health was particularly concerned that full advantage has not yet been made of the potential for rare-earth intensifying screens.

Digital imaging modalities such as computed radiography (CR) or direct radiography (DR) systems can perform conventional radiographic examinations using a wide range of radiation exposures. Whereas a conventional screen-film combination typically requires a certain radiation dose to result in satisfactory film blackening, CR or particularly DR systems could generate satisfactory images using a far lower radiation exposure. On the other hand, image quality can be improved by increasing the dose, although this causes a radiation protection problem for the patient. Changing the radiation dose used to perform the radiographic examination does not affect the level of film blackening, but the degree of image noise, which limits the visibility of subtle lesions. It is important to note that until the advent of digital radiology, the choice of the level of radiation used in conventional radiography was, in effect, fixed. Digital technologies offer a wide range of new possibilities in the use of radiographic techniques.

The dose requirement of the image receptor is used to characterize the sensitivity of digital imaging modalities. It is misleading, as well as technically meaningless, to use the current concept of speed to describe the performance of any digital imaging system [1]. To avoid the scientific and semantic difficulties of ascribing speed to any digital imaging system, it is recommended that the radiation dose on a digital receptor be specified when characterizing the system performance [2].

Specifying the radiation dose used to create a digital image involves easy measurements and avoids the ambiguities associated with the term 'speed'. Because digital detectors are generally quantum-noise limited, the radiation dose used to create a digital image is directly related to the signal-to-noise ratio and patient dose. The optimized amount of radiation in a diagnostic procedure performed with a digital system is one that strikes an appropriate balance between image quality (i.e., signal-to-noise ratio) and patient dose [3,4].

Within the scope of the regular inspections conducted by the Federal Office of Public Health in hospitals, audits were performed with the aim of supervising the quality assurance of the digital imaging modalities. Furthermore, the dose requirement of the digital image receptors of radiographic units installed in Swiss hospitals has been measured by evaluating the image receptor dose behind a 25 mm aluminum plate phantom and compared with international and national recommendations [5,6].

The results show that for CR systems there is an optimization potential of about 50% in terms of all supervised installations. In many cases the dose requirement could be reduced by up to 50% without significant loss of image quality. In DR systems the dose requirement is systematically lower and the reduction potential is therefore considerably smaller.
**FIG. 1.** Statistics of the survey and the optimization potential for CR and DR systems.

<table>
<thead>
<tr>
<th>Number of Installations (n=178)</th>
<th>Origin Site (n=178)</th>
<th>Optimization potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>DR</td>
<td>Radiology Institutes</td>
</tr>
<tr>
<td>152</td>
<td>26</td>
<td>36</td>
</tr>
</tbody>
</table>

**Optimization potential**

CR: ~52% (n=152)

DR: ~12% (n=26)

**FIG. 2.** Dose reduction after optimization for a CR system.

**REFERENCES**

Optimization of image quality and patient dose for chest examinations in digital radiology

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Digital radiology may represent the greatest technological advance in medical imaging over the last decade. With the application of faster computers, larger storage capabilities and new X ray detector systems, film for X ray imaging is becoming obsolete. While digital techniques have the potential to reduce patient doses, they also have the potential to significantly increase them. Experience has shown that the radiology departments which have transitioned to digital equipment have not reduced but measurably increased patient doses. In digital radiology, higher patient dose per image usually means improved image quality. However, there is a tendency to use higher patient doses than necessary and this should be avoided [1].

Radiologists constantly face the dilemma of trying to reduce the exposure of a patient while still using exposures that are high enough to produce images of good quality to provide proper diagnosis. Quality assurance helps to achieve this goal. Therefore it is necessary for the QA programme to include assessment of image quality, patient dose evaluations and periodical measurement of physical parameters of the X ray machine.

Chest X ray examination is one of the most frequently required procedures used in clinical practice. It is because X ray image often provides information in deciding for further step in the establishment of diagnosis and treatment of many diseases [2]. For studying the image quality of different X ray digital systems and for the control of patient doses, the standard anthropomorphic lung/chest phantom RSD 330 is used, where animal lungs simulate the size and structure of lungs of adult male, as well as the left coronary artery.

For comparison of different techniques of chest examination a special software was elaborated which enables to compare DICOM images from different modalities (CR, DR), based on the support of a special viewer of those images.

The user of the software can compare different images gained at variable exposure values (kV, mA, etc.) on the screen of their diagnostic station and the values can be changed and set. The software provides standard features of DICOM viewers (enlargement, contrast settings, blackening, etc.) and also has information about the dose at which the image was gained.

Various examination techniques were used in accordance with European guidelines for good practice in chest examination. The possibilities of using the software for optimization, education and training of medical students, radiological assistants, physicist and doctors’ in the field of digital radiology will be described.
REFERENCES


Standard digital radiography: Dose optimization using an anthropomorphic phantom


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Introduction

In digital radiography with automatic exposure control (AEC), there are several standard protocols settled in each equipment depending on the characteristics (age, weight) of the patient, the position of the patient and the anatomical part to be exposed.

The goal of any radiographic system is to obtain a good diagnostic image with the lowest dose.

The grey scale manipulation of the image is a very powerful tool to reduce the dose. It is possible to have the same information from images obtained with different dose levels.

Objective

The objective of this work is to optimize the dose to the patient in digital radiography, preserving the diagnostic information required for each examination, by redefining the AEC settings for each protocol, using as reference the equipment standard protocols.

Methods

To perform this study, an anthropomorphic Alderson (sections 11–20) phantom was used. This phantom is a tissue equivalent to chest/lung/heart/bones. The equipment used is a DigitalDiagnost system from Philips. The Anatomically Programmed Radiography is a tool that has recorded settings, in the AEC mode, for the Exposure voltage, Density correction and Screen-film combination. In this equipment the Exposure voltage range is 40 kV to 150 kV; the Density correction range is -4 to 4 with steps of 1 and Screen-film combination values are 200, 400 and 800.

We studied two protocols: "Thoracic spine ap" and "Chest ap insp". For the first one the standard parameters are: Exposure voltage is 77 kV, the Density correction is 0 and Screen-film combination is 400. For the second one the standard parameters are: Exposure voltage is 102 kV, the Density correction is 2 and Screen-film combination is 400.

For the first protocol we performed acquisitions using the following settings: for the Exposure voltage we ranged from 70 kV to 150 kV; for the Density correction we ranged from -4 to 0; and for Screen-film combination we used all values allowed. We acquired a total of 27 images.

For the second protocol we performed acquisitions using the following settings: for the Exposure voltage we ranged from 90 kV to 150 kV; for the Density correction we ranged from -4 to 2; and for Screen-film combination we used all values allowed. We acquired a total of 19 images.
For each image acquired we recorded the following parameters: mAs, time of exposure, area dose product and the exposure index.

Each image quality was visual analysed by three radiologists.

**Results**

For the first protocol, when we fixed the kV and the Screen-film combination to 77 kV and 400 and changed the Density correction from 0 to -4, we achieved a dose reduction of 36.4%. When we fixed the kV and Density correction to 77 kV and 0 and changed the Screen-film combination from the 200 to 800, we achieved a Dose reduction of 50%. For an exposure Voltage of 77 kV, a Screen-film combination of 800 and a Density correction of -4, we achieved a dose reduction of 67%.

For the second protocol, when we fixed the kV and the Screen-film combination to 102 kV and 400 and changed the Density correction from 2 to -4 we achieved a dose reduction of 34%. When we fixed the kV and Density correction to 102 kV and 2 and changed the Screen-film combination from the 200 to 800, we achieved a Dose reduction of 34%. For an exposure Voltage of 77 kV, a Screen-film combination of 800 and a Density correction of -4, we achieved a dose reduction of 49%.

**Conclusions**

With this work we verified that it is possible to reduce the patient dose in standard digital radiography keeping the exposure voltage and adjusting the parameters Density correction and Screen-film combination.

**REFERENCES**


New monoenergetic X ray medical digital imaging system based in gamma sources and low radiation dose

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Buenos Aires, Argentina

A method for X ray medical imaging, based on gamma sources and low radiation dose was investigated. A radiographic technique with extensive monoenergetic X rays sources is proposed in the present work, these sources produce only characteristic X rays by means of photo-excitation with gamma sources.

A selection of suitable materials for photo-stimulate with a Co-57 source was made. The ones with high fluorescence yield \( \omega_k \), and a useful X ray energy for medicine use, were selected: Mo, Ag, Sn, I, Ba, Ce, W, Au, Pb, Bi.

A detailed study of the properties of emission for these materials was made with tables and a Monte Carlo simulation tool (MCNP). This simulation showed us the behavior of the materials about several parameters as: material thickness, incidence angle of radiation, \( K_\alpha \) and \( K_\beta \) characteristic X ray flux emitted, total production of X photons in bulk of material, Bremsstrahlung radiation flux and Compton scattering. Spectral graphics were obtained, too.

These data allowed us to optimize variables as thickness and incidence angle of radiation for each material in order to maximize the wanted X ray flux and minimize the Compton scattering. For example, when photons impinge on a foil of Mo with a grazing angle of 2.8°, we obtained the results of Fig. 1. The maximum efficiency of X ray production can be as high as 58% for Bi.

The design of the geometrical form of the source implied a new work of optimization (maximum X ray flux, minimum \( \gamma \)-ray scattering and minimum physical dimensions).

We tested various geometrical forms: pills, cones and several types of arrays of shells, in order to improve X ray emission and maintain a low level of \( \gamma \) ray scattering. Optimization of the geometrical forms increased the flux of X rays by a factor of 6 over the simpler pill form.

In order to obtain a reasonable photon flux, these sources must have finite dimensions far from the point geometry, avoiding blurring in the image taking place.

We developed a new image processing by means of geometric simulation that allows to correct the blurring of edges due to the finite size of the source.

We simulated the image obtained with an extensive X ray monoenergetic source of a cylindrical phantom.

We have rescued with great contrast the edges of the object, diminishing the distance source-plane detector and maximizing efficiency of photon flux (Fig. 2).

We have corroborated that the method still works with greater dimensions of the source to the size of the object.
The method can be generalized to human body radiography simulation, with the aid of 3D vectorial geometric modelling techniques available [1]. Combining this small and monoenergetic flux (or discreet in energies) of X photons with the digital detectors 2D of high quantum efficiency and acquisition in counting mode [2], it is possible to diminish the dose to the patient in comparison with the continuum spectrum of the X ray tube, optimize the energy for each radiographic technique and still select two energies for dual energy X ray absorptiometry (DEXA) techniques.

![Variations of parameters](image)

**FIG. 2.** Variations of parameters $R_1, R_2, R_3, \eta_X$ and $T_{\gamma}$ with Mo foil thickness at incidence grazing angle of 2.8° and $\gamma$ radiation of Co-57 (122.1 KeV and 136.5 KeV). $R_1$: total number of $\gamma$ photons backscattered / total number of X photons emitted by fluorescence. $R_2$: total number of X- photons emitted on $4\pi$ / total number of X photons generated by fluorescence in bulk. $R_3$: number of X photons emitted on top / number of X photons emitted underneath. $\eta_X$: X ray emission efficiency = total number of X photons emitted / total number of $\gamma$ photons incoming. $T_{\gamma}$: transmittance for $\gamma$ radiation of Co-57

**FIG. 2.** Left: Image of cylindrical phantom with a finite dimensions source and small distance source-detector. Right: The same image after the geometrical processing. It is remarkable the enhanced contrast of the edges and the elimination of the $1/r^2$ noise.

**REFERENCES**


Assessment of image quality and radiation dose on a modern flat panel angiography system

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Angiographic procedures are often associated with high patient and staff dose that can be reduced without image quality deterioration. This work is on assessment of image quality and patient doses on a modern flat panel angiography unit. Because of the limited number of digital systems in Bulgaria, quality control protocol for testing these units does not exist currently and this work is aimed to develop and test the methodology.

Methods and materials. A GE Innova 4100 Flat Panel Detector angiography unit was examined. Low and high contrast resolutions were assessed using FL18 test object placed at the isocentre between the sheets of a PMMA phantom with total thickness varying from 16 to 30 cm for FOV of 16 to 40 cm at pulsed fluoro mode of 30 frames/s. The image detector was set up at 5 cm above the 30 cm PMMA phantom. The Entrance Surface Dose Rate was measured by Mult-O-Meter dosimeter (Unfors, Sweden). The Incident Dose rate and Dose Area Product were measured with Diamentor M4-KDK (PTW, Germany) for the same FOVs and phantom thicknesses. The quality of images at acquisition mode was examined also using DIGI 13 test object (Wellhofer, Germany). The homogeneity, dynamic range, alignment, high contrast spatial resolution and low contrast resolution and signal-to-noise ratio were measured. The digital subtraction angiography image quality was examined using RöVi-8 test tool (Wellhofer, Germany).

Results and discussion. The Entrance Surface Dose Rate measured for 20 cm PMMA and the 40 cm FOV, 30 frames/s was 11.29 mGy.min\(^{-1}\) and 5.58 mGy.min\(^{-1}\) for the ‘normal’ and ‘low’ mode, respectively. The dosimetric results obtained via both dosimeters are used for calculation of calibration coefficients for the DAP and ESD values shown by the system on the display monitor at the control console.

The low contrast sensitivity varies from 1.6% to 6.6% depending on the thickness of PMMA phantom and FOV, as the limiting spatial resolution is changing from 2.24 to 1.12 lp.mm\(^{-1}\). For the acquisition mode of four frames/s the low contrast resolution varied from 1.1% to 3.3% and the limiting spatial resolution was changing from 1.12 to 2.8 lp.mm\(^{-1}\). Generally the Low Contrast Sensitivity and the High Contrast Resolution improves with minimizing FOV and PMMA thickness, but some exceptions were found. These exceptions can be explained with the automatic software control of the beam quality and filtration, which is totally independent from the operator’s control.

Conclusion. The flat panel unit shows very good performance in terms of image quality and dose. It completely satisfies the quality control requirements set for the conventional image intensifier systems. Because a manual mode is not available many of the typical quality control tests are difficult to perform. Although by theory the high contrast spatial resolution should not be affected by FOV, the results showed it is not the case when using the set up mentioned. The actual X ray beam quality and filtration is changed automatically by the software and there is no possibility to control it even in a service mode. That causes situations in which the system contrast and spatial resolution are being determined under uncalibrated
conditions. This further complicates the analysis of the results observed. Additional studies are needed for finding out proper quality control protocols for such types of units.

ACKNOWLEDGEMENT

The study was performed within the SENTINEL (Safety and Efficacy for New Technique and Imaging using New Equipment to Support European Legislation) project under the Sixth Framework programme of the European Commission.

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Session 6c:  
Radiation Imaging  
DUAL MODALITY AND EMERGING IMAGING TECHNOLOGIES
Acceptance testing and QA and control in PET/CT

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Improvement in quality assurance in nuclear medicine and, in particular, in quality control of related equipment has been a major field of interest of the International Atomic Energy Agency (IAEA). Several technical documents pertaining to scintigraphic imaging have been published and are still used as reference manuals by many professionals in the field (e.g. IAEA-TECDOC-317, IAEA-TECDOC-602, STI/PUB 1141). Positron emission tomography (PET) scanners and related performance assessment and quality control were not included in the previously published documents as PET has been mainly a research tool with limited worldwide distribution until the 90s. The tremendous role played presently by PET and PET/CT in whole-body oncology for lesion detection, staging and follow-up as well as the increasing role for PET in cardiology and neurology, associated with increasing reimbursement of multiple PET indications; have prompted the need for updated guidelines specific to PET and PET/CT in terms of acceptance testing as well as quality control and assurance. The aim of this work is to present an overview of acceptance testing and quality assurance and control for PET and PET/CT.

The refinement of standardized performance measurements for PET scanners has been an ongoing process over the last 10 years. The initial efforts initiated by the Society of Nuclear Medicine and further elaborated by the National Electrical Manufacturers Association of the Unites States of America (NEMA; USA), have resulted in the creation of an initial standard, the NU 2-1994 document [1]. In 1998, the European Economic Community started to develop a standardized performance test, which resulted in the International Electrotechnical Commission (IEC) Standard [2]. Despite similarities in the way some procedures were performed, there were distinct differences in how the performance tests were conducted, including the use of different phantoms, the data acquisition procedures as well as the image reconstruction procedures performed. In 2001, the NEMA standards were updated to the NEMA NU 2-2001 standard [3] that is more in agreement with the IEC standards, although some differences with the IEC standards still exist. Meanwhile, several developments in PET scanner technology have been introduced into clinical practice, such as three dimensional imaging 3D. The 3D scanning required the definition and standardization of oblique lines of response in the performance tests. Furthermore, the development and wide use of whole body imaging capabilities required axially longer imaging phantoms. In this context, the new 70 cm long phantom with an off center line source was a better surrogate of whole body activity distribution that included the influence of out-of-field activity. Finally, the introduction of image quality tests that assessed the overall performance of the scanner using a torso phantom with out-of-field activity, allowed to compare the performance of different scanners under more realistic conditions. Despite the recent improvements, NEMA NU 2-2001 does not address several aspects of PET scanners such as the CT component, the accuracy of registration of PET and CT and significant natural radioactivity in the detector material. Furthermore, it is essentially designed for quality control by manufacturers, although it can be used during acceptance testing of new equipment to compare to the vendor’s published specifications.
In contrast, the guidelines that are presented in this work and being presently developed under a new TECDOC by the IAEA are intended for the user and do address the main deficiencies of the NEMA NU 2-1001 standard regarding: CT component, quality of PET/CT registration, the natural radioactivity in the detector material, as well as objective assessment of image quality. Once the instrument that is being tested passes all of the acceptance tests, “benchmark tests” must be performed. These tests are a set of quality control tests that are performed in the same way as the routine quality control procedures. The “benchmark” tests should serve as a baseline for instrument performance and are used to evaluate subsequent quality control tests. They should also be used to evaluate instrument performance after major service and updates in software and must be repeated after upgrades in hardware.

This work provides guidance about the specifications and prerequisites required for acceptance testing of PET and PET/CT scanners, including professionals to be involved, definition of applications, minimal required configurations and corresponding performance parameters as well as ancillary equipment. It also provides guidelines and detailed description of acceptance testing and routine quality control for PET and PET/CT scanners. This in turn should provide guidelines for routine quality control of PET and PET/CT scanners and a framework for setting reference values, tolerances and action levels. Following these guidelines would ensure operation of the scanner under optimal conditions that yield the best performance in routine clinical tasks that involve lesion detection as well as quantitation of radioactive concentration. Such tasks are crucial for early detection of lesions in whole body oncologic PET as well as staging, follow-up and therapy monitoring in oncologic PET. These tasks are also crucial for activity quantitation when assessing the response to therapy or quantitating uptake of a radiopharmaceutical. The same applies to other indications of PET/CT in cardiac, neurological and inflammation imaging.

REFERENCES


QC of the attenuation correction method for SPECT using attenuation maps based on CT data or transmission scans

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Background and objectives. Accurate attenuation correction in SPECT must be based on patient specific attenuation maps which may be created using (a) separately performed but co-registered CT scans, (b) sequential CT and emission scans done using a SPECT/CT system, or (c) transmission scans performed simultaneously or sequentially with the emission study. Since a wide range of different scan sequences and system configurations can be used in all these cases, it is difficult to propose a ‘generic’ quality control protocol which would address all potential problems and pitfalls [1]. Nevertheless, in this paper we suggest a series of QC tests which we consider essential for proper operation of attenuation correction and discuss the rationale for these tests.

Tests description. Serious problems in attenuation correction arise when the distribution of $\mu$-coefficients does not match the distribution of activity in the object, or the attenuation coefficients ($\mu$-values) in the map do not correspond to the true density distribution. These can be due to misalignment of the two data sets [2], incorrect $\mu$-values in the reconstructed maps and/or truncation of one or both data sets. Incorrect $\mu$-values may be caused, for example, by photon absorption in high density foreign objects or contrast agents in CT scans, uncompensated cross-talk photons, low intensity of transmission source, misalignment of the blank and transmission scans and errors in map rescaling. Additional problems may be created by the image reconstruction/correction software.

Our QC protocol attempts to address all these issues. The tests are performed in three stages and include: (i) performance evaluation of the CT or transmission system alone, (ii) checks of the attenuation maps ($\mu$-values, distribution, alignment with emission data), and (iii) assessment of the accuracy of the attenuation corrected emission images.

In addition to the CT quality control phantom that is routinely supplied with the SPECT/CT camera and used in testing of the CT system, a Thorax phantom with the heart, lungs and spine inserts (Data Spectrum Corp. Hillsborough, NC) and a set of plastic syringes with activity are employed in the tests. Alternatively, a cylinder containing a few small inserts filled with activity, an air-filled insert and a few water bags attached on the outside may be used to create a non-uniform activity and density distribution phantom.

Tests for stage 1. In the case of a CT system the first part of the QC protocol includes resolution tests, verification of image uniformity and accuracy of $\mu$-values for a water-filled cylinder. For transmission systems our tests first check the strength of the transmission source by evaluating the statistical quality of the data in the blank scans. Then we verify if transmission and blank scans are properly aligned for all angular positions of the camera. Since attenuation maps are calculated using the ratio of these two values, the uniformity of the blank scan itself is not important (see for example Siemens Profile system), as long as the same non-uniformity is present in both scans and for all tomographic projections.

Tests for stage 2. At this level the Thorax phantom is scanned, the attenuation maps are reconstructed and the accuracy of the $\mu$-values is evaluated. A cold phantom, filled only with water and a phantom with activity are used. The activity in the phantom is set to match typical activity levels of patient MIBI cardiac scans. About 17 MBq of $^{99m}$Tc is used for the heart insert and 170 MBq for the thorax. The maps are also checked for uniformity and potential truncation
problems. For simultaneous transmission/emission scans the quality of cross-talk correction is assessed by comparing attenuation maps obtained with cold and hot phantoms. For sequential scans, when the patient bed moves between scans, the alignment between the CT (or the map) and the emission images is measured. This test is best performed with small three syringes (0.5 ml) positioned along three axes of the camera and filled with 10E–20MBq of $^{99m}$Tc. These syringes are well visible in both CT and emission scans and provide better position definition than the thorax phantom.

![Attenuation maps and profiles](image)

**FIG.1.** Attenuation maps of the water filled thorax phantom, and the profiles drawn through (a) a uniform part (only spine is visible) of the phantom and (b) a part with lungs and heart (central chamber of the heart was filled with air). The value of $\mu=0.17\text{cm}^{-1}$ corresponds to the attenuation coefficient of water for 100keV photons. ($\mu$-values x1000 on the vertical axis).

**Tests for stage 3.** At the last stage, accuracy of the iterative attenuation correction reconstruction method is tested. For this test, the thorax phantom is scanned and the data processed using a standard clinical cardiac protocol. The activity levels reconstructed in anterior, inferior, septal and lateral parts of the heart insert are compared visually and numerically. Additionally, the uniformity of the images corresponding to the uniform section of the thorax phantom is checked. Alternatively, this test can be performed using a cylinder filled with activity with air insert and hot sources positioned at different depths.

![Images of heart insert](image)

**FIG. 2.** Images of the heart insert of the thorax phantom without (upper) and with (lower) attenuation correction.

**Conclusions.** A comprehensive protocol for QC tests of the SPECT attenuation correction is presented. The proposed tests are designed to evaluate the accuracy of different acquisition approaches and attenuation maps based on CT and transmission scans. A discussion of the tests’ rationale and several examples of correct images and results containing artifacts obtained from the phantom studies are included.

**REFERENCES**


The Swiss project for PET units: Acceptance and status testing

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The recent growth of the applications of positron emission tomography modality has led to a drastic increase in the number of units installed in western countries, prompting public health authorities to define a strategy concerning acceptance and regular tests (i.e. status tests and stability tests) to be performed on these systems. In parallel, standards concerning the qualification of PET systems have been updated (introduction of body scan characterization conditions) and appeared to be useful to set legal requirements, in spite of the fact that this is not their goal. The aim of this study is first to choose a set of tests described in the standards to define measurements to be performed at the acceptance of the systems after the regular maintenance (at least once every six months) and for assuring the stability of the systems. To verify the feasibility from technical and time requirements points of view, the quality assurance programme proposed has been applied on PET systems (Philips Gemini and GE Discovery LS). This study will present the feasibility and time requirements of the quality assurance programme proposed based on measurements performed independently from manufacturers.

Introduction

In its Ordinance related to the use of the unsealed radioactive sources (November 1997), the Swiss Public Health Authority requires the supplier to carry out an acceptance test on all imaging devices used in the field of nuclear medicine before they can be used on patients. Moreover, a maintenance procedure of the imaging device has to be performed at least every six months by properly trained staff. This maintenance has to be followed by a status test that assures the integrity of the system before it can be used for further clinical applications. Daily and weekly stability tests under the responsibility of the users of the system are also defined. According to this Ordinance, all the measurements required for the acceptance and status tests should follow the international standards set by either the NEMA (National Electrical Manufacturers Association) or IEC (International Electrotechnical Commission). In order to set the list of tests required to accept a PET unit to be used on patients and to assure its stability over time, a working group has been created by the Swiss Public Health Authority involving manufacturers and medical physicists. On the basis of the two standards recently published within the framework of the qualification of PET (NEMA-NU-2, 2001 and IEC 61675-1, 1998) [1–2], this group has proposed a set of recommendations which will be presented in this paper. The results of the measurements performed on two PET systems (Philips Gemini and GE Discovery LS) will be reported.
Content of the tests

The background documents of this work are the standards NEMA NU-1994 and NEMA NU-2001. Table 1 summarizes the tests required in the framework of the acceptance and status tests (RT: acceptance (or reception) tests and ST: Status tests (six month frequency).

TABLE 1. PARAMETERS AND MINIMAL FREQUENCY REQUIRED FOR PET SYSTEMS IN SWITZERLAND

<table>
<thead>
<tr>
<th>Assessed parameter</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image homogeneity and SUV precision (RT, ST)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>Measurement in NEMA – NU-1994 test object (diameter 200 mm, length 190 mm)</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution without scatter (RT)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>1. (Section 3 of NEMA-2001 standard)</td>
<td></td>
</tr>
<tr>
<td>2D and 3D acquisitions if available</td>
<td></td>
</tr>
<tr>
<td>Scatter fraction, count losses, random (RT)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>2. (Section 4 of NEMA-2001 standard)</td>
<td></td>
</tr>
<tr>
<td>2D and 3D acquisitions if available</td>
<td></td>
</tr>
<tr>
<td>Scatter fraction, count losses, random (ST)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>Alternative method with 2 phantoms without use of the sinogram (to be discuss if really useful every 6 months)</td>
<td></td>
</tr>
<tr>
<td>Accuracy of correction for count losses and random (RT)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>3. (Section 6 of NEMA-2001 standard)</td>
<td></td>
</tr>
<tr>
<td>2D and 3D acquisitions if available</td>
<td></td>
</tr>
<tr>
<td>Image quality and precision of measured activity and attenuation correction strategy (RT, ST)</td>
<td>According to manufacturer</td>
</tr>
<tr>
<td>4. (Section 7 of NEMA-2001 standard)</td>
<td></td>
</tr>
<tr>
<td>2D and 3D acquisitions if available</td>
<td></td>
</tr>
<tr>
<td>Dose assessment of attenuation correction process (CE)</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

This introduction of the proposed protocol should allow an objective qualification of the systems. However, the main problem that remains to be solved is to decide whether (a) $^{18}$F has to be provided by the centre to the manufacturer’s staff, who should then perform NEMA type tests or (b) if these tests have to be performed by in site medical physicists.

REFERENCES


**QA and QC in SPECT/CT and PET/CT**

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Quality assessment (QA) and quality control (QC) in SPECT/CT and PET/CT are more than the summation of individual QA and QC procedures. In addition to individual emission (PET or SPECT) and CT QA and QC procedures, a QA and QC procedure for fused emission and CT images has to be established.

The main advantage of SPECT/CT [1] and PET/CT [2] imaging systems is the almost perfect correlation of the emission images with the corresponding CT images. CT images are also used for attenuation correction of emission images, as well as the anatomical templates used for localization of the increased radiotracer uptake. However, the “perfect” coregistration of the emission and CT images should be verified by a specific QC procedure, which should be a part of QA for the entire SPECT/CT or PET/CT system used.

Here, we are presenting the GE volumetric registration phantom used for volumetric quality control (VQC) and realignment for the Infinia SPECT/CT system and Discovery LS PET/CT system. In addition to the manufacturer’s phantom, we also used a Jaszcak phantom in order to test and confirm volumetric registration between the emission (SPECT or PET) and transmission (CT) scans.

The GE volumetric registration phantom (Fig. 1) used for VQC consists of low attenuation material and contains holes and positions where six syringes can be placed in X, Y and Z directions.

For the DLS PET/CT system, the tolerated maximum offset X, Y and Z specifications are: 1.3 mm at the center of FOV and 2.0 mm at 20 cm from the center of FOV. The vendor-provided QC software automatically calculates the gantry and table alignments and, if mechanical alignment is necessary, notifies the user.

For the Infinia SPECT/CT system, the mean of the absolute CT to emission image differences are calculated and stored with typical values in the X and Y direction around 0.5 mm and in the Z direction around 1 mm (the CT slice thickness is 1 cm). These values are then used to correct the alignment.

The Jaszcak phantom (Fig. 2) transaxial, coronal and sagittal CT and emission images are compared, and positions of the sphere centers and offsets measured and expressed in mm. Typical offset values are in the region of 0.3–0.7 mm.

In conclusion, with proper volumetric QC and QA on SPECT/CT and PET/CT systems, it is possible to achieve submillimeter coregistration of CT and emission images.
FIG. 1. Front side of the VQC 6 syringe phantom. The other three syringes are positioned on the opposite side.

FIG. 2. SPECT/CT transaxial images of the Jaszczak phantom used for alignment assessment between emission and CT images. Coronal and sagittal images are also used for full 3D alignment assessment.

REFERENCES


Performance assessment of triple head coincidence gamma camera

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IRIX tomographic gamma camera (Philips Medical Systems, USA) is capable of performing both SPECT and PET studies due to the installed electronic circuitry for triple head coincidence imaging. It also features additionally installed module for non-uniform attenuation correction.

For such complex and versatile imaging instrument to be used optimally in a clinical environment, its performance characteristics must be evaluated. We describe here the following quality control tests of the IRIX gamma camera: planar uniformity, SPECT spatial resolution, PET sensitivity for point source in air and phantom uniformly filled with $^{18}$F-FDG, and PET spatial resolution in air according to NEMA method [1].

The module for non-uniform attenuation correction (NUAC) comprises of two $^{133}$Ba point sources, each of initial activity 296 MBq. Quality of the transmission scan used for attenuation correction in both SPECT and PET studies was evaluated using cylindrical ECT phantom with six cold rods segments and six cold spheres, and a special Plexiglas phantom.

For each acquisition with a given radionuclide, a specific flood correction table is present on the system for uniformity correction. Such correction matrix comprises of: collimator response table (factory determined), energy response of a detector crystal for a given isotope (determined at the installation time), and intrinsic flood source calibration image performed periodically as a part of a QC procedure. The daily uniformity check is performed using uniform flood source of $^{57}$Co and low energy all-purpose parallel collimators.

Reconstructed SPECT spatial resolution using cylindrical ECT phantom, filled with $^{99m}$Tc activity, is such that four out of six (4/6) cold rods segments (minimal visible reconstructed rods diameter: 7.9 mm), and 5/6 cold spheres (minimal visible reconstructed sphere diameter: 12.7 mm) are clearly visible.

Results of PET sensitivity for two combinations of energy windows: Photopeak (centreline: 511 keV, window width: 30%) and Photopeak + Compton (centreline: 300 keV, window width: 30%) are given in Table 1. Results of PET spatial resolution for point source in air are given in Table 2 as full width at half-maximum (FWHM) values. There is a noticeable degradation of axial resolution outside the camera’s field of view centre due to the single slice rebinning method applied [2].

Quality control assessment of the NUAC module gave the following results: value of $\mu$ - linear attenuation coefficient was within the tolerance range (0.1410–0.1730 cm$^{-1}$ ); on reconstructed transmission scan slices, 3/6 cold rods and 4/6 cold spheres were clearly visible; uniformity was within 10%. These results are in accordance with the manufacturer’s specification of the system’s performance characteristics.
The QC procedures described above serve an important role in gamma camera testing. This helps that clinical findings obtained by analysis of the patient scintigrams could lead to the right diagnosis and decision making about the most appropriate subsequent therapy.

TABLE 1. PET SENSITIVITY

<table>
<thead>
<tr>
<th>Sensitivity (@ max. detector distance)</th>
<th>Photopeak</th>
<th>Photopeak + Compton</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point source</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c⋅s⁻¹⋅MBq⁻¹)</td>
<td>606</td>
<td>778</td>
</tr>
<tr>
<td><strong>20×20 cm phantom</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c⋅s⁻¹⋅MBq⁻¹)</td>
<td>127</td>
<td>173</td>
</tr>
<tr>
<td>(c⋅s⁻¹⋅Bq⁻¹⋅ml)</td>
<td>0.8</td>
<td>1.1</td>
</tr>
</tbody>
</table>

TABLE 2. PET SPATIAL RESOLUTION

<table>
<thead>
<tr>
<th>Point source in air</th>
<th>FWHM (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 1 cm radius</td>
<td></td>
</tr>
<tr>
<td>Transaxial</td>
<td>5.9</td>
</tr>
<tr>
<td>Axial</td>
<td>5.5</td>
</tr>
<tr>
<td>@ 10 cm radius</td>
<td></td>
</tr>
<tr>
<td>Transverse radial</td>
<td>5.3</td>
</tr>
<tr>
<td>Transverse tangential</td>
<td>8.9</td>
</tr>
<tr>
<td>Axial resolution</td>
<td>13.3</td>
</tr>
</tbody>
</table>

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“Meet the Experts”
MAESTRO WORKSHOP
About MAESTRO — Methods and advanced equipment for simulation and treatment in radio oncology

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The integrated project MAESTRO under contract with the European Commission in Life Sciences, FP6 n° LSH 503564, proposes innovative research to develop and validate in clinical conditions the advanced methods and equipment needed in cancer treatment for modalities in highly conformal external radiotherapy employing electron, photon and proton beams.

The MAESTRO project aims to improve the conformation of dose delivered to the target (tumour and nearby tissues) whatever its shape, in order to spare the surrounding tissues. New technologies in the field of patient positioning and organ tracking, advanced software for treatment planning systems, dose calculation and measurement have to be developed, and linked to the emerging intensity modulated radiation therapy (IMRT) technique and proton therapy. The expected results will greatly improve quality assurance (QA) in innovative treatments allowing more patients to be treated more consistently in hospitals with these new modalities.

1. Dynamic phantom for adaptive radiotherapy and contribution to QA

Anthropomorphic phantoms can play an essential part in the development and validation of radiotherapy treatment. The rapid development of adaptive techniques to accommodate organ motion means there is a need for an effective range of dynamic phantoms. MAESTRO seeks to produce dynamic phantoms with materials and movement characteristics, which will simulate the challenges faced by adaptive techniques. These phantoms will enable both the geometric and dosimetric evaluation of dose delivery. In this presentation the technical requirements, design and

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performance for a thorax phantom will be presented. The pelvic phantom to simulate the challenges faced by adaptive therapy for prostate and bladder treatment will also be outlined.

2. 2D dosimeter: QA procedures and protocol developed for IMRT

The aim of this talk is to address the protocols and procedures for the validation of the 2D detectors to be used in IMRT, developed inside the MAESTRO project. Parameters suitable for their dosimetric characterization will be introduced and discussed and the methodology and procedures to be applied for their determination will be reviewed. Due to the large variety of the available dosimetry systems, only general indications will be given. The specific items for a 2D silicon detector will be presented in detail and examples of measurements and results will be shown.

3. Evaluation of dosimetry properties of a new 2D ionization chamber array

The aim of this study was to analyse the basic dosimetry properties of a new 2D ionization chamber array (MatriXX) and to investigate its feasibility for IMRT QA dosimetry and QC of radiation beams used at the level of a Reference Dosimetry Laboratory. The device consists of a $32 \times 32$ matrix of 1,020 vented plane parallel ionization chambers arranged in a square of $24 \times 24\text{cm}^2$ area. Each single chamber is independently read out with a custom microelectronic chip without dead time and automatically compensated for temperature and pressure variation. Basic parameters of radiation beams (TMR, OF, penumbra, field size, flatness, symmetry) measured by MatriXX are compared to ion chamber measurements in water. The MatriXX response in the steep dose gradients is compared with the film data and the results of Monte Carlo simulation. The analysis of measured (Film, MatriXX, Ionization chamber) versus calculated absorbed dose distribution has been performed for IMRT fields in various Linac/TPS combinations. Capability to perform dosimetry verification of dynamic fields (including EDW commissioning and start-up behaviour of Linac beams) has been verified at different speeds of MLC leaves. The long term stability of MatriXX response has been measured over a period of one year in a secondary standards dosimetry laboratory. The MatriXX dosimetry performance has been compared with “standard” devices used for QC measurements in LNHB, (French Primary Dosimetry Laboratory).

4. Novel two dimensional thermoluminescence dosimetry – clinical applications

A novel thermoluminescence (TL) reader which uses a sensitive CCD to produce real-time two dimensional (2D) digital images of the dose distribution read out from thin TL sheets, has been developed at the Institute of Nuclear Physics (IFJ PAN) in Krakow, Poland. The TL foils, also developed at IFJ PAN, of density 1.9 $\text{g/cm}^3$, thickness 0.27mm and size $4 \times 4\text{ cm}^2$ are a hot pressed fusion of LiF:Mg,Cu,P powder and ETFE copolymer. These re-usable foils are water resistant and show a linear dose response up to 20 Gy or more. Some applications of this system to clinical dosimetry will be demonstrated: measurements of in-water dose profiles of 6 MV photon microbeams for stereotactic radiosurgery obtained by micro multileaf collimators, 2D dose distributions around brachytherapy sources and Bragg peak measurements in a 62 MeV proton beam. We are developing a $20 \times 20\text{ cm}^2$ 2D CCD TL reader system that will make TL foils competitive with photographic dye films or even EPID in radiotherapy applications.

5. QA tools developed for proton therapy

Proton therapy nowadays represents a relatively new technique in cancer treatment with external radiation beams. It is based on the use of complex particle accelerators and beam delivery systems. In Europe the number of proton therapy centres is growing so that the lack of a general common operative QA protocol is becoming more and more evident. In the framework of Maestro, a QA protocol for proton therapy centres has been developed. Its main features will be presented.
Lunch Forum I:
BRACHYTHERAPY
Brachytherapy for cervical cancer

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Megavoltage external beam pelvic radiation therapy (EBRT) combined with intracavitary brachytherapy is the standard radiotherapeutic management for patients with carcinoma of the cervix. Low dose rate (LDR) brachytherapy has been used since the early 1900s but starting in the late 1950s with the “Cathetron” cobalt-60, high dose rate (HDR) brachytherapy has become an acceptable treatment modality.

With the use of HDR brachytherapy, treatment times are shorter (in the order of minutes rather than days) thus there is no need for hospitalization and treatments are performed on an ambulatory basis. There is also less patient discomfort and lower risk of thrombo-embolic complications since prolonged bed rest is eliminated. There is a reduced risk of applicator displacement during therapy. The dose to the bladder and rectum can be reduced by the use of vaginal packing or a rectal retractor. Modern HDR devices utilize a small diameter source to use with a thinner tandem, thus reducing the need for dilatation of the cervical canal and allowing to perform the procedure under mild sedation. Modern treatment planning systems for brachytherapy permit dose distribution optimization.

Significant evidence from developed as well as developing countries accumulated over the last two decades clearly support the clinical advantages of the use of HDR brachytherapy in terms of clinical outcomes comparable to those obtained with LDR, plus the added benefit of ambulatory treatments and elimination of staff exposure.

Because HDR and LDR brachytherapy differ in their biological effect and HDR is frequently fractionated, there is still a controversy regarding the optimal total dose and fractionation schedules and an ideal regimen has not yet been clearly determined. Accordingly, dose-fractionation schedules for HDR brachytherapy vary across countries and institutions. Hendry and Zubizarreta [1] compared 24 HDR brachytherapy dose schedules applied in various centres around the world and normalized them using the BED method. A wide range of schedules was found, with institutions following the American Brachytherapy Society (ABS) recommendations being at the upper end of the range of BED values. The ABS fractionation guidelines are based on the published literature, the experience of the panel members and calculations using the linear-quadratic formula. On the other hand, level I evidence from two randomized trials [2,3] shows that 2–3 fractions of HDR were as effective as LDR and more convenient for the patients.

With applicator systems such as the Fletcher or Henschke type, the rectal dose is relatively unpredictable and, at least, an orthogonal set of radiographs, and more time and effort are required to calculate the rectal dose. The use of fixed geometry applicators (tandem-and-ring) simplifies and speeds up the treatment planning process and reduces the chance for error. It is very important to use retractors or packing to temporarily displace the rectum and bladder from the high dose region for the duration of treatment. Preliminary experience suggests that the tandem-and-ring type of applicators have the advantage of a fixed and thus reproducible geometry which in turn yields a reproducible dose distribution. This model ensures that the
rectal dose will be acceptable. Repeat simulator films and dose calculations for each individual treatment fraction may not be necessary when using this type of applicator.

A prospective randomized trial by the IAEA is currently comparing two brachytherapy fractionation schedules in the treatment of cervical cancer. This study compares four fractions of 7.0 Gy to two fractions of 9.0 Gy, with or without cisplatin chemotherapy (four arm study). The IAEA is also conducting a new clinical study in which radiotherapy alone including HDR brachytherapy (3 fractions of 8.0 Gy) is compared to the same regimen with concomitant cisplatin in HIV-positive patients.

The following recommendations are based on available evidence at this time. Future research, including the results of an ongoing trial by the IAEA comparing two fractions of 9.0 Gy vs. 4 fractions of 7.0 Gy, may provide further data relevant to recommendation 5 below: (1) Cervical cancer in developing countries is not a hopeless condition. Data from non-randomized and three randomized trials showed that, with adequate QA, patients have acceptably good local control and survival rates with radiotherapy alone. (2) Brachytherapy must be a mandatory component in the curative treatment of cervical cancer. (3) High dose rate (HDR) brachytherapy is a legitimate and convenient modality of treatment for centres in developing countries treating a large number of cervical cancer patients per year. (4) Chemotherapy is not a primary modality of treatment in cervical cancer, but may be used concurrently with radiation for the treatment of bulky tumours (IB2 or higher). Cisplatin is the most commonly used drug. The benefits of adding cisplatin to radiotherapy in developing country settings has not yet been proven. Chemotherapy increases toxicity, and in these settings, radiotherapy alone is still an acceptable option. (5) Several studies indicate that the total number of HDR fractions can be safely reduced to not more than two or three, thus representing convenience for the patients and resource sparing for the treatment centre. (6) Preliminary experience suggests that the use of the tandem-and-ring applicator allows for a reproducible geometry which in turn reflects in reproducibility of the radiation dose distribution throughout subsequent fractions. Current research is aimed at demonstrating that, given this advantage, treatment planning can be carried out in the first fraction only. (7) The rectal total dose and dose/rate should be kept low to minimize the risk of complications. When using 2–3 fractions, this can be achieved by keeping the total dose low and using rectal retraction. (8) Hyperthermia has not been shown to add benefit to radiotherapy alone for cervical cancer in developing countries. In view of the added cost and logistic difficulties associated with its delivery and thermometry, the routine use of hyperthermia is not recommended.

REFERENCES

Use of $^{60}$Co as an alternative to $^{192}$Ir for remote afterloading

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Introduction

In the last decades $^{192}$Ir has established a leading role as a widely used nuclide in brachytherapy. This originates mainly from its high specific activity and, therefore, the potentiality of manufacturing miniaturized sources.

Since a while also highly active miniaturized $^{60}$Co line sources are available. As a consequence of the different mean gamma energies of the isotopes, 1.2 MeV (Co) vs 370 keV (Ir), some distinctions, e.g. in the resulting dose distributions or tissue dependent absorbed dose are expected.

Methods and materials

1. Two miniaturized high active sources, $^{192}$Ir and $^{60}$Co, of comparable properties (size and dose rate at specific distance) from one vendor were under examination.

2. Technical, physical and radiobiological parameters of both isotopes were compared with particular consideration to AAPM TG-43 formalism, absorbed dose in tissues, dosimetric issues and cost efficiency.

3. Monte Carlo calculations were performed for various sizes of phantoms and distances to the centre of the line source and compared with published data.

4. The specific source data were entered in a commercial dose planning system and various applications (vagina, cervix and prostate) were simulated.

Results

The resulting dose distributions of the investigated nuclides showed only little differences and the energy dependent absorbed dose effects were less than 2%.

The radial dose distribution differs only by some percent up to 20 cm distance. The high energy of the $^{60}$Co gamma rays led to a less pronounced self absorption inside the source.

Therefore, the $^{60}$Co line source has a very good isotropic dose distribution. From the dosimetric point of view no different clinical outcomes are expected when switching from $^{192}$Ir to $^{60}$Co.
Discussion

The physical data showed that there is no relevant difference in using $^{60}$Co sources instead of $^{192}$Ir.

The smaller dip of the $^{60}$Co source may even result in some advantage. Also, dose rate and biological effects are negligible for the chosen range of activities.

The long half-life time of $^{60}$Co reduces the number of source exchanges from 39 for $^{192}$Ir to 1 for $^{60}$Co in 10 years, which may result in improved cost effectiveness for $^{60}$Co.
Session 7:

*Plenary III*

TECHNOLOGY RELEVANT TO THE NEEDS
Issues in health technology assessment

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In general, the main justification for the provision of health services is to improve the health of individuals and populations. Some experts focus on other goals for the health care systems, such as promoting health care innovation and increasing employment. Information on the efficacy of a diagnostic or therapeutic procedure has become more widely available during the last 25 years, both through increased research and increased availability of data based on, e.g. the Cochrane Collaboration and the Health Technology Assessment Database (INAHTA). At the same time, the most relevant information is often in proprietary hands, that is, in private organizations such as the manufacturing industry or in organizations that collect health information. The American Food and Drug Administration routinely assesses efficacy of devices and makes this information openly accessible. Unfortunately, the European Union focuses on trade issues, including innovation, and does not have a strong focus on public health.

Competition for health care resources is a major concern even in segments of the population living in the richest countries. The problem of limited resources is, of course, much more pronounced in poor countries, in particular in the poorest countries. Although cost effectiveness of health care is very important conceptually, data are often not available. Cost effectiveness is often developed within the context of national needs and is very difficult to transfer to other jurisdictions. In addition, data on cost effectiveness are often not available to compare different options in health care. There is thus enormous scope for such studies in the future.

Broader issues, such as health care organization and morals and ethics are also important. For example, is it ethical to promote advanced technology in poor countries that cannot provide even basic health care services? Is it ethical for researchers to overlook the basic needs of poor countries when working on new technological systems?

The problems for developing countries include the relative lack of information, but also other issues, for example:

1) Equipment is often purchased by donors, which often requires the purchase of the national product of the donning country in the case of bilateral aid. This makes it difficult to develop effective international equipment policies.

2) Industry plays a key role in promoting equipment and furnishing information. International industry is relatively good at furnishing technical information and purchasers can make contracts that also require reasonable support to ensure continued operation of the equipment. However, industry does not often furnish information that helps to determine if the equipment is actually useful in the particular context of limited resources or poor countries.

3) Developing countries rarely have a policy structure that encourages comparisons between different options. Frequently, policy-makers in developing countries point out that they feel they must accept what is offered or be left with little or nothing.
4) R&D focuses on the market in industrialized countries, paying little attention to the specific needs of poorer countries, which may result in a general lack of appropriate technology. In the 1970s, the WHO defined a basic radiology system for developing countries, which was marketed by companies such as General Electric and Siemens. Although this effort failed due to various reasons, in general, such attempts by industry to design products for developing countries are rare.

So what is to be done? From the standpoint of those working in industrialized countries, the key point is probably to develop and help develop better information on equipment and its efficacy in providing health benefits. From the standpoint of those working in developing countries, there is an urgent need to develop policy structures. A key point is that developing countries must be prepared to say “no, thank you,” in order to have ownership of their health care systems.

Essential elements of national policies for effective health care include:

1) Statements of national priorities in health.
2) Attention to how investments can improve health and attention to strategic choices.
3) Procurement policies, including the capability of developing effective contractual arrangements with industry concerning cost, delivery, product quality and technical support/service contracts.

Some developing countries have made progress in the last few years, for example Malaysia where the government has initiated an inventory of existing equipment; has started to assess equipment on offer by industry or requested by health policy-makers and clinicians; and has begun to regulate quality, with particular attention to quality of medical equipment. By these initiatives, health technology will hopefully become more relevant to the people of Malaysia.

International organizations, such as the World Health Organization, have made some attempts in this area and the World Bank has become active in this field in recent years. The current interest from IAEA is encouraging. In particular, it would be very useful if a standard protocol were developed to aid both developing countries and donor agencies on appropriate technology in different settings.
Running radiotherapy services in a limited resource setting

N. Ndlovu

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The setting up and running of radiotherapy services of a good standard is still a challenge in many resource-poor settings. There are many issues that are a challenge. They include clinical aspects, staffing, quality assurance, quality control, choice and maintenance of equipment. These issues may need to be dealt with differently in a low resource setting as compared to resource-rich settings.

The following relates to the experience in the Radiotherapy Centre at Parirenyatwa Hospital in Harare, Zimbabwe. The country has a population of 13 million people from which approximately 7,000 cancers are diagnosed per year. Of these only 1,300 to 2,000 gain access to the only two radiotherapy centres for treatment. Often patients from neighbouring countries with no radiotherapy facilities have to be accommodated in these treatment facilities as well.

Over the years the number of external beam treatments administered had remained constant until the year 2000 when the numbers started declining. This corresponds to the general economic decline and the emigration of skilled personnel that resulted. There was also a sharp decline in the number of available treatment machines from 3 in 1999 to 1 by 2003. It is noted, however that 2004 and 2005 saw a marked rise in the number of treatments administered without a corresponding increase in resources (Fig. 1). This shows that the number of treatments delivered is not necessarily dependent on personnel and equipment availability but more on the organizational aspects of the services.

The management of waiting lists becomes one of the priorities of daily practice as patients that require radiotherapy at any given time cannot all be accommodated on the machines. Such a problem is encountered worldwide [1] but it is further complicated in our setting by a number of issues such as the fact that booked patients may not be contactable as they predominantly reside in the rural areas where postal and telecommunications are scarce.

Patient follow-up after treatment is similarly affected, resulting in poor documentation of outcomes of treatment. This has a large impact on quality control as measured by outcomes of therapy. Similarly, defaulters are difficult to trace.

The choice of equipment for the centre can be very difficult based on what is deemed suitable in an environment such as ours. Machine downtime occasionally gets to a level that compromises treatment credibility and sometimes denies patients the chance of ever getting the treatment at all. In our centre we have had the experience of using Co-60 as well as linear accelerators. Whilst the Co-60 unit has been hailed as the appropriate treatment machine for the economically constrained environment, the linear accelerator has proven to be of value in our setting where it has been used for the past 22 years.

The role of the linear accelerator in the provision of a good radiotherapy service even in resource-poor settings is pivotal. All its advantages such as varying photon energies, better skin sparing, better beam shaping and electrons become even more important in a setting where the side effects of treatment, both early and late may be difficult to follow up. If evidence based practice is the goal, this equipment becomes indispensable as most current
evidence on radiotherapy treatment is decreasingly based on Co-60 treatments as the general worldwide trend is towards linear accelerators [2]. Technological advances cannot be ignored even in our setting as information on which to base guidelines for patient management becomes inapplicable where there is a lag in technological advancement.

What may be a relatively longer downtime for a linear accelerator in our setting is not only attributable to operational conditions such as housing, staff training and experience. The lack of supportive services, not only at the institutional level but also by the equipment providers themselves plays a large role in this.

The training of radiation oncologists and radiographers has been ongoing at the institution. Whereas in the past numbers trained were limited and tailored to meet demand, this is no longer possible due to increased migration of staff. Numbers in training have been increased to counter the brain drain. Training has been the mainstay of replenishing the numbers of core staff. In running these programmes, another threat of the limited numbers of trainers has been highlighted. With registered training programmes that have set syllabi and offer certification, it is a challenge to keep up to such standards of practice that ensure adequate exposure to the candidates, but this is still possible.

In conclusion, the problems of running radiotherapy services in resource-poor setting are many. Whilst most are not entirely unique, it is their magnitude that is a threat toward providing an acceptable standard of radiotherapy treatments. With some innovation and strategic partnerships, radiotherapy in Africa could develop to high standards of quality.

![FIG. 1. Trends in the number of external beam treatments administered, machines available and staffing levels over 18 years (1988–2005).](image)

REFERENCES

According to the Brazilian Geography and Statistics Institute, Brazil has an estimated population of 188 million inhabitants spread over 8,500,000 km$^2$ (Table 1).

TABLE 1. DISTRIBUTION OF RESIDENT POPULATION IN MAJOR REGIONS OF BRAZIL

<table>
<thead>
<tr>
<th>Region</th>
<th>Population (%)</th>
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<tbody>
<tr>
<td>North Region</td>
<td>7.6</td>
</tr>
<tr>
<td>Northeast Region</td>
<td>28.1</td>
</tr>
<tr>
<td>Southeast Region</td>
<td>42.6</td>
</tr>
<tr>
<td>South Region</td>
<td>14.8</td>
</tr>
<tr>
<td>Central West Region</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Nuclear Medicine is growing fast in Brazil and this has resulted in an increasing demand for radioisotopes and radiopharmaceuticals. Positron emission tomography (PET), which is a non-invasive molecular imaging procedure, is one of the causes of this increase. PET detects changes in metabolic activities, which may take place before any detectable change in anatomical structure occurs. PET is used to help diagnose and to plan and assess the treatment of cancer, heart disease, and brain disorders.

Taking into account all these advantages, it was decided to start the production of PET radiopharmaceuticals at IPEN – Energy and Nuclear Research Institute of CNEN – the Brazilian National Nuclear Energy Commission, located in the city of São Paulo, the largest city in Brazil. The production of FDG started in 1998. In 2003, a second FDG production unit was installed at IEN – Nuclear Engineering Institute of CNEN – in Rio de Janeiro, the second largest city in Brazil. Both have much experience in radioisotope and radiopharmaceutical production, and both centres have had cyclotrons for a long time. It is interesting that the production of FDG has increased more than a factor of 17 since 2000 in Brazil.

One of the greatest advantages of PET radiopharmaceuticals is due to their short lives. On the other hand, this is also a problem because it means that the production centre needs to be located not too far from the place where it will be used. This can limit the population access to PET technology.

Taking into account this scenario and considering that short-lived radioisotope production was a State monopoly until 2006, the Brazilian Government has decided to disseminate the production of PET radiopharmaceuticals to other populated areas of the country where there is a CNEN institute. The objective is the diffusion of cyclotron produced radiopharmaceuticals in order to improve quality of life for patients by providing them with the benefits of using this technology. This contributes to the Brazilian Multi-Annual Programme related to Health, Science and Technology.
Since there are CNEN institutes in the States of Minas Gerais (Southeast Region) and Pernambuco (Northeast Region), which are both heavily populated, it is natural to implement the production of radiopharmaceuticals in these places.

Many reasons, beyond the clinical benefits already known, have been considered for this kind of investment in both regions:

1. To create conditions of incrementing research and applications of short-lived radiopharmaceuticals and radioisotopes
2. To encourage personnel qualification, searching the homogenization of the knowledge and development in the country
3. To make possible the use of these facilities for teaching and research.

Considering the facts that both places have an adequate hospital infrastructure, a group of qualified physicians to use PET radiopharmaceuticals and a potential demand should give sustainability to this programme. A previous agreement with the local medical community was made to guarantee their commitment to use PET technology, once the needed investment by the hospitals is adequate to support its use.

Another relevant aspect is the multipurpose characteristic of the project involving both the production of radiopharmaceuticals and research activities. The design of both projects includes, in both cyclotrons, an external beam, in a separated cave, in order to allow the development of research through the use of a proton or deuteron beam. The rationale behind this, beyond the developments that it can bring, is to stimulate the participation of the scientific community in new projects and, on the other hand, human resources development.

The viability of the project is a significant point to be stressed. The new laboratories are considered a priority project by the Brazilian Government for which costs have reached more than US$12 million. The goal is to have the two facilities operating in 2007. The institutions, CDTN/CNEN (Nuclear Technology Development Center) in Minas Gerais, and CRCNNE/CNEN (Nuclear Science Regional Center – Northeast) directly involved in this project, will be in charge of PET radiopharmaceutical production and supply for an estimated demand of more than 30,000 PET scan procedures per year.

Some important considerations and actions that were taken during the project design included:

1. Development of a clear scenario of the PET technology demand and the available infrastructure necessary and fundamental to achieve sustainability
2. Agreement and participation of the local nuclear medicine group, and other relevant stakeholders
3. Commitment of the local politicians where these units would be set up.

The IAEA support to the next phase of the project is fundamental and strategic because it allows personnel capacity building in order to have well trained teams, and also allows technology transfer due to the assistance of experts helping with the implementation of the project.
Evaluation of IMRT as a treatment modality: Recommendations of an IAEA expert panel

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In June 2006, the IAEA convened a meeting with several physicians and physicists experts on the field of IMRT to provide guidelines to the IAEA and its Member States for transitioning to IMRT in hospital-based radiotherapy centres, as well as indications and resource requirements for IMRT implementation. This document presents a summarized version of the recommendations.

IMRT is a relatively new, more advanced and complex three dimensional (3D), linac based, radiation therapy technique whereby the radiation beams are divided into “beamlets” that can be modulated in fluence generating a higher degree of conformity to the target volume and greater sparing of normal tissues, as compared to conventional two dimensional and traditional 3D conformal radiation therapy. It represents a new paradigm in radiation therapy that requires close collaboration and expertise of an appropriately trained multidisciplinary team including radiation oncologists, medical physicists, dosimetrists and radiation technologists. Due to its complexity, IMRT requires proper patient selection, adequate imaging capability, appropriate patient immobilization devices, a sound knowledge of anatomy, physiology and the natural history of the disease for delineation of target and organs at risk, advanced and reliable treatment planning software, stringent requirements for clinical commissioning of planning and delivery systems, increased effort for quality assurance and planning activities, careful plan evaluation and accurate treatment delivery.

It is important to fully appreciate that IMRT techniques present a set of challenges that are significantly more complex than traditional forms of radiation treatment. These include the following developing challenges:

- IMRT requires a detailed understanding of radiographic anatomy, as well as, other developing 3 and 4D representations of the patient in order to correctly delineate both tumour/target volume(s) and organs at risk (critical structures). With IMRT using inverse planning, the target must be outlined precisely or it might not be treated to the prescribed dose. More importantly, if a critical structure is not outlined, it might not be spared.

- The conformal dose distribution and high dose gradients in IMRT mandate improved patient immobilization as well as quantitative assessment of target and organ motion detection and control.

- IMRT dose distributions are often more inhomogeneous within the target than traditional conformal therapy. It has been observed that: dose inhomogeneity increases

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1 Technical Meeting on “Evaluation of intensity modulated radiation therapy (IMRT) as a treatment modality in radiotherapy”, June 2006: S. Vynckier (Belgium), C. da Cruz (Brazil), L. Souhami (Canada), P. Besa (Chile), W. Schlegel (Germany), M.J. Calaguas (Philippines), P. Mayles (UK), A. Eisbruch (USA), S. Huq (USA), J. Palta (USA); E. Rosenblatt, K.R. Shortt, S. Vatnitsky, and E. Zubizarreta (IAEA).
as the required dose gradient between the target and an adjacent critical structure increases; the concavity of the required dose distribution increases; the distance between the target and a critical structure decreases; and the number of available beam directions decreases. Therefore, volume dose prescriptions are required for IMRT and prescribing dose to a single point is unacceptable.

- IMRT doses are often calculated by dividing beams into smaller sections, called subfields, which have varying amounts of uniform fluence. Therefore, the mechanical accuracy of the IMRT delivery system and accurate modeling of the delivery machine dosimetry characteristics, such as, head scatter, penumbra, and transmission, become very important. Also, these subfields often have small areas and can be problematic for dose computation algorithms. Thus additional patient specific quality assurance tests are required.

- Accounting for heterogeneities is important for IMRT because they can affect some subfields more than others, giving rise to localized dose distribution differences that may be significant.

- IMRT plan evaluation requires more diligence than does traditional 3DCRT planning.

- IMRT can create cold spots or hot spots in unexpected locations, which are not easily appreciated on dose volume histograms (DVHs). IMRT plan evaluation requires inspection of isodose distributions on each image slice.

Respiratory motion can cause far more problems for IMRT treatments than for traditional treatments. The effect of breathing motion and other patient motions on the summation of subfields with different intensities on a static image can be significant. Care must be taken in the acquisition of the CT dataset used in the planning process to avoid motion artifacts while being representative of the average location of the anatomy.

- IMRT may not be capable of dosimetrically covering target volumes located near the skin surface. Addition of bolus in the imaging and treatment of the patient can mitigate this problem.

- The expansion of target contours in 3D to account for uncertainties in treatment planning and delivery may result in the overlap of two or more structures. In some commercial systems, this creates problems in inverse planning optimization and in storage of the original structure contours. Expansion into air or into the buildup region may also cause problems.

- IMRT plans that allow simultaneous treatment of gross and sub-clinical disease at different doses per fraction can have radiobiological consequences that differ from those of traditional plans delivered with a uniform dose per fraction. The longer treatment times typical of some IMRT treatments may also be radiobiologically relevant.

- IMRT results in a higher whole-body dose due to leakage radiation because IMRT plans often require substantially more monitor units (MU) to deliver the prescribed dose. Currently, most published reports on the clinical use of IMRT are single institution studies, and are either treatment planning studies for a limited number of cases showing the improvement in dose distributions generated by IMRT, or dosimetric studies confirming IMRT treatment. There are no published reports at present of prospective randomized clinical studies involving IMRT, and this lack of information clearly limits
our knowledge of the effect of the use of IMRT on clinical outcomes. It is clear that IMRT offers the opportunity of more conformal dose distributions and for increasing the daily treatment fraction to the target volume with a decreased dose to normal tissues. Although most agree with these potential advantages in physical dose distribution with IMRT, and therefore the potential for improvement in patient outcomes, there exists concern for actual IMRT treatment execution, including proper plan optimization, as optimization algorithms and quality assurance (QA) procedures for this new modality are still evolving. Specific concerns include the potential to miss the tumour (or at least underdose a portion of the tumour) and/or to have significant high dose volumes in the normal tissues. There is also the additional concern that the widespread use of IMRT could lead to an increased incidence of radiation therapy associated carcinomas due to the larger volume of normal tissue exposed to low doses and the increase in whole body doses as a result of the increased MU required for the delivery of IMRT. This may be especially important in the pediatric and young adult patient populations.

Considering the complexity of the IMRT technique and its possible detrimental consequences if improperly delivered, it is apparent that comprehensive QA is vital for the safe practice of IMRT. However, it is not guaranteed that all institutions that may wish to use IMRT in a routine practice perform adequate quality assurance. This may be a serious problem due to the high dose gradients and non-intuitive nature of the treatment planning. Taking the above into account the panel recommends the following:

1. Since IMRT requires more time and resources, its introduction should not be allowed to compromise standard care provided to the whole population of patients in the institution and at the national level. A centre wishing to engage in IMRT should justify its decision on the basis of improved patient outcome: tumour control, treatment complication rate and patient survival.

2. Only radiation oncology departments that have sufficient experience with 3DCRT are in a position to transition to IMRT. It is important to fully appreciate that IMRT techniques present a set of challenges that are significantly more complex than traditional forms of radiation treatment. These include the following issues:

   - patient immobilization
   - volumetric imaging
   - patient setup and internal organ-motion uncertainties
   - three dimensional (3D) heterogeneous dose calculation
   - large scale optimization and dynamic beam delivery of non-uniform beam fluences
   - multi-modality and functional imaging
   - tumour control and normal tissue complication probability modeling and radiobiological consequences of altering geometric and time-fractionation scheduling.

3. Adequate training in IMRT technology for all members of the team is essential prior to the initiation of the programme. Ideally, the team members are best trained on equipment that they plan to use for IMRT in their department. The existing QA system operated by the institution for 3DCRT must be strengthened in the following areas:

   - Defined clinical protocols for IMRT with clear objectives
   - Use of radiographic anatomy in clinical planning
- Patient immobilization with adequate inter-fractional reproducibility and intra-fraction respiratory motion control
- Dose volume prescriptions
- Sufficient mechanical accuracy of the IMRT delivery system
- Patient specific QA tests
- Diligent plan evaluation.

4. Radiotherapy centres of Member States that are ready to make a transition from 3DCRT to IMRT must follow IAEA guidelines and employ additional full-time staff (medical physicists, radiation oncologists and radiotherapy technicians) devoted to the implementation of IMRT.
Positron emission tomography (PET): Current achievements and survey of diffusion in IAEA Member States

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**Background.** Positron emission tomography (PET) is a medical imaging technique that can be used to diagnose a wide variety of diseases including cancer and heart disease. Like other nuclear medicine techniques, it involves injecting a radioactive tracer into a patient. Each molecule of this tracer contains a radioactive isotope that decays by positron (beta positive) emission. This produces a three dimensional image of functional processes or molecular distributions in the body. PET imaging shows processes such as metabolism, protein synthesis, or neurotransmitter activities. The great benefit of PET is that simple biological molecules can be labelled with positron-emitting isotopes, and the distribution of these molecules in the body can then be imaged. Labelling involves making molecules that have an unstable isotope of an element replacing the usual stable isotope of that same element, so the molecules behave in the same way chemically, but the location of these labelled molecules in the body can be identified because a small fraction of them decay each second. For this reason, PET imaging is sometimes also called "molecular imaging". PET scanning is very sensitive, which means that only a few pico-moles of the labelled molecule need to be injected into the patient, which is far too small an amount to have any actual biological effect. For this reason, PET can also be used for drug discovery research. Very small amounts of a drug, which are much smaller than a therapeutic dose, can be labelled with a PET isotope, injected into the patient, and used to find out where the drug will go. For example, to identify cancer cells, a glucose molecule, may be used. This tracer makes it possible to identify areas in the organism where glucose uptake is higher than normal, notably in the case of cancer cells, which have a higher metabolism than normal cells. Fluorine-18, incorporated into fluorodeoxyglucose (or FDG), is the most commonly used isotope in PET scans. Other isotopes used are oxygen-15, nitrogen-13 and carbon-11.

**Technology assessment of PET.** As was the case for several other medical imaging technologies, the clinical use of PET developed before its efficacy and efficiency were demonstrated. The fields of application of PET continue to evolve, thanks to the contribution of research. PET has been extensively scrutinized by several independent Health Technology Agencies [1–5]. This process entailed a careful appraisal of scientific papers, checking their methodological quality on the basis of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) checklist [5]. PET’s value in definite pathologies has been fully recognized. Depending on the type of cancer, PET is used for diagnostic purposes, for detecting metastases and for monitoring response to therapy.

**Current role of PET in clinical practice.** Notwithstanding the existence of already established and very powerful diagnostic techniques like CT and MRI, which still remain the first-line diagnostic modalities, in oncology, PET is finding a strong role and, indeed, its application in several clinical conditions is becoming standard clinical practice. The reason arises from PET’s ability to pick up tumour deposits even when anatomical changes, on which CT and MRI rely to identify pathological conditions, are not yet detectable. In the light of these findings, PET has been found to be cost effective by allowing clinicians to better
select the more appropriate treatment option. In the end, this means better and more efficient allocation of financial resources by sparing unnecessary surgical interventions or futile therapies. PET results may assist in avoiding an invasive diagnostic procedure, or PET results may assist in determining the optimal anatomic location to perform an invasive diagnostic procedure. PET is considered medically necessary in situations in which clinical management would differ depending on the stage of the cancer identified, provided that the stage of the cancer remains in doubt after completion of a standard diagnostic workup, including conventional imaging (computed tomography, magnetic resonance imaging, or ultrasound). After completion of treatment, PET is useful for the purpose of detecting residual disease, for detecting suspected recurrence or to determine the extent of recurrence. Use of PET is also considered medically necessary if it could potentially replace one or more conventional imaging studies when it is expected that conventional study information is insufficient for the clinical management. PET is considered medically necessary for monitoring tumour response during the planned course of therapy when a change in therapy is being contemplated. Restaging occurs only after a course of treatment is completed.

Although PET is the most expensive diagnostic modality available so far, its use is getting more and more space for the clinical management of several cancer conditions like lung cancer, colorectal cancer, melanoma, head and neck cancer, and lymphomas. In USA, 4.4 million PET studies per year are predicted by 2010, from 1.2 million in 2005 and an increase of 36% expected for 2006. As regards IAEA Member States, several countries have already started, or are very close to do so, PET programmes, while some others are in an advanced stage of programming (Table 1).

<table>
<thead>
<tr>
<th>TABLE 1. PET IMPLEMENTATION IN IAEA MEMBER STATES (BY REGION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Already established</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Next to</td>
</tr>
<tr>
<td>Feasibility study</td>
</tr>
</tbody>
</table>

Overall, PET is already a reality in 25 countries, close-to-be in four more; while seven are seriously planning - for a total of 36, a quarter of the IAEA membership.

REFERENCES

Session 8a:  
*Radiation Treatment*  
QUALITY ASSURANCE OF TREATMENT PLANNING AND DOSE DELIVERY
QA of computerized radiation treatment planning systems

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During the last decade there has been a technological revolution in radiation oncology. Enhanced use of imaging combined with computer controlled methods of dose delivery provides a capability of escalating tumour doses without increasing morbidity. A pivotal component of this modern technology is the computerized radiation treatment planning system (RTPS) which is used to develop optimal treatment techniques for individual patients. Compared to older technologies, modern RTPSs make increased use of patient images, have enhanced 3D displays, have more sophisticated dose calculation algorithms, more complex treatment plan evaluation tools, in addition to the production of images which can be used for treatment verification. The implementation of intensity modulated radiation therapy (IMRT) combined with automated optimization software has added a further complexity to the RTPS.

In recent years, various national and international organizations have developed reports that have made recommendations regarding the commissioning and quality assurance (QA) of RTPSs. In 1998, the American Association of Physicists in Medicine (AAPM) published the Task Group 53 (TG53) report [1] giving guidelines for users and vendors on QA for radiation therapy planning. In 2000, the International Electrotechnical Commission (IEC) produced a report (IEC 62083) [2] identifying safety requirements for manufacturers of RTPSs. In 2004, both the International Atomic Energy Agency (IAEA) [3] and the European Society of Therapeutic Radiation Oncology (ESTRO) [4] published reports on commissioning and QA of RTPSs. Furthermore, the IAEA has recently developed a protocol for the acceptance testing of RTPSs [5]. In 2006, the Netherlands Commission of Radiation Dosimetry also produced a report on QA of RTPSs [6]. The IAEA TRS-430 [3] is perhaps the most comprehensive of all of these reports since it attempts to be a guide for the entire gamut of RTPSs found in the world. TRS-430 begins by providing a rationale for QA of RTPSs by describing significant treatment errors that have occurred due to inappropriate development of QA procedures in the clinic. While this report is intended as a generic guide for the commissioning and QA of RTPSs, it does not provide a simple or unique protocol for these tasks because: (a) internationally, there is wide variety of treatment machine capabilities ranging from simple cobalt-60 machines to complex treatment machines with multileaf collimators (MLC) and the possibility of using IMRT, (b) there is a wide variety of treatment procedures depending on the institutional resources, patient imaging availability for treatment planning, and treatment machine capabilities, and (c) commercial RTPSs have a wide variety of capabilities ranging from relatively simple 2D systems to comprehensive 3D treatment planning capabilities making full use of 3D image data sets possibly from various imaging modalities. To provide guidance for this very large scope of capabilities, this report provides a comprehensive process that should be useful to every institution providing radiation treatments. The report provides specific examples of the kinds of tests that need to be performed both for commissioning and quality control purposes.

IAEA TRS-430 does not address issues related to acceptance testing in adequate detail. While acceptance testing is well-defined and a standard process for the purchase of other radiation therapy equipment, it is not nearly as straightforward for RTPSs. This process is complicated
by the fact that the clinical implementation of an RTPS involves the user to obtain, usually by measurement, very specific data that are needed by the RTPS for the proper functioning of the dose calculation algorithm for the radiation therapy machine that is used to treat patients in the user’s clinic. To address this issue the IAEA has developed a new report [5] which is being completed in 2006. This report uses the IEC safety requirements [2] for RTPSs as a guiding document. The IAEA acceptance protocol requires vendors to perform and document a series of “type” tests using beam commissioning data supplied by the IAEA. The beam data and added tests were based on concepts originally developed by AAPM Report 55 [7] and later updated by Venselaar and Welleweerd [8]. Using the beam data provided with the IAEA acceptance protocol, the user selects a subset of the vendor type tests and performs “site” tests to ensure that the software complies with the standards defined in the protocol.

REFERENCES

Dose verification using the pelvic phantom in high dose rate (HDR) brachytherapy

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\textsuperscript{b}Department of Radiation Oncology, Kangnam St. Mary's Hospital,

Seoul, Korea, Republic of

High dose rate (HDR) brachytherapy for treating cervix carcinoma has become popular, because it eliminates many of the problems associated with conventional brachytherapy. In order to improve the clinical effectiveness with HDR brachytherapy, a dose calculation algorithm, optimization procedures, and image registrations need to be verified by comparing the dose distributions from a planning computer and those from a humanoid phantom \cite{1}. In this study, the humanoid phantom was fabricated in order to verify the absolute doses and the relative dose distributions. The measured doses from the humanoid phantom were then compared with the treatment planning system for the dose verification.

The pelvic phantom needs to be designed such that the dose distributions can be quantitatively evaluated by utilizing the dosimeters with a high spatial resolution. Therefore, the small sized thermoluminescent dosimeter (TLD) chips with a dimension of 1/8" and film dosimetry with a spatial resolution of <1 mm are used to measure the radiation dosages in the phantom. The humanoid phantom called a pelvic phantom was made from water and the tissue-equivalent acrylic plates in Fig. 1 (a). In order to firmly hold the HDR applicators in the water phantom, the applicators were inserted into the grooves of the applicator holder in Fig. 1 (b). The dose distributions around the applicators, such as Points A and B, and the limiting factors in intracavitary brachytherapy, the bladder and rectum dose \cite{2}, were measured by placing a series of TLD chips (TLD-to-TLD distance: 5mm) in the three TLD holders in Fig. 1 (c), and placing three verification films in the orthogonal planes. This study used a Nucletron Plato treatment planning system and a Microselectron\textsuperscript{192}Ir source unit.

The results showed good agreement between the treatment plan and measurement. The comparisons of the absolute dose showed agreement within 1.48\%–2.95\% of the dose at point A and B, and 2.07\%–3.74\% of the dose at the bladder and rectum point in Table 1. In addition, the relative dose distributions by film dosimetry and those calculated by the planning computer show good agreement.

This pelvic phantom could be a useful to verify the dose calculation algorithm and the accuracy of the image localization algorithm in the high dose rate (HDR) planning computer. The dose verification with film dosimetry and TLD as QA tools are currently being undertaken in the Catholic University, Seoul, Korea.
FIG. 1. Pelvic phantom (a) Side view, (b) HDR applicator in the holder, (c) TLD holder.

TABLE 2. TLD RESPONSE

<table>
<thead>
<tr>
<th>Description</th>
<th>Planning system (cGy)</th>
<th>TLD Response (cGy) mean</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A point</td>
<td>500</td>
<td>507.4</td>
<td>1.48</td>
</tr>
<tr>
<td>B point</td>
<td>111.9</td>
<td>115.2</td>
<td>2.95</td>
</tr>
<tr>
<td>OS point</td>
<td>1111</td>
<td>1113</td>
<td>0.18</td>
</tr>
<tr>
<td>Bladder</td>
<td>159.2</td>
<td>155.9</td>
<td>2.07</td>
</tr>
<tr>
<td>Rectum</td>
<td>240.4</td>
<td>249.4</td>
<td>3.74</td>
</tr>
</tbody>
</table>

REFERENCES

Radiation treatment planning system verification

M. Budanec\textsuperscript{a}, T. Bokulić\textsuperscript{c}, I. Mrčela\textsuperscript{a}, Z. Knežević\textsuperscript{b}, B. Vekić\textsuperscript{b}, Z. Kusić\textsuperscript{a}

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\textsuperscript{b} “Rudjer Boškovic” Institute,

Zagreb, Croatia

The verification of the Theraplan Plus V3.7 (MDS Nordion) treatment planning system (TPS) calculations was done by means of input data checks and comparisons between calculated and measured doses [1]. The treatment machine is Cobalt 60 unit (Cirus, Cis Biointernational, France).

Input data checks were made by comparing measured percentage depth doses (PDDs) and off-axis ratios (OARs) with those calculated by the TPS. The percentage difference between the measured and calculated PDDs for the square field sizes from 4×4 to 30×30 cm\textsuperscript{2} was within ±2%. The OARs were checked for the field sizes 4×4, 5×5, 8×8, 10×10, 15×15, 20×20 and 30×30 cm\textsuperscript{2} and for the depths 0.5, 1.0, 2.0, 5.0, 10.0, 20.0 and 25.0 cm. The percentage differences (in vertical direction) were (in most of the cases) in the range of ±3%.

To check the accuracy of the treatment times calculation, several test cases representing different treatment planning conditions were constructed (the test cases are similar to those proposed in AAPM Report No. 55 [2]). The calculated treatment times were compared with measurements made with Farmer type chamber (30002 PTW Freiburg, calibrated following the IAEA 277 protocol [3]) positioned in a water phantom and with thermoluminescent chips (TLDs, TLD'700, Harshaw, USA) positioned at several spots in the Alderson phantom. In ref. [4] it is stated that the uncertainty for the treatment time calculation in the case of single field should be within ±2%. The overall uncertainty for the determination of the absorbed dose at the reference point in the Co'60 beam for the Farmer type chamber was estimated to 2.8% (1 SD). For this reason we used the value of ±2.8% in the evaluation of results.

The differences between calculated (D_{d,\text{calc.}}) and measured dose (D_{d,\text{meas.}}) for the point of interest on the depth \(d\) were stated as percentage deviation \(\Delta D_{d}(\%)\):

\[
\Delta D_{d}(\%) = 100 \ast \frac{D_{d,\text{calc.}} - D_{d,\text{meas.}}}{D_{d,\text{meas.}}}
\]

The test cases included the dose measurements at depths of \(d_{\text{max}}\), 5 and 10 cm in square and rectangular fields (see Table 1.), varying source to skin distances (SSDs), oblique incidence of the beam, wedged fields and the dose under the central block and «L» shaped field.

The irradiations in the Alderson phantom were made for the treatment of the larynx (with two lateral opposed field) and pelvis (with three fields: AP, left and right lateral). The TLD chips were of the size 3×3×0.9 mm. With the special adapters they were inserted into the Alderson phantom, at the predefined points. The TLD chips were calibrated in Co-60 beam and corrected for linearity. The dose measured at four points in the larynx region was within ±2.2%; for the pelvis region the discrepancy was higher; it ranged from 0.2% to 10.7%.
TABLE 1. THE PERCENTAGE DEVIATION BETWEEN THE MEASURED AND CALCULATED (PRESCRIBED) ABSORBED DOSES FOR SQUARE AND RECTANGULAR FIELDs

<table>
<thead>
<tr>
<th>Field size</th>
<th>$\Delta D_{\text{max,5}}$(%)</th>
<th>$\Delta D_{\text{max,10}}$(%)</th>
<th>$\Delta D_{\text{max}}$(%)</th>
<th>$\Delta D_5$(%)</th>
<th>$\Delta D_{10}$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5×5</td>
<td>-0.7</td>
<td>-0.4</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>10×10</td>
<td>0.0</td>
<td>-0.4</td>
<td>-0.5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>16×16</td>
<td>-0.8</td>
<td>-0.3</td>
<td>-0.5</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>20×20</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>25×25</td>
<td>-0.7</td>
<td>-0.7</td>
<td>-0.3</td>
<td>-0.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>5×15</td>
<td>-1.9</td>
<td>-1.8</td>
<td>-1.8</td>
<td>-1.7</td>
<td>-1.6</td>
</tr>
<tr>
<td>5×20</td>
<td>-2.3</td>
<td>-2.3</td>
<td>-2.7</td>
<td>-2.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>5×25</td>
<td>-2.9</td>
<td>-3.0</td>
<td>-3.2</td>
<td>-2.5</td>
<td>-2.7</td>
</tr>
<tr>
<td>10×20</td>
<td>-1.2</td>
<td>-1.2</td>
<td>-1.7</td>
<td>-0.7</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

The test on PDD and OAR comparison showed the differences that mostly fall within the limits specified in ref. [4]. All the results for the test cases are within the limits of ±2.8%, except for the field size 5×25 cm² at the depth of $d_{\text{max}}$.

It could be concluded that Theraplan Plus works well for the majority of cases, except in the case of very elongated fields, and in the region of higher tissue inhomogeneities.

REFERENCES


Pilot QC dosimetric verification of LDR and HDR brachytherapy sources at Mexican hospitals

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México, Mexico

We describe the pilot quality control program for brachytherapy of LDR and HDR proposed to be used in the Radiotherapy Department of some Mexican Hospitals. The program consists of three parts:

a) Development of calibration procedures at SSDL, performed in terms of air-kerma strength for calibration of $^{137}$Cs and $^{192}$Ir brachytherapy sources, and for the calibration of well-type ionization chambers for $^{137}$Cs and $^{192}$Ir, according to the report IAEA-TECDOC-1274, for an thimble chambers with air kerma standards [1].

b) Verification of absorbed dose to water $D_W$, given by the hospitals for LDR. It consists on the characterization of a TLD-100 powder dosimetry system at SSDL: The calibration curves for powder response (nC or nC/ mg) vs $D_W$. The statistical validation of the calibration curve by normality of the residuals and the lack of fit tests were realised. In the other hand, TLD’s were irradiated in the hospital to a nominal $D_W = 2$ Gy with sources of $^{137}$Cs. The percent deviations $\Delta\%$, between the $D_W$ imparted by the Hospital and the determined by SSDL, are $1.2\% \leq \Delta \leq 6.5\%$ which are consistent with the expanded uncertainty $U\%$ for $D_W$, $5.6\% \leq U\% \leq 10\%$.

c) Verification of absorbed dose to water $D_W$, given by the hospitals for HDR-$^{192}$Ir, TLD-100 powder is calibrated in terms of absorbed dose to water $D_W$, using the protocols AAPM TG61, AAPM TG43 and IAEA TRS-398, for the energy of RX 50, 250 kV, $^{137}$Cs and $^{60}$Co respectively. The calibration curves, Reading (R) versus $D_W$, are fitted by least square with quadratic and lineal models, which are validated with the lack of fit test. The slope of these curves corresponds to the sensibility factor: $F_s = \frac{R}{D_W} \cdot \text{nC Gy}^{-1}$; the uncertainties for this factor are obtained from the ANOVA tables. Later, the value of the $F_s$ is interpolated using the effective energy $h\nu_{\text{effc}}$ of the $^{192}$Ir.
TABLE 1. THE $F_s$, THEIR UNCERTAINTIES, THE $F_s$ NORMALIZED TO THE VALUE $F_s(137\text{Cs})$, AND THE PERCENT DIFFERENCES $\Delta\%$ RESPECT TO REPORTED VALUES [2].

<table>
<thead>
<tr>
<th>$h\nu_{\text{eff}}$</th>
<th>$F_s$ Nc Gy$^{-1}$</th>
<th>$U%_{k=1}$</th>
<th>$F_s/F_s(137\text{Cs})$</th>
<th>$F_s/F_s(137\text{Cs})$ Pradhan</th>
<th>$D%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1170.00</td>
<td>5,176.60</td>
<td>3.60</td>
<td>0.93</td>
<td>5.20</td>
</tr>
<tr>
<td>Cs-137</td>
<td>661.60</td>
<td>5,585.90</td>
<td>3.75</td>
<td>1.00</td>
<td>5.30</td>
</tr>
<tr>
<td>Ir-192</td>
<td>357.62</td>
<td>5,672.93</td>
<td>2.24</td>
<td>1.02</td>
<td>4.49</td>
</tr>
<tr>
<td>RX-250 $\text{Kv}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RX-50 $\text{Kv}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the case of the X ray 50 and 250 Kv the ionization chamber used is a PTW model 30001 Farmer chamber with traceability to the Central Laboratory of Electric Industries (France), for $^{137}\text{Cs}$ the ionization chamber used is a thimble chamber NE2611 traceable to the National Institute of Science and Technology (USA), and for $^{60}\text{Co}$ the chamber used is a PTW N30013 Farmer chamber with traceability to the National Research Council (Canada).

The TLDs were irradiated in two hospitals to a nominal $D_w = 2$ Gy with sources of $^{192}\text{Ir}$. The percentage deviations $\Delta\%$, between the $D_w$ imparted by the Hospitals and the determined by SSDL, are -7% for the Hospital A and 28% for the Hospital B. We are looking for the assignable causes for such subestimation.

REFERENCE

Commissioning and acceptance tests of Eclipse at Clinicas Hospital according to TRS-430

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With the recent new technologies it is becoming mandatory to establish a series of tests to be performed in order to implement a quality assurance program for computerized treatment planning system.

In this work, will be presented the goals and the necessary steps in order to implement a quality assurance program for the treatment planning system Eclipse 7.3.10 \textregistered from Varian at Clinicas Hospital in compliance with TRS-430 [1].

According to the new IAEA publication TRS-430 [1], the recommended tests are mainly divided into acceptance tests, commissioning and routine tests. The commissioning tests include both dosimetric and non-dosimetric tests. Since Eclipse 7.3.10 \textregistered from Varian Medical System has been recently installed at Clinicas Hospital, the IAEA document was implemented for this treatment planning system for two linear accelerators, namely Varian Clinac 600C and Clinac 2100C. One ionization chamber Victoreen was used in a water phantom on 30 x 30 x 30 cm\textsuperscript{3}, source-surface distance of 100 cm in reference conditions, with a dose rate de 320MU/min and 50 monitor units for the dosimetric tests.

For the acceptance tests, several checklists have been elaborated in order to apply the TRS-430 recommendations. These tests include the following parameters: hardware; integration of network system; data transfer; software (tools and calculations); general and complementary tests of software. The results thus obtained show good agreement with the manufacturer’s specifications.

For the commissioning of dosimetric tests, measurements for non-reference conditions have been performed to verify the algorithm effectiveness and system limitations in order to compare the values obtained with the absorbed dose determination by the treatment planning system. The measurements have been performed for both accelerators, and for both photon energies at Clinac 2100C. Measurements were performed for square and rectangular fields, maximum and minimum field sizes, off-axis ratios, diagonal fields, complex fields and behavior of the build-up region. Most tests presented 95% to 80% of the data within acceptance levels in accordance with the experimental values obtained by Eclipse. According to Venselaar [2] and TRS-430 [1], the values must be within 95% as acceptance criteria. These tests demonstrate for which settings the experimental values deviates from the given values by the treatment planning system in such way that some limitations of the system were thus determined.

For the non-dosimetric tests, several checklists have also been performed and the concerning settings verified. These checklists were able to verify the tools capacities, such as the system
calculations tools. The acceptance criteria have been applied for a comparison between the values of monitor units generated by the TPS and the values of MUs obtained by hand calculation. For these tests, a difference of at least 2-3% has been found for conformal fields compared to the tolerance level of 3% established by TRS-430 [1].

The IAEA document recommends a variation of 2% as acceptable for the dosimetric tests for ordinary fields, whereas a variation of 3% for wedged fields or off-axis ratios and at least 10% for build-up region or complex fields. The results showed that 95% to 80% of the data within this tolerance level, showing a good performance of TPS for the dose calculation for most experimental settings. For the acceptance tests and non-dosimetric, has been found a good agreement with the manufacturer’s specifications. For the monitor unit tests, the system presented differences of 3% according to TRS-430 [1] recommendations.

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Pilot study of the IAEA protocol for clinical commissioning of treatment planning systems

S. Vatnitsky\textsuperscript{a} K.R. Shortt\textsuperscript{a}, E. Gershkevitsh\textsuperscript{b}, R. Schmidt\textsuperscript{c}, G. Velez\textsuperscript{d}, D. Miller\textsuperscript{e}, E. Korf\textsuperscript{f}, F. Yip\textsuperscript{g}, S. Wanwilairat\textsuperscript{h}

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\textsuperscript{b}North Estonia Regional Hospital, Tallinn, Estonia
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Clinical test cases to facilitate the commissioning process of radiotherapy treatment planning system (TPS) were developed by participants of the IAEA coordinated research project (CRP) on “Development of procedures for quality assurance for dosimetry calculation in radiotherapy”.

The tests cover basic treatment techniques in typical radiotherapy installations and are based on the use of CIRS torso phantom. The practicability of the commissioning tests is assured through their trial use in the clinical facilities of different sizes. All hospitals used the same type of phantom which was scanned twice with computer tomography (CT). At the first scan different inserts were introduced into the phantom to derive the CT number to relative electron density conversion curve. At the second scan the phantom CT slices were acquired for planning of different clinical test cases on TPS. The dose was measured with ionization chamber placed inside the phantom.

In this work we present the results from eleven hospitals which are using fifteen different TPSs. Altogether there are 37 different combinations of algorithms and beam qualities. The use of the phantom and the tests proposed in the CRP enabled the evaluation of accuracy and limitations of different algorithms as well as inconsistencies in the loaded data. The differences between TPS dose calculations and measurements for different photon beam algorithms and inhomogeneity correction methods which exceed 3% tolerance limit are shown on Fig. 1. More results for different clinical test cases as well as test descriptions will be presented at the conference.

Results of the pilot study have shown that proposed test cases can not only serve to ensure the safe use of the TPS in a specific clinic, but may also help the user to appreciate the possibilities of their system and understand its limitations. The set of tests for clinical commissioning can be performed in reasonable time in the majority of hospitals, particularly in those with limited resources.
FIG. 1. Percentage of clinical test case dose measurement points which differs by more than 3% from TPS calculated dose for different algorithms and beam qualities.
Influence of the CT calibration process on the dose computation in radiotherapy treatment planning

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The impact of the experimental CT calibration process on the dose computation was investigated. For the studies three different phantoms were used: CIRS Model 62, CIRS Model 002LFC and a phantom from Scanditronix-Wellhofer. The first is a very flexible phantom that consists of a two part arrangement of rings and can simulate either a slice of the head or of the abdomen. The 18 embedded holes can accommodate any of the eight different inhomogeneities provided with the phantom. The second phantom is a thorax phantom consisting of three different materials that are in a fixed arrangement. The cylindric Wellhofer phantom consists of five inhomogeneities that are arranged in a circle. The phantom can be included in the IMRT-phantom “Easy Cube”. The “Easy Cube” can be extended to different shapes (abdomen, ring).

At first the three phantoms were scanned in a CT (Siemens Somatom Emotion) with the same scan protocol as used in routine for abdominal scans. The Hounsfield Units (HU) were measured for each inhomogeneity and assigned to the corresponding electron densities (ED). To create a calibration curve the data were fitted in two linear parts.

The obtained calibration curves for the three phantoms showed a dependency of the CT values on the used phantom (see Fig. 1). The Wellhofer phantom was also studied in different body shapes and here also an influence on the CT value appeared. These results show that it is problematic to use one calibration curve for all purposes (head, abdomen, ...) because the dimension of the body influences the CT value due to the shifting of the energy spectrum as the depth increases and the CT value resp. the attenuation coefficient changes with the energy.

Then the impact of the used reconstruction kernel was evaluated. Therefore the phantoms were scanned with an abdomen and a head protocol. Both protocols use the same voltage but different reconstruction kernels. The obtained HUs were different for both data sets.

The analysis process was detected to have also an influence on the measured CT value, because the reconstruction kernel leads to increased CT values at the edges of each insert. To be aware of this the radius of the region in which the HUs were averaged should be half of the maximum radius located around the middle of each insert.

To estimate the influence of all these effects on the dose computation, the technique of the equivalent pathlength was used to perform a theoretical evaluation. The use of two calibration curves obtained with different phantoms leads to a deviation in the calculated dose in the order of 1–2%, depending on the used photon energy and depth of the irradiated material. A planning study with the treatment planning system CMS XiO 4.2.0 also confirmed these estimations. In a worst case scenario, where all mentioned effects sum up, almost 5% deviation is possible.

Studies show that there is no unambiguous CT calibration curve. This has to be considered in a dose verification, particularly if the treatment planning system does not allow an own
implementation of the HU-ED conversion table and a generic calibration curve is used for CT data sets of different CT scanners [1]. The largest influence is due to the used voltage of the CT scanner that influences the energy spectrum and leads to different HU for the same material [2].

**FIG. 1. CT calibration curves obtained with different phantoms.**

**REFERENCES**


Pre-clinical tests of the virtual wedge option of a linear accelerator Primus-HE and verification of dose calculation algorithm in TPS Helax TMS

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The Virtual Wedge (VW) is a technique to modify the dose distribution to be similar to the one obtained by physical wedges. In this technique a gradual opening of one of the collimator jaws is combined with controlled alteration of beam intensity. The advantages are: forming dose distributions with arbitrary wedge angles, shortening of the irradiation time and constancy of the radiation quality.

The aim of this study was to check the long time stability of the wedge angle and the wedge factor (WF) of Virtual Wedges obtained with 6 MV and 18 MV X rays, as well as the accuracy of the calculation algorithm of the Treatment Planning System (TPS) HELAX-TMS.

All measurements were performed in water, applying the single channel dosimeter UNIDOS with the 0.3 cm$^3$ ion chamber, the beam analysing system MP3 and the multi channel dosimeter MULTIDOS attached to the 47 ion chamber array LA48 calibrated for field size 40×20 cm$^2$, at $d_{\text{max}}$ toward the readings of the single channel dosimeter system with the thimble chamber type31003 (all produced by PTW, Germany).

All tests were performed for 6 MV and 18 MV X rays and wedge angles 15°, 30°, 45° and 60°.

The long time stability of the WFs and wedge angles were checked in accordance with the International Standard IEC 976, i.e. for field size 20×20 cm$^2$, SSD = 90 cm and nominal wedge angles 15°, 30°, 45° and 60° during four consecutive years.

The acceptable difference between the stated and measured values of the wedge angles is ±2°. The WFs at the different geometrical beam parameters have to deviate from 1.00 with maximum 0.05.

To verify the TPS calculation algorithm the field sizes 6×6, 10×10 and 20×20 cm$^2$ at the isocenter were chosen and the source to surface distance was set to 90 cm. For this purpose, measured and calculated by HELAX-TMS, data have been compared:

1. the beam profiles at $d_{\text{max}}$ i.e. 1.6 cm for 6 MV and 3.2 cm for 18 MV, 5.0, 10.0 and 20.0 cm depths,
2. the central axis depth dose distributions,
3. the absorbed dose values, measured at $d_{\text{max}}$ for precalculated monitor units, i.e. verification of monitor unit calculations.

The criteria for acceptance levels for TPS accuracy are deviation of 3% for the dose values in the low dose gradient region, 4 mm displacement in the high dose gradient region and deviation 3% for the monitor units (MU) calculation.
The results obtained are:

- the long time stability of the wedge angle is ±2° as long as the flatness of the open field is within 2.5%;
- the values of WFs are of good constancy and in the acceptable limits, except the WF for the 6 MV beam with wedge angle 60° and field size 20×20 cm² the average value of which is 1.065;
- coincidence of the measured and calculated axial dose distributions has been found;
- the dose profile for depth up to 10 cm in low dose gradient region manifested a coincidence within 2% and in the high dose region the displacement is less than 4 mm. Non-acceptable deviations have been found for beam profiles at depth 20 cm and field size 20×20 cm² for both 6 and 18 MV – up to 6% in the low dose gradient region the calculated values being smaller than the measured. The displacement in the high dose gradient region reaches up to 8 mm and calculated profiles are larger than measured;
- the differences between calculated and measured dose values are in the acceptable limits except for wedge angle 60°, field size 20×20 cm² and 6 MV photons where the measured dose is 5% bigger than calculated.

From this study one may draw the conclusion that the Virtual Wedge Option of the Linear accelerator Primus-HE in combination with the TPS Helax can be applied with confidence for radiotherapy of patients with wedged beams with field parameters smaller than 20×20 cm² and 60°.

**BIBLIOGRAPHY**


New phantom design testing magnetic resonance image transmission integrity and image fusion in radiotherapy treatment planning

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The design challenge was to develop a phantom composed of materials and objects which can be imaged optimally by both computed tomography (CT) and magnetic resonance (MR) imaging modalities. The material used must simulate human body density for CT while providing sufficient magnetic properties for ample signal strength in MR. Test objects should provide high contrast resolution based on the same properties and be machinable for precise physical dimensions.

The phantom material consists of a proteinous gelatin (GEL) containing $1.0 \times 10^{-2}$ mol/L of copper sulfate ($\text{CuSO}_4$). Copper sulfate has been frequently used in aqueous solutions as MR phantom material in the past. Utilizing a solution of water and copper sulfate ($1.0 \times 10^{-2}$ mol/L) as the basis for preparation of the GEL provides the paramagnetic properties required to produce sufficient MR signal strength. Several objects within the phantom material were made of Delrin, a homopolymer acetal made by Dupont. Three basic object shapes were chosen for inclusion in the initial design: a sphere, a cylindrical column, and a square column. A simple 5 liter rectangular plastic container (PC) constituted the overall phantom shape. Multi-modality markers were placed on the exterior of the PC to allow reproducible positioning on both imaging devices and to use as reference points during image fusion.

A clinical brain scanning protocol for both modalities was used to image the phantom. The American College of Radiology MR Accreditation phantom was scanned using the same technique for comparison purposes. While the phantom was evaluated using $T_1$, $T_2$, and proton density technique, the material ($\text{CuSO}_4$) was chosen to enhance the $T_1$ response. A Siemens Somatom Sensation 16 CT scanner and a Siemens Magnetom Symphony MR unit (1.5 T), operated and maintained by the radiology department, was used for scanning.

**TABLE 1. MR SIGNAL STRENGTH COMPARISON**

<table>
<thead>
<tr>
<th>Position</th>
<th>GEL Phantom $T_1$</th>
<th>ACR Phantom $T_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 o’clock</td>
<td>930.5</td>
<td>1307.6</td>
</tr>
<tr>
<td>3 o’clock</td>
<td>966.7</td>
<td>1374.9</td>
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<tr>
<td>6 o’clock</td>
<td>897.7</td>
<td>1202.1</td>
</tr>
<tr>
<td>9 o’clock</td>
<td>917.8</td>
<td>1306.6</td>
</tr>
<tr>
<td>Sphere</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Circular Column</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>Square Column</td>
<td>9.9</td>
<td></td>
</tr>
</tbody>
</table>

The signal strength of the GEL phantom is approximately 70% of the ACR phantom material. The concentration of copper sulfate can be adjusted such that the signal strength can be increased to mimic the ACR phantom. This would have the added effect of increasing the contrast resolution of the Delrin objects.
The preliminary treatment planning tests, using the new phantom design, were to evaluate the integrity, fidelity and accuracy of the MR image transmission over the hospital network as well as the fusion tool of the treatment planning system.

The Varian Eclipse treatment planning system was used to evaluate the transmitted images. The image registration module of Eclipse provides three methods: registration points, mutual information registration, and manual registration. The registration point method was used for our initial evaluation since it requires no specialized skill and is the least sophisticated in terms of software. It was obvious that the MR image fidelity was excellent. Subtle changes in image display were facilitated by the wide grey scale window (range) available. The multi-modality markers were easily visualized on both CT and MR images. Four registration points in a single axial plane corresponding to the marker positions were used. The registration results, as reported by Eclipse, showed a mean error of 1.61mm and a maximum error of 2.06 mm. The results could be improved by placing additional markers/registration points at superior and inferior locations on the phantom.

**TABLE 2. VOLUME ACCURACY**

<table>
<thead>
<tr>
<th>Object</th>
<th>Physical volume</th>
<th>MR volume</th>
<th>CT volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Delrin Column</td>
<td>68.18 cc</td>
<td>68.06 cc</td>
<td>67.55 cc</td>
</tr>
<tr>
<td>Cylindrical Delrin Column</td>
<td>40.56 cc</td>
<td>40.36 cc</td>
<td>42.26 cc</td>
</tr>
<tr>
<td>GEL Column</td>
<td>119.40 cc</td>
<td>118.89 cc</td>
<td>113.77 cc</td>
</tr>
<tr>
<td>Sphere 1</td>
<td>8.2 cc</td>
<td>9.42 cc</td>
<td>9.22 cc</td>
</tr>
<tr>
<td>Sphere 2</td>
<td>8.2 cc</td>
<td>8.36 cc</td>
<td>8.02 cc</td>
</tr>
<tr>
<td>Sphere 3</td>
<td>8.2 cc</td>
<td>8.15 cc</td>
<td>7.77 cc</td>
</tr>
<tr>
<td>Sphere 4</td>
<td>8.2 cc</td>
<td>7.88 cc</td>
<td>8.26 cc</td>
</tr>
</tbody>
</table>

The volume accuracy results were all within 5% of the expected volume except for Sphere 1. This sphere’s calculated volume from the MR and CT datasets agree within 2.2% and indicates the true physical size of the Delrin sphere is larger than specified by the manufacturer. The image size and aspect ratio was evaluated for each dataset. The results show excellent agreement with physical dimensions (0.995).

In conclusion, the new phantom design presented is acceptable for evaluation of MR image accuracy and integrity in radiotherapy planning. Additionally, the phantom can be used for QA of image fusion methods used for treatment planning purposes. The high contrast resolution seen in both modalities makes it a viable design for developing more sophisticated test objects for quality assurance in radiation therapy treatment planning.
A comparison of different stereotactic radiosurgery treatment techniques for extra-cranial lesions

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The purpose of this study is to compare circular collimators arc based and mini multileaf collimator (mMLC) based radiosurgery treatment plans using isodose distributions and dose-volume histograms. A total of 12 patients were treated by conventional arc based radiosurgery for extra-cranial malignancies, seven patients with one isocenter, four patients with two isocenters and one patient with three isocenters. The same cases were re-planned using a test version of mMLC-based radiosurgery software for multiple static non-coplanar fields. For non-spherical targets, treatment planning is relatively intuitive with mMLC based radiosurgery. It reduces the time required for planning. Moreover, a lower dose of radiation is delivered to normal tissue with mMLC based radiosurgery than with arc based radiosurgery, which may lead to the reduction of complications.

FIG. 1. Illustration of DVHs for target and normal tissues in using circular arc-based radiosurgery and, mMLC-based radiosurgery for (a) slightly non-spherical target, and (b) highly non-spherical target.
### TABLE 1. DATA ANALYSIS OF CIRCULAR ARC-BASED RADIOSURGERY AND MMLC-BASED RADIOSURGERY FOR SLIGHTLY NON-SPHERICAL TARGET

<table>
<thead>
<tr>
<th>Patient’s name</th>
<th>No. of iso-center</th>
<th>Technique</th>
<th>No. of arcs/ beams</th>
<th>Target vol. (cc)</th>
<th>Prescribed isodose surface (%)</th>
<th>Normal tissues covered prescription isodose surface% (cc)</th>
<th>Conformity index</th>
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<tbody>
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<tr>
<td>Case 1</td>
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<td>2.51</td>
<td>69</td>
<td>118</td>
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<td>Arc-based</td>
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<td>10.95</td>
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<td>Case 6</td>
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<td>208</td>
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<td>mMLC</td>
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<td>Case 7</td>
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<td>8.98</td>
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</table>

**Conclusions**

For spherical and slightly non-spherical targets, circular arc based radiosurgery treatment planning gives good dose distributions and spares more normal tissues than mMLC based radiosurgery. For non-spherical targets, mini multileaf collimator based treatment planning is intuitive and, therefore, reduces labor requirements. Moreover, mMLC based radiosurgery spares more normal tissue than arc based radiosurgery. Choices between these two techniques should be based and depend on the shape and regularity of target volumes which should theoretically lead to a reduced risk of complications.
3D dose distribution in gamma knife treatment near tissue inhomogeneities

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The treatment planning system, GammaPlan, uses CT, MR or angiographic images to calculate and simulate the dose distribution in a matrix volume of interest assuming that tissues in human head are homogeneous and water equivalent. The absence of electronic equilibrium in the vicinity of air-tissue inhomogeneity in the head will misrepresent the deposited dose under the above assumption. Polymer gel dosimetry has already been used in different scenarios of radiotherapy dosimetry; however, little work has been reported for polymer gel phantoms with air cavities irradiated in Gamma Knife surgery. Increasing dose levels are reflected into lower MR relaxation time constants $T_1$ and $T_2$, in the neighbouring water protons [1]. The MAGIC Gel was manufactured under normal atmospheric conditions using the formulation proposed by Fong, et al. [2]: 8\% Gelatine Type A from porcine skin Sigma Bloom 300; 10mmol/l Hydroquinone, 99\%; 2 mmol/l Ascorbic Acid, 99\%; 0,02 mmol/l CuSO\textsubscript{4} \textsuperscript{5 H\textsubscript{2}O; 9\% Methacrylic acid, and 83\% distilled water.

For the paranosal sinuses cavity experiment (a lesion in the head near the paranosal sinuses is simulated), two spherical glass balloons with a volume of 2 liter each were the phantom containers. Both glass balloons were filled with the MAGIC gel. The inhomogeneous phantom was prepared by placing a cylindrical cork to represent the air cavity: the diameter was 2,5 cm and the length 8 cm (3). The homogeneous phantom simulates the physical structure considered in the GammaPlan.

Seven plastic vials of 100 ml were filled with the gel and were irradiated with doses of 0, 3, 5, 10, 15, 20 and 25 Gy with the Cobalt-60 TeleTherapy machine to obtain the calibration curve in order to derive the equivalent dose values from GammaPlan.

The simulated tumour was given one shot with a dose of 20 Gray in the Gamma Knife using the 18 mm Helmet. A week following the irradiation, the phantoms and vials were scanned in a clinical Siemens 1.5 Tesla MR unit. For calculating the dose distributions in the phantoms, $T_2$ mapping of the exposed normoxic gel is performed by using the Spin Echo MR sequences with TR=2000 ms and TE=10, 100, 110, 120, 170 and 269 ms, respectively. The phantoms were scanned in 9 slices of 3 mm each. MR images were reconstructed solely using $T_2$ relaxation time constants, with each pixel value calculated by exponential nonlinear least-squares fitting for different TE values.

Both phantoms were irradiated with the same dose and the same coordinates. The Gammaplan dose distributions were compared by selecting the slices where the maximum dose has the largest area. In terms of the Leksell frame coordinates, this slice was located at $Z=105$ in the axial plane and $Y=105$ in the coronal plane. By using the fudicial marker system and Leksell frame coordinate conversion, identical slice coordinates were used in the GammaPlan. The 30\%, 50\% and the 70\% isodose distances in the GammaPlan slices were measured using the pointer system on the monitor.
In the case of the homogeneous phantom, the dose measured distribution is in good agreement with the GammaPlan calculated dose distribution. The dose distribution in the inhomogeneous phantom shows significant differences with that of the homogeneous phantom. The dose distribution in the inhomogeneous phantom is perturbed by the air cavity. The 30%, 50% and 70% isodoses in the inhomogeneous phantom are all asymmetric with respect to the shot center. We can conclude that there is a significant dose perturbation in the air cavity regions under Gamma Knife surgery, which is normally ignored by the GammaPlan.


**REFERENCES**


Patient plan-related beam verification in IMRT

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Patient plan-related beam verification is the only possibility to check the entire treatment chain of IMRT treatment from treatment planning to delivery. LINAC QA is not sufficient for complete quality assurance due to the complexity of this new technique standard. The finally delivered dose has to be evaluated.

Most centers beginning with IMRT start their patient plan-related beam verification with a film. Advantages of a film are obvious for resolution and understandability.

A disadvantage of film dosimetry is the extensive time required for the calibration and development of the film.

Furthermore, many hospitals tend to work without films in diagnostic radiology. If the radiotherapy department is the only department using films, it is difficult to guarantee the stability of the developer. The high price of dry films limits their use to special cases.

More and more LINACs are equipped with EPIDs. The advantage of these units is the integration into the LINAC system. However, EPIDs are not suitable for absolute dose verification. Transferring the measured fluence into dose requires a complex mathematical algorithm. Measurements in the isocenter are normally not possible, so are measurements in a phantom.

Two dimensional detector arrays make it possible to automate the measurement. The huge time gain in relation to measurement with films enables the user to verify all patient plans. One limitation for all commercially available two dimensional detector arrays is the limited resolution of these units.

Higher resolution is sometimes required, especially for small fields or fields with steep dose gradients close to organs at risk (OAR).

A new software tool from PTW-Freiburg makes it possible to move the two dimensional detector array (2D ARRAY seven 29, PTW-Freiburg) in four positions and deliver the beam four times. Instead of the 729 data points, a matrix of 2916 data points is acquired. The entire field can be analysed without any gap, thanks to the rectangular shape of the ionization chambers. No dose information is left out.
This enhanced analysis is needed for special cases. Routine patient plan-related beam verification can be performed with one irradiation.
Analysis of pre-treatment QA in dynamic IMRT fields


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Patient specific quality assurance (QA) was recommended to perform for intensity modulated radiotherapy (IMRT) treatment to ensure proper dose calculation and delivery [1]. The IMRT treatment at King Chulalongkorn Memorial Hospital, Bangkok, Thailand was started in May 2005. Patient specific QA verification was undertaken for 99 plans, 62 patients from May 2005 to December 2005. The measurements were performed to search for the suitable method for orientation of film, the angle of the beams and type of chambers. The aim of this research is to analyse the dosimetric results of our patient specific film QA and absolute dose using ion chamber for various techniques of measurement.

The pre-treatment QA for dose distribution in dynamic IMRT fields were performed with EDR2 film. The scanner was Vidar VXR-16 with the Wellhofer OmniPro IMRT software to analyse the result. The treatments were delivered with Varian Clinac 21 EX and Varian Clinac 23 EX, and the treatment planning was Eclipse. The phantoms used were solid water phantom for film measured in coronal plane and IMRT Med-Tech phantom for film measured in transverse plane. Film calibration was performed for each QA session using an eight dose level $^2$ to convert measured optical density to absolute dose. The composite plan for all gantry angle at zero degree or at the actual treatment angle were chosen. The absolute doses were measured with Wellhofer CC13 chamber or FC65-P chamber or PPC40 parallel plate chamber with Wellhofer Dose1 dosemeter placing in the same phantom with film.

The isodose distribution from film in axial and coronal position showed an agreement to the Eclipse calculation in the same direction. Both the isodose distribution for actual gantry and zero degree gantry were not different from the calculation. For 99 plans, most of the measured line profile showed good agreement with the calculation. The difference occurred at the edge of the field. Using gamma index of 3% dose difference and 3 mm distance agreement, most of the plan were in the limit.

The comparison of absolute dose measured by ionization chamber using actual gantry angle and zero gantry angle of 10 cases showed the difference from the calculation in the same direction, with the mean difference of 1.51% and the standard deviation of 1.2. The mean difference from calculation of doses measured by film which averaged at five points of (0,0),(0,2),(0,-2),(2,0),and (-2,0) for 42 plans was 2.47%, and the standard deviation was 1.07.

Table 1 shows the mean difference from the calculation of doses measured by three types of chambers which are 1.89% for FC65-P, 1.73% for CC13 and 1.38% for PPC40 chamber. So the PPC40 chamber seem to be more close to the calculation value. However, the PPC40 chamber could be measured only with the gantry angle equal to zero degree.

Table 2 shows the 99 cases of measured doses for nasopharynx, lung and other cancers. The mean difference from the calculation are 2.12% for Nasopharynx, 1.55% for lung and 1.78% for others cancer with the standard deviation of 1.12, 1.10 and 1.2, respectively. The large
unagreeable occurred in the large field which split into subfield and the fluence were complicated.

TABLE 1. THE DIFFERENCE BETWEEN MEASURED AND CALCULATED DOSE FOR THREE TYPES OF CHAMBER

<table>
<thead>
<tr>
<th></th>
<th>FC65-P</th>
<th>CC 13</th>
<th>PPC40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean diff.(%)</td>
<td>1.89</td>
<td>1.73</td>
<td>1.38</td>
</tr>
<tr>
<td>Maximum diff.(%)</td>
<td>4.34</td>
<td>4.14</td>
<td>2.50</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.16</td>
<td>1.24</td>
<td>1.10</td>
</tr>
</tbody>
</table>

TABLE 2. THE DIFFERENCE BETWEEN MEASURED AND CALCULATED DOSE FOR SPECIFIC TYPE OF CANCER

<table>
<thead>
<tr>
<th></th>
<th>Nasopharynx</th>
<th>Lung</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Plan</td>
<td>43</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>Mean diff.(%)</td>
<td>2.12</td>
<td>1.55</td>
<td>1.78</td>
</tr>
<tr>
<td>Maximum diff.(%)</td>
<td>4.34</td>
<td>3.20</td>
<td>4.14</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.12</td>
<td>1.10</td>
<td>1.20</td>
</tr>
</tbody>
</table>

For routine QA, we conclude that the composite fields of zero gantry angle with the film in coronal plane at depth 5 cm and IC13 chamber at depth 10 cm in the same solid water phantom were chosen for simple set up, less time consuming and accurate dose.

REFERENCES


A leaf positioning accuracy test derived from measured IMRT fluence distributions

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Purpose

IMRT in step and shoot mode is based on the accurate delivery of the invers planned fluence maps. The multileaf collimator used for forming the field shapes, therefore, has to undergo a rigid quality assurance. Beside other parameters especially the leaf positioning accuracy is of high importance. Special checks like the “garden fence test” have been developed to ensure that leaves reach the desired position everywhere within the modulated field. Alternatively an analysis of measured fluence maps from patient plans can be performed. We present a method that uses a gradient detection algorithm to find leaf positions from a fluence map measured by film dosimetry and automatically compares the results to the positions taken from the invers treatment planning system.

Materials and methods

In our institution the delivered fluence map for each IMRT beam direction is measured during the first fraction by the exposure of a radiographic film. For this purpose we have developed a special film tray (Fig. 1) to be inserted in one of the accessory slots of the accelerator. The tray consists of a base frame with a 0.1 mm plastic foil to reduce sagging and a copper plate to eliminated electrons from the accelerators head. The tray is used on a Siemens Primus 6MV machine equipped with 82 leaf optifocus multileaf collimator. Four guided needles are used to mark a coordinate system on calibrated EDR II radiographic films (Kodak). Scanned films can be analysed for fluence level, fluence position and fluence size by an IDL (Research Systems) software tool [1].

Beside this application for individual patient QA, the fluence map can be checked for the leaf positions used in the superposition of the field segments. Scanned film data are imported, scaled, rotated and a coordinate system is set to the origin marked with 4 pinpricks. A “Canny edge detection algorithm” [2] is then used to detect fluence gradients which indicates that at least one leaf was positioned there for some time during the dose delivery. Along the leaf moving path the positions found by the maximum gradient are calculated and are compared to the data derived from the treatment planning system. Therefore, a special import tool reads in the treatment plan and computes the fluence pattern form the leaf positions and monitor units found in this file (Fig. 2). Plotted on the film image, the difference between measured and planned leaf position are displayed. Alternatively an error histogram (Fig. 3) can be shown either with all leaf positions of a selected leaf pair or as a sum of all leaf positions found on the whole fluence map.

Results

This method can be used routinely to perform leaf positioning checks for each fluence map taken during the patients first IMRT fraction. It is therefore an additional test to the weekly or monthly done MLC quality assurance. From the histogram data, calculated on the leaf
positioning errors, it is easy to detect leaves exceeding the limits indicating a necessary leaf recalibration.

This leaf positioning check can be performed easily although there are some minor drawbacks: First, if there was no fluence step in the distribution as found on match lines, the algorithm is not able to detect these positions correctly or not at all. Second, a fluence gradient might also be generated by multiple leaf positions and therefore it might not be clear which leaf of the leaf pair caused the problem. Third is the documentation of the leaf positioning errors detected. The large number of data and the fact that for each leaf pair multiple positions are detected makes them difficult to handle.

![FIG. 1. Film tray equipped with film (left) and film tray mounted on the accelerator (right).](image1)

![FIG. 2. Fluence film with leaf measured positions indicated.](image2)

![FIG. 3. Error histogram planned versus leaf positions leaf positions for a treatment plan.](image3)

REFERENCES


Dosimetry verification using radiochromic film for intensity-modulated radiation surgery

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\textsuperscript{b}Institute of Physics, National University Autonomous of México, Mexico

A well known acceptance criteria for dose difference between calculated and measured dose distribution is 5\% [1]. But, when the technique of intensity modulated radiation is used in radiosurgery (IMRS) the high dose delivery imply to carry out a commissioning to verify these recommendations. This work proposes a methodology to verify the dose distributions in IMRS treatments using radiochromic film.

The experimental methodology to measure the spatial dose distributions use radiochromic films GafChromic MD-55-2\textsuperscript{®} previously calibrated in the same linear accelerator, for which it settled down a protocol in its handling and analysis according to the recommendations for film dosimetry [2]. For that purpose an spherical phantom of 16 cm of diameter MAPM (meth-acrylate of poli-methyl or acrylic) [3] was designed and constructed to simulate a head in whose interior it is possibile to interchange pieces capable to simulate an injury and to place the films (Fig. 1).

According to the protocol suggested by the AAPM-TG55 [2] all the films were cut to fit the phantom dimensions 24 hours before being irradiated and read it 48 hours later. The reading was performed using a commercial scanner (Agfa DuoScan T1200) in transmission mode. The films were digitized using 16 bits/pixel per chanel in RGB mode color depth and 300 dpi. The analysis was performed using in-house software. In the analysis the isodoses curves that were measured experimentally and calculated by the system were compared, obtaining the discrepancies among them (FIG 2). The results showed that the best agreement between isodoses curves happens for the high doses (80\% and 60\%), whose deviations are in Table 1; for the low isodoses curves the discrepancies are greater, a possible answer of this difference is the sensitivity of the film that is of order of 3 Gy, comparable with the dose that is moderate in those curves, combined to it, this sensitivity depends on the scanner response. With the use of radiocromic films, GafChromic MD-55-2\textsuperscript{®} implemented a methodology to determine the dose and its spatial distribution in IMRS treatments. This protocol can be implemented in hospitals that can use commercial scanners; it has the possibility to use radiocromic films; observing that the times to manage the film must be shorter, in order to apply this protocol in real time.
**FIG. 1.** Design of phantom used for the simulation of a stereotactic radiosurgery treatment. (A) phantom of head. (B) phantoms of irregular lesions.

**FIG. 2.** Isodoses curves 80% y 20% in polars coordinates.

**TABLE 1.** DEVIATION AVERAGE OF THE DISTANCE BETWEEN THE CURVES OF TRACED AND MEASURED ISODOSES

<table>
<thead>
<tr>
<th>Isodose Curves</th>
<th>Average deviation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>0.441</td>
</tr>
<tr>
<td>60%</td>
<td>0.456</td>
</tr>
<tr>
<td>40%</td>
<td>0.575</td>
</tr>
<tr>
<td>20%</td>
<td>1.041</td>
</tr>
</tbody>
</table>

**REFERENCES**


External beam dose verification with GafChromic EBT film

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The capability of the new GafChromic EBT for external beam dose verification was investigated. First, the general dosimetric characteristics of this film (dose response, postirradiation colouration, influence of calibration field size and energy dependence) were derived using a commercially available flat-bed scanner Microtek ScanMaker 8700).

In the dose range from 0.1 to 8 Gy, the sensitivity of the GafChromic EBT film is 10 times higher than the response of the GafChromic HS, which so far was the GafChromic film with the highest sensitivity. Compared with the Kodak EDR2 film, the response of the EBT is higher by a factor of 3 in the dose range from 0.1 to 8 Gy (Fig. 1).

The optical density of all GafChromic film types prior to the EBT was unstable with time. It is impossible to evaluate the films directly after irradiation. So it is recommended to wait for 24 h until the films are nearly stable. The GafChromic EBT does not show this temporal growth of the optical density and the films can be evaluated directly after irradiation.

There is no influence of the chosen calibration field size on the dose response curve of the GafChromic EBT film. Within the energy range (keV to MeV) the GafChromic EBT film is energy independent.

After investigating if the GafChromic EBT is theoretically a reasonable detector for dose verification of external beam therapy, a SRT fraction and an IMRT fraction were measured with the EBT film. To compare the planned dose distribution with the actually applied dose, the dose matrix of the treatment planning system was exported using an ASCII format. The films were scanned using the flat-bed scanner. The obtained digital data were 42 bit RGB TIFF images. A MatLab program was written to evaluate the two dimensional dose distributions from treatment planning systems and GafChromic EBT film measurements. Fig. 2 depicts the output of the self written MatLab program. Illustrated is the difference between the planned and the measured data (smaller region in the middle) for the IMRT verification. The maximum deviation is 0.1 Gy and can be found in regions with a steep dose gradient, e.g. the edges of the beams, and possibly results from the tolerance of the leaf positions and the gantry positioning. Minimal deviations result in large errors. Considering this, the plan and measurements are in good agreement.

The GafChromic EBT together with the flat-bed scanner and MatLab is a successful approach for making the advantages of the GafChromic films applicable for verification of external beam therapy.
FIG. 1. Response of the GafChromic EBT compared with the GafChromic HS and the Kodak EDR2. If the red channel of the EBT RGB TIFF image is used, the response of the EBT is 10 times higher than the response of the HS. Compared to the response of the Kodak EDR2 the response is 3 times higher.

FIG. 2. External beam therapy verification for an IMRT fraction. Comparison of the measured dose distribution and the dose distribution provided by the treatment planning system. The color bar ranges from 0 to 1.0 Gy.
Dosimetric comparison and QA of 3D conformal and intensity modulated radiotherapy (IMRT) for para nasal sinus carcinoma


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Treatment planning for para nasal sinus carcinoma (PNS) is quite complex for its close proximity to organs at risk (OARs) and the presence of air filled cavities near the tumour. 3D CRT and IMRT have reduced the doses to OARs significantly (1–3) compared to conventional techniques. In this study, an attempt has been made to obtain a class solution of 3D CRT plan that is comparable to an IMRT plan with respect to the tolerance doses to the OARs and PTV coverage. Plan parameters of 3D CRT were compared with IMRT. Dose delivery of 3D CRT was also verified using ion chambers and TLDs.

Five patients with PNS who were treated with 3D CRT were studied. 3D CRT and IMRT plans were created for each patient. Planning CT of 5 mm slice thickness was obtained with the immobilization system in treatment position. Target volumes and OARs were drawn in accordance with ICRU 50.

For 3D CRT plan, four 6 MV photon beams one anterior/vertex, two laterals, and a small anterior boost field with optimal wedge angles and weights were used. Bolus was used for tumours, involving skin. To reduce the dose to the eyes and the lens, eyes were shielded from the lateral beams. Hence there was a significant dose deficit near the region of maxillary sinus and posterior ethmoid. Since the final outcome for PNS tumours is a function of the control at the primary site, it is essential that the PTV be adequately covered by the prescription isodose. Hence to boost the dose to this region a small optimally weighted anterior field is added. Multi leaf collimators (MLCs) are shaped in such a way that in none of the beams, eyes and lens will be in the direct beam. Also small segments of MLC leaves are pulled in the beam to reduce the hotspots. The small anterior boost field where isocentre is shielded will have some uncertainty for its small size and more weight. Hence quality assurance was carried out, MLC shapes from the patient plan has been transferred to the head and neck phantom. Dose at the isocentre and at off axis, near the boost field were measured using ion chamber, and TLDs.

IMRT plan is produced using seven coplanar beams placed 50 degree apart. Dose volume constraints were set, as follows: 95% of PTV should receive 95% of the dose; no volume of PTV should receive more than 107% of dose. The maximal tolerance dose to OARs are as follows: Spinal cord 45Gy, brain stem 54Gy, optic nerve 54 Gy, lens 6 Gy, and mean parotid dose 24Gy. Helios Optimization algorithm from Varian medical system is used for inverse planning. Dose prescription to PTV was 60 Gy in 30 fractions.

For each patient, 3D CRT was compared with IMRT using isodose curves, dose volume histograms, and dose volume statistics. The minimal dose, maximal dose, percentage of PTV volume receiving 95% and 107%, V\textsubscript{95}%, and V\textsubscript{107}%, dose conformity, homogeneity, maximum tolerance dose to OARs, dose to normal tissue were compared.
There was no significant difference in the maximal dose (112-119%) and minimal dose (84-92%) for 3D CRT and IMRT. For two patients in 3D CRT the minimal dose was as low as 75%, and it was found that the tumour was extending up to skin wherein in the build up region dose calculation was not very accurate. Mean $V_{95\%}$ of PTV is 93% and 95%, mean $V_{107\%}$ was 5% and 4% in 3D CRT and IMRT respectively. Both 3D CRT and IMRT were homogenous in PTV coverage, but conformity was superior in IMRT than in 3D CRT. IMRT doesn’t offer any significant advantage of doses to critical structures. The normal tissue receives more dose in IMRT than in 3D CRT. $V_{10\%}$, percentage volume of normal tissue receiving 10% of the dose is 40% and 55%, $V_{50\%}$ is 18% and 15% for 3D CRT and IMRT respectively. The dose measured for 3D CRT at isocentre and at off axis using both ion chamber, TLD is found to be with in ±4%.

From the above results we conclude that with a few number of optimally placed beams with MLCs shielding the critical structures, 3D CRT can be an effective alternative to IMRT for PNS cancer to deliver 60Gy/30fractions. IMRT plan uses large number of beams which makes the treatment time longer. 3D CRT plan presented here consists of just four beams was faster to implement on linac, where time is a constraint. It also is less prone to error, and very much suitable to our country where most of the centers still do not have the infrastructure to treat patients with IMRT. Further the 3D CRT plan reduces the integral dose received by the normal tissue. Quality assurance results also confirm that the dose delivery is within ±4%. This 3D CRT plan has been accepted as an effective treatment modality for PNS tumours in our hospital.

REFERENCES


MIMiC IMRS and IMRT delivery system

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Radiosurgery is a single application of high radiation dose to a stereotactically defined target volume. Treatment delivery involves multiple stereotactically targeted, arced fields. The goal of radiosurgery is to deliver a high dose to the target while sparing the normal tissue just a few millimeters away. We will present the first experience of planning, verification and realization of treatment with a new treatment and navigation system for IMRS and IMRT as well as present the first comparison of these methods.

1. Introduction

Since 1993, the stereotactic radiosurgery on linac is used at St. Elisabeth Cancer Institute in Bratislava. Until September 2006 we have treated 870 patients with primary brain tumours, metastases, recurrences and AV malformations with Leibinger stereotaxy circular collimators system on Clinac 600C/D of Varian accelerator. Since May 2005 we have been using also a Nomos MIMiC (with BEAK) stereotaxy IMRS and IMRT delivery system with Corvus treatment planning system and Autocrane positioning of cauch. Till September 2006 we have treated 36 patients with MIMiC and five patients with 120 MLC Milenium.

2. Method

2.1. Navigation and immobilization equipment. For the reason of continuity, for stereotactic immobilization at STRS we use Leibinger system with autocrane mowing system on Clinac 600C/D and for IMRT thermoplastic masks.

2.2. MiniMLC MIMiC with active monitor. MiniMLC MIMiC is atatched to the gantry of linac. It is used for dynamic arc IMRS and IMRT. The device consists of 20 pairs of leaves 1 cm wide in two rows, with pneumatic control of the position of each leaf by the active monitor according to the data for a given treatment from the treatment planning system transferred on a floppy disc. Each leaf has its own position control.

The active monitor also contains a system for angle gantry detection with an accuracy of 0.1°. Taking into account the position of gantry and data in memory, it opens or closes the respective leaves almost immediately, with respect to the pressure system.

2.3. Linear accelerator with a verification system. MiniMLC MIMiC can be connected to any arbitrary linac used in radiation therapy. For MLC IMRT we use 120MLC Milenium (Varian).

2.4. The autocrane. Autocrane fixed to a linac table enables longitudinal and lateral positioning of the patient within 50 cm with an accuracy of 0.1 mm by the active monitor directly on autocrane or on the monitor in the control room.

2.5. Computer net coupled to CT, MRI and PET. The Pacs system makes it possible to process data from CT, MRI and PET by DICOM, enables data delivery to the planning system Corvus.
2.6. *The treatment planning system Corvus* was used for calculation of dynamic arc IMRT therapy with MIMiC and MLC, as well as the calculation of conformal technique. The system also enables an active plan optimization by shift of isodose on planning monitor “to optimum position”. The IMRT plan received is applied on selected phantom for direct checking of calculation dose on linac by film, TLDs, and ionization detectors.

2.7. *Verification IMRT phantom.* In our department we use a home made IMRT water equivalent plate phantom with an aperture for ionization chamber and apertures for identification of film position.

2.8. *Software for IMRT evaluation.* For checking the application of hybrid plan dose we use the IMRT PRO software (Wellhofer). Also, to check the calculated dose in a selected point with PingPoint ionization chamber (Wellhofer).

2.9. *Treatment.* From May 2005 to December 2005 we treated 36 patients with various types of tumours and lesions by IMRT at linear accelerator 600C/D. Twenty (20) patients (with meningiomas, with A-V malformations, patient with brainstem tumour) were treated by stereotactic IMRS delivery system, autocrane positioning of cauch and Corvus TPS. The target volume ranged 3–24 cm$^3$ (Ø 11,3cm$^3$), the dose 12–18 (Ø 14,8 Gy). For long experience with stereotactic radiosurgery by Leibinger collimators system we compare volume of isodoses between the mentioned system and IMRT with MIMiC, we calculated factor conformity and index homogenity for both systems. Sixteen (16) others patients with various diagnosis were treated by fractionated IMRT (orbital lymphoma, prostate cancer, meningiomas, olfactorial neuroblastoma) and five (5) patients were treated with MLC (prostate cancer, brain tumours).

3. *Results*

Treatment results are preliminary, we had no serious complications.

Index homogeneity and factor conformity were better at IMAT with MIMiC than by MLC or circular collimators.

4. *Conclusion*

IMRS and IMRT with MIMiC and autocrane is an effective treatment modality with good conformity and homogeneity, sparing healthy tissue. Disadvantage: this technique is time consuming.
Dose verification for step-and-shoot IMRT and its feedback potential to improve the dose calculation with the treatment planning system by modifying the input for pencil beam kernels used in the TPS

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Introduction. Agreement between the measured dose obtained from the dose verification procedure and the calculated dose depends on the accuracy of both the measurement system and "dose engine". TRS 430 suggests that an accuracy as close as possible to 3% should be achieved by the TPS. In step-and-shoot IMRT, the requirement for a high accuracy must also be met in particular down to very small field sizes. As the smallest field size; we allow a $1\times1\text{cm}^2$ segment. In our TPS, the calculation algorithm uses a pencil beam algorithm based on such dosimetric measurements like total scatter factor ($S_{c,p}$) and off axis ratio (OAR). Therefore, detectors with a high spatial resolution are needed to correctly measure total $S_{c,p}$ OAR down to a $1\times1\text{cm}^2$ segment. By routinely checking the results of the TPS with our dose verification procedure, the degree of agreement between TPS and measurement has been investigated in a large number of IMRT cases. A simple statistical analysis revealed a clear correlation between the quality of input data used in the TPS and the agreement between calculation and measurement.

Methods and material. To date approximately 800 patients have been treated with IMRT at DKFZ with Siemens linacs (6MV photons). We have implemented a fast dosimetric total plan verification procedure by measuring absolute dose simultaneously inside a solid water matrix phantom with five ionization chambers ($0.125\text{ cm}^3$) located at positions with a high dose low gradient. Interference between the different ion chambers was found to be negligible. The whole procedure is described in more detail in Rhein and Häring 2005 [1]. Dose calculation was carried out with a fast pencil beam kernel algorithm which was derived from standard measurements ($S_{c,p}$, TPR, OAR) [2]. At the beginning, $S_{c,p}$ was measured in a water phantom over the whole field size range ($1\times1\text{ cm}^2$ and $40\times40\text{ cm}^2$) with a diamond detector (~3mm³) and a $0.125\text{ cm}^3$ ionization chamber. Later on, the measurements were repeated and, for comparison, supplemented by an energy shielded p-type diode ($1\text{mm}^2\times2.5\mu\text{m}$). Up to 2005, the pencil beam kernel was derived based on the diamond measurements. Since one year it is now based on the new data of the diode measured $S_{c,p}$. Percentage deviation between calculated and measured dose for the chosen chamber locations inside the matrix phantom have been evaluated in two series. In the first series (108 IMRT cases, 424 measuring points), the dose calculation of the TPS was based on $S_{c,p}$ measurements performed with a diamond detector. After modification of the input data using an energy shielded p-type diode for $S_{c,p}$ measurements, the second series was evaluated (103 IMRT cases, 450 measuring points).

Results. $S_{c,p}$ factors for the different detectors are shown in Fig. 1. Deviations are related basically to the detector volume and to a minor part to the non-water equivalence of the detector material. Monte Carlo calculations (BEAMnrc) showed that the difference between the secondary electron spectra from a 6 MV photon beam inside a $1\times1\text{ cm}^2$ and $10\times10\text{ cm}^2$ field will result in a diode $S_{c,p}$ overestimation of 0.5%. Probably the energy shield material surrounding the p-type diode compensates to a certain part the lateral secondary non-electronic equilibrium and therefore leads to an additional over-response at the smallest field size. Fig. 2 shows the frequency distribution of the percentage deviation between the dose
calculations with the diamond derived PB kernel and the ionization chamber measurements for 108 IMRT cases and 424 measurement positions inside the matrix phantom. A systematic shift of the mean of +1% with a 1σ standard deviation of 2.15% can be observed. The result for the second comparison between the energy shielded n-type diode derived PB kernel calculation and the ionization chamber measurements is shown in Fig. 3. No systematic shift of the mean is now observed while the 1σ standard deviation of 2.05% is comparable to the result shown in Fig. 2. Two conclusions are drawn from this result: (a) the diode based measurements appears closer to the correct total scatter factors, and (b) our dose verification procedure is indeed able to improve the quality of the TPS calculation.

**REFERENCES**


In vivo QC of beam deliveries to patients in IMRT

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In recent years IMRT treatments became feasible and were improved by using complex treatment and planning facilities. The combination of such complex systems carries potential risks of (hidden) malfunctions.

Most clinical sites concentrate on the pre-treatment verification of IMRT fields. During the treatment the focus of interest is on patient positioning rather than on dosimetric questions [1]. But only by in vivo quality control of the delivered beam it is possible to detect deviations from the predicted outcome.

A simple solution for in vivo quality control of beam deliveries is a flat translucent rectangular ionization chamber. The chamber is installed on the beam entrance side of the patient and the active area of the chamber covers the entire radiation field [1]. The chamber voltage is 400 V.

The chamber contains as many electrodes as there are MLC pairs. The electrodes are formed by wires. Every wire stretches along the projection line of an MLC leaf pair. Consequently the signal of every electrode corresponds to the line integral of the dose rate (dose length product) [1]. The signal is determined by the energy, dose rate and in particular by the opening of the leaf pairs.

A software associated to this chamber records the values for every electrode. The resulting values of the ongoing measurement are compared with those of the reference field. The reference field has been measured previously during the pre-treatment dosimetric verification of an IMRT plan. In case of a deviation between corresponding measurement results, a visual warning is activated.
FIG. 2. Reference and actual measurements.

The necessary data transfer from the measuring unit to the computer is performed by Bluetooth® wireless technology. The electronics and the chamber form one single unit. To avoid any cables the unit is powered by rechargeable batteries.

The system is able to detect errors of less than 1 mm for an isocentric 1 cm×1 cm field and 1 mm for an isocentric 20 cm×20 cm field [1]. It is suitable for step-and-shoot MLC systems and sliding window technique.

The commercial system is called “DAVID” (Device for Advanced Verification of IMRT deliveries). It is produced by PTW-Freiburg and will be available by the end of 2006.

REFERENCE

Application of 2D LiF TLD foils to the QA programme of the M3 micro-multileaf collimator

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A prototype planar thermoluminescence (TL) reader with sensitive CCD and 2D TLD foils, were developed at the Institute of Nuclear Physics in Kraków (Polish acronym IFJ) in cooperation with the Mikrolab company. The TLD CCD reader, equipped with a 12-bit CCD PCO camera with a resolution of 640×480 pixels, allows for evaluation of 70 mm in diameter TL foils.

The new TLD system was applied to support tests of M3 Micro – Multileaf Collimator connected to the linear accelerator Clinac 2300C/D (Varian Medical Systems) with 6 MV X ray beam.

The standard SSD of 100 cm was used for in-water measurements of dose profiles for various field sizes from 30×30 mm down to 6×6 mm regarding the limited size of TL detectors.

The TLD foils, developed as a mixture of highly sensitive LiF:Mg,Cu,P powder and ETFE polymer pressed in sheet of thickness 0.3 mm and constant rectangular size of 50mm side, were placed at the water tank, thanks to PMMA holder.

Measurements were performed for different depths in water, down to 20 cm in 5 mm steps. The dose for single measurement was 4Gy.

2D TLD sheets have been used to determine profile shapes of the beam at the different depths in water with resolution better than 0.5mm. These measurements were compared with 2D profile measurements and the “beam efficiency” assessment conducted simultaneously for the MLC and accelerator arrangement as final acceptance and QA tests with the use of ionization chamber and diamond detector.

We expect this newly developed system to be especially useful in clinical verification of small irregularly shaped fields of diameters below 10 mm.
REFERENCE

Uncertainty estimation in IMRT dosimetry verification: measurements and Monte Carlo simulations

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For IMRT verification, the comparison between calculated dose (treatment planning) and measured dose in terms of absorbed dose to water is the most powerful method. Calibrated ionization chambers are frequently used. For reference conditions the combined relative standard uncertainty amounts to 1-2%. However, if such reference conditions do not apply, the uncertainties will be higher. In particular, when measurements are performed in an IMRT verification measurement a departure from reference conditions will generally occur. In order to characterize the behaviour and the uncertainty of ionization chambers in IMRT verification, a systematic investigation of dose verification was performed.

To provide reproducible conditions, a cylindrical phantom made of a water-equivalent plastic (RW3, PTW, Freiburg) was prepared. Each measurement referred to the center of the phantom. A set of inlets were made such that the reference point of each chamber can be reproducibly located at the center. Three ionization chambers (all from PTW) have been selected: the Farmer chamber (model M30013), the Semiflex type (model M31010), and the Pinpoint chamber (model M31014). Two solid state detectors have also been employed: a diamond detector and a diode. Based on a large number of clinical cases treated with IMRT at the DKFZ in Heidelberg and at the Santa Maria Nuova Hospital of Reggio Emilia, 13 cases have been selected for verification measurements. These cases have been taken to be representative for different aspects such as the variety of tumor sites, complexity of beam arrangements, or step-and-shoot versus dynamic IMRT. The measurements were also simulated by the MC method. Details are given in [1,2].

The underlying concept of assessing the additional uncertainty introduced by the non-reference condition with IMRT is to determine the spread of the dose measurements when using different detectors in different IMRT cases and, at the same time, taking the reference conditions to convert the measured charge into absorbed dose. For this purpose, a cross calibration procedure was introduced. A reference absorbed dose, $\hat{D}_w$ was first determined, which is the dose obtained under reference conditions with a reference ionization chamber (Farmer chamber M30013). A cross calibration factor, $N_{detector}$ was then obtained for each of the five detectors by:

$$N_{detector} = \frac{\hat{D}_w}{M^*_{Farmer}} \left( \frac{M^*_{detector}}{M^*_{Farmer}} \right)$$

where $M^*$ is the measured charge corrected for influence factors such as air density, ion recombination, etc. The absorbed dose in an individual measurement is then obtained by multiplying the measured and corrected charge with the cross calibration factor $N_{detector}$. The uncertainty in this procedure is determined from the uncertainty of $N_{detector}$ (between 0.5% for the Farmer chamber and 1% for the solid state detectors) and the reproducibility uncertainty which was in the order of 0.5%. Since results are given in terms of relative differences between the measurement and the calculation obtained from TPS, the uncertainty in the determination of $\hat{D}_w$ cancels out. Variations larger than about 1% can then be attributed to the influence of the
non-reference conditions. Frequency distributions of relative deviations obtained in this way are shown in Fig. 1.

Non-reference correction factors $c$ defined as in [1,2] have also been obtained by MC calculations. Results are given in Fig. 2.

Main conclusions drawn were: (a) the increment of the relative standard uncertainty in the absorbed dose determination with ionization chambers introduced by the non-reference conditions is in general about 1–1.5%, provided that appropriate chambers are employed, (b) solid state detectors and big active volume chambers are less well suited, (c) the distribution obtained for the $c$ factors confirm the findings with ionization chambers, (d) occasionally larger discrepancies are found. In this case a visual inspection into single beamlet and their positions with respect to the position of the chamber can help to identify possible reasons for discrepancies.

REFERENCES


Multi-segment IMRT verification with a 2D ion chamber array: Dosimetric results

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The two dimensional verification of intensity modulated radiation plans is one of the major requirements for the safe application of this technique. The present study examines the performance of a 2D array seven29 from PTW in combination with the VeriSoft analysis software as a dosimetric verification tool of clinical IMRT fields.

IMRT treatment planning is done with the OTP Oncentra Master Plan treatment planning system, and the modulated photon fields are delivered by Precise Elekta linear accelerator which is equiped with an 80-MLC. The Precise linac uses a fast tuning magnetron [1] and the fluence modulation is created by the multileaf collimator with the so-called multi segment method [2] (also referred to as step-and-shoot delivery) which approximates the continuously modulated optimized fluence of each fixed field direction by a stepwise fluence distribution. This is done by combining a set of small homogeneous field segments of different weights, which are shaped by the MLC.

The dosimetric verification of IMRT treatment plans is performed by applying the phantom substitution method [3] following the field related approach. For this aproach, each single treatment field is transferred separately to a slab verification phantom with the couch, gantry and collimator angles set to 0°. Dose measurements are performed in a plane perpendicular to the central axis using a 2D array seven29 which is a 729 vented plane parallel ion chamber matrix in a plane, providing a maximum field size of 27 cm×27 cm. The chambers are 5 mm×5 mm×4 mm in size, and the center to center spacing is 10 mm.

We use a sandwich setup of water equivalent plates with a stack of 3 cm below and 5 cm above the array. The phantom arrangement is CT scanned with a slice thickness of 2 mm and then imported via DICOM to OTP. A user origin is defined in OTP at the effective measuring point of the central ion chamber of the array, which is located in the middle of the chamber area and 5 mm below the surface of the array. Before performing verification measurements we calibrate the array using a simple calibration field with a known dose to define a calibration factor, which is used for the correction of all later verification measurements. 

First, a number of dosimetric characteristics were investigated: the detector short, medium and long term reproducibility have been tested through an extensive set of repeated measurements, and dose linearity and output factor measurement were assessed. 

Measured in the phantom and computed by OTP, dose distributions are compared using Verisoft which supports the gamma evaluation method of Depuydt, et al. [4] and determines the maximum and average deviation between those two distributions.
The short term reproducibility obtained with the 2D array seven 29 was within 0.3%, and the medium and long term reproducibility were within 1%. The system response to dose was verified to be linear within the range of 4–500 MU and output factor matched very well 31002 type chamber measurements with a maximum difference of 1.2% for field sizes below 4 cm×4 cm.

In the comparison of the array versus treatment planning system, in most evaluated cases the number of pixels where the acceptance criteria (3% dose difference and 3 mm distance to agreement) were reached was 96.5%. The acceptance criteria were not met for points below 20% isodose. After the standarization of the process, the average time required in our Center for the verification with the 2D array of one patient plan is one hour.

The results of our study confirm that the 2D array evaluated is a reliable system and that it is a useful tool for the quality assurance and verification of IMRT radiotherapy plans. The method has proven to provide a fast and effective detection of differences between the computer predicted and measured dose distributions.

REFERENCES


Window-based MU calculator for independent dosimetry check in routine radiation oncology practice

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It is estimated that over one hundred thousand deaths are associated with medical errors each year in the USA alone. Most of these errors are preventable. Calculation errors in medical physics are no exception which are mostly preventable through sound quality assurance programmes [1].

Preventable radiation dosimetry errors in Panama have resulted in numerous deaths [2]. Confirmation of Monitor Unit (MU)/treatment time on a radiation producing machine by a second check forms the backbone of a dosimetry QA programme in any radiation oncology setup.

The existing MU computer programs are either incorporated in treatment planning systems or they are marketed as stand alone programs to double check the calculations. Such programs, though robust in nature, are not affordable for most developing countries because of their cost.

A trend has been evolving to use window based MU calculators for photon and electron dosimetry [3]. A simple window based monitor unit program has been designed and developed using Visual C++ software for independent MU check. The program reads TMR data from a data file. The data file is organized for each scanned field size and depth in a two dimensional matrix. Field size and depth in between the existing data are interpolated by the program. The pull-down menus allow the user to select tray, compensator and wedges, if used. Field sizes, depth and other information are typed in for computation. It has been tested against our existing dosimetry calculation and found within 1\% of hand calculation for different field sizes and depth interpolations.

The computed results may be printed out as hard copy for record. The calculator is easily programmable for a particular radiation machine by tailoring the TMR/PDD data tables and other parameters.

The existing programming platform may be modified for contour based planning system in future. The existing module provides a second check to improve the QA by verifying the computed MU independently.
REFERENCES

www.fda.gov/cdrh/ocd/panamaredexp.html

electron monitor unit calculator using a sector-integration algorithm and exponential curve-
A method for carrying out backup QA calculations on plans produced using modern radiotherapy planning systems

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Radiation therapy treatment planning systems are used to plan treatments for the majority of patients receiving radiation therapy. These systems perform calculations based on measurements initially performed on the radiotherapy equipment and use computer algorithms describing the interaction of radiation with tissue. Computed Tomography scans are often used to provide details of the patient surface topography, anatomy and target volumes. Once an acceptable treatment plan is generated, the systems output the required treatment machine settings for treatment.

Quality assurance of the entire radiation therapy process is essential for quality patient care. With regard to the planning process, it is imperative that the planning system commissioning process establish that the system is acceptably accurate. Periodic checks are also needed to ensure that the systems continue to produce accurate results. In addition, it is necessary to ensure that each plan produced is accurate and that the treatment is given according to the plan. Of paramount importance is the verification of the treatment machine monitor unit or time setting for each field.

Virtually all monitor unit or time calculations are checked, preferably by a second person. However, if the same calculation process is used, or the initial plan is only reviewed for errors, it is easy for mistakes to be missed. It is preferable for two different people to follow two different calculation processes. For modern planning systems, this process is often difficult because the dose calculation details are not evident and the person checking the plan has to resort to verifying the input parameters and reasonableness of the final output. A simple hand calculation can be done, but with the complex plans being produced on modern systems, the manual check is often not sufficiently accurate to catch important mistakes on individual plans. An option is to plan the same treatment on a second planning system but this is generally not viable because of the time needed and the cost of maintaining a second planning system.

As a solution to this issue of providing an acceptably accurate backup calculation we have developed a Microsoft\textsuperscript{\textregistered} Excel based spreadsheet that calculates an independent monitor unit or time setting and compares it to the output from the planning system. The spreadsheet input includes options to enter the shape of the field and inhomogeneity considerations along the ray path to the point of calculation. The correction for the beam shape, as compared to a standard rectangular field, is accomplished by first having the spreadsheet calculate the distance from the dose calculation point to the field edges for eight vectors at 45 degree separations around the point of calculation. When shielding is present the person doing the second calculation enters adjusted values of any of the vectors that encounter a shield or a
skin contour before contacting the field edge. Standard scatter integration techniques [1] are then used to calculate a correction to the monitor unit or time calculation that approximately accounts for the field shape. If there is significant bone or lung along the ray path to the calculation point, the approximate thickness of bone or lung can be entered and a simple tissue-air ratio correction [2] is applied to approximate the effect of inhomogeneity. The spreadsheet also corrects the output for asymmetrical fields and for off axis calculations. The treatment parameters from the planning system (beam energy, field size, treatment distances, wedges, MU etc.) are displayed on the same page as the approximate MU or time values calculated by the spreadsheet. The percentage differences between the planning system MU or time values and the Excel-based results are calculated for reference purposes.

The spreadsheet as described above is routinely used as a second calculation to provide for a check on the output from the main treatment planning system. The MU or time calculation from the main system is used for treatment. The worksheet page is printed out and placed in the chart as evidence of the second calculation.

REFERENCES

QA tests and software tools relevant to the accuracy of treatment planning taking into account inhomogeneity correction in dose computations

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This study considers 3D treatment planning based on CT for conformal photon beam radiotherapy. Factors that cause errors in inhomogeneity correction were investigated. Quality assurance (QA) tests and software tools were determined to verify accuracy in treatment planning process in heterogeneous media. For this purpose only appropriate QA procedures related to the tissue inhomogeneity correction in treatment planning system were described with an assumption that all tests that correspond to other parts of the QA programme of treatment planning process are completed.

The algorithms used in the treatment planning were analysed in detail. A comparison between treatment plans which were carried out by different algorithms was done. The results were discussed from a radiobiological point of view, taking into account the total dose delivered with different treatment schedules. Real clinical cases with various tumour sites and PTVs, respectively, were used in this study.

Treatment plans obtained from different input data for electron density were done. Dependancy of CT integrity in TPS was evaluated in two aspects:

– user-defined electron density versus electron density from CT data
– electron density obtained from incorrect (uncalibrated) CT-ED curves.

QA procedures related to tissue inhomogeneity were described briefly, arranged in three categories according their designation:

1. to calibrate TPS and planning CT with regard to the HU;
2. to evaluate calculated results from a planning system;
3. to carry out periodical checks of planning system under defined and reproducible conditions.

Some of the procedures were considered in detail in order to provide information for recommendations to measurement setups [1].

Special attention was given to “in flow” software QA tests. The independent monitor unit (MU) calculations are beyond the most important of them [2]. For this reason, this paper was aimed to emphasize these aspects in algorithm which are relevant for checking the dose computations in areas with high electron density gradient.

In our QA programme, this test was designed as software tool in MS Excel Worksheet. The treatment stuff should enter a choice of treatment unit, beam energy and treatment setup conditions. Also, the treatment aids, such as blocks and wedges, were taken into account in the calculations.
The tissue inhomogeneity correction was obtained using power law TAR method. This means that the user should enter the depths where the electron density was changed. Also, the user must determine the tissue layer from list of tissues in worksheet and/or directly enter electron density measured with TPS measurement tool in any point from corresponding tissue or an organ.

The relationship between the considered QA procedures was presented as appropriate flowcharts. The algorithm follows steps, when any discrepancy with the tolerance levels are observed. Generalized block scheme is outlined to determine position of described QA procedures within overall QA program.

Analyses of reported results in this study suggest that accurate dose assessment cannot be achieved without taking into account quality assurance relevant to the dose computations in heterogeneous media.

FIG. 1-A,B. The main frames of QA software for independent MU check using inhomogeneity correction. The results for real clinical case are shown in Fig. 1-A (left window). Inhomogeneity correction for lung was done using electron density measured with TPS. Standard deviation was 1.37%. Fig. 1-B (right window) presents fields for inhomogeneity correction and demonstrates messages, when a human mistake caused errors in computations.

REFERENCES

Evaluation of Argus IMRT for routine IMRT QA

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A new method for performing IMRT QA using DynaLog files has been evaluated. A new software product has been developed to provide automated and time saving QA for IMRT. The use of DynaLog files provides for immediate analysis of MLC leaf motions and positions and linac dose rates when compared to imported fluence maps from supported inverse treatment planning systems. With this analysis the need for film has been eliminated and the time spent performing IMRT QA has been greatly shortened.

Dynamic log files (DynaLog) are recorded data of the actual dose fraction and MLC leaf positions versus the expected, taken at 50 ms interval snapshots throughout a dynamic treatment. Argus takes this stored information and compares actual and expected leaf motions, performs statistical analysis, simulates leaf motions, and performs a graphical analysis of individual leaves or gaps. These analyses show which individual leaves failed, where in their travel they failed, and can aid in predicting the failure of the individual MLC motors. Individual leaf analysis compares actual to expected leaf position, actual to expected leaf velocity, and actual to expected gap size to within a tolerance specified by the user.

DMLC Plan Comparison and DMLC Field Comparison are two features which analyse fluence maps. DMLC Plan comparison allows the entire treatment plan to be delivered and analysed, comparing the derived data from the treatment plan to the data from the DynaLogs. Included in the analysis is fluence difference, gamma evaluation, leaf analysis, and gap analysis. Fluence difference is a pixel by pixel subtraction between the fluence calculated based on the actual leaf positions and fluence calculated based on the expected leaf positions. The gamma evaluation follows the algorithm of D. Low, et al., where they describe regions where dose distributions disagree with measurement [1]. However, Argus uses this for fluence analysis rather than dose, still utilizing the 3% and 3 mm tolerances. DMLC Field comparison is useful when analysis of a single field is needed rather than the entire plan. The DMLC Field Verification test is also designed to be a regular MLC test procedure in that it has the ability to graph the results in order to take an in depth look at trends and distributions of motor warnings and failures, fluence differences, gamma differences, and histogram analysis.

The treatment planning system can use the DICOM RT transfer to export fluence maps for import into Argus for Fluence Map Cross-Comparison. Fluence Map Cross-Comparison allows close comparison of fluence maps from the treatment planning system to those produced by the DynaLog files. Up to four of the treatment plan optimal fluence and actual fluence, test DynaLog expected fluence and derived fluence, and reference DynaLog expected fluence and derived fluence can all be compared to one another with an analysis of the fluence difference and gamma evaluation.

Argus provides a unique feature which allows the conversion of the DynaLogs to MLC Shaper files that can be imported into supported treatment planning systems. Once the Shaper MLCs have been imported into a verification plan, they can be converted to actual fluences and the plan can be recalculated using the new information on actual leaf positions and
motions. This verification plan can then be compared to the treatment plan via plan subtraction to obtain the dose difference.

Argus IMRT has provided a streamlined approach to IMRT QA by providing the tools necessary to test, analyse, and report in one thorough and detailed package. By eliminating the need for film analysis, time has been reduced significantly. With IMRT as a mainstream form of treatment, it is important that physicists are not bogged down with excessive testing and paperwork.

REFERENCE

Monitor unit calculation by means of a functional representation of output factors and tissue phantom ratios

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Several attempts to represent basic dosimetric data by analytical functions can be found in the literature. The reasons for such an approach are manifold: denoising measured data, discover outliers, better interpolation between data, reduce the amount of measurements, etc. Xiao, et al. proposed a four parameter representation of the tissue phantom ratio (TPR) as a function of depth \( d \) and field size \( s \). Their fit works well for \( d > 10 \text{ cm} \) and \( s > 10 \text{ cm} \), i.e. in the domain of full electronic equilibrium. It may be useable for smaller fields and shallower depths with less accuracy. Our aim was to achieve a reliable functional representation for \( s \geq 4 \text{ mm} \) and all depth. The data serve as high quality input physics data to a treatment planning system, or for calculating monitor units and dose to any point in water for the full range of \( s \) and \( d \).

TPR were measured in a PTW water tank for an Elekta Synergy S linac, having a MLC with 4 mm leaf width. In order to achieve the parameters for the functional representation of TPR, we employed a two step fitting process. For each field size, TPR was fitted to

\[
\text{TPR} = (D_s + (1 - D_s) (1 - \beta d)) a \exp(- \mu (1 - \eta) d)
\]

The first factor describes the build up, with \( D_s \) being the surface dose and \( \beta \) a build up gradient. \( a \) is a normalization factor, set in order to normalize TPR to 1 at a depth of 100 mm. The exponential, adopted from Xiao et al., describes the declining part of the curve, where \( \mu \) is a pseudo attenuation coefficient and \( \eta \) a beam hardening coefficient.

For the field size dependences of each parameter, the following relations were used:

\[
D_s = \text{const.} = \text{mean}(D_s(s))
\]

For the build up coefficient \( \beta \), an increase up to \( s \approx 40 \text{ mm} \) and a decrease for large fields was observed (see Fig.1, 1. row, 2.column). Therefore the data were fitted to:

\[
\beta = (\beta_{\text{max}} (1 - b^s)) + cs
\]

\( a, \mu \) and \( \eta \) are covariant parameters and all decrease exponentially with field size:

\[
y = y_0 + A_y \exp(-\frac{s}{\gamma_y})
\]

\( y \) stands for \( a, \mu \) and \( \eta \), respectively.

Results for 6MV are shown in Fig. 1. The deviation of measured to calculated TPR data is generally less than 1%. Especially the maximum region and small fields are all well modelled. Only for small fields and large depth and in the vicinity of the surface, some points showed bigger deviations.
FIG. 1. Results of fitting measured 6MV TPR data to Eq. 1. The red lines are the fitting curves according to Eq. 2 to 4. The green symbols are data from a repetition of the measurement.

As for the TPR, also for the output factors (OF) a parameterization working for the full range of field sizes was developed:

\[ D = P n \frac{S^p}{S^n + S^p} + S_\infty \left(1 - e^{-bs}\right) \]  

(5)

where D is the dose at a distance of 1 m in 100 mm depth, P, n, S and b are again fitting parameters.

As shown in Fig. 2, Eq. 5 perfectly describes the field size dependence of the OF. Eq. 1 and 5 together build a framework in order to calculate dose per monitor unit with very high accuracy.

FIG. 2. Output factors measured with different detectors. The red curve represents Eq. 5.

REFERENCES


Can record and verify systems eliminate radiotherapy delivery errors? The Rambam Medical Center experience

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The use of record and verify (R&V) systems in radiotherapy departments has been well known for a long period of time. These tools, originally created for recording and verifying radiation field parameters, have developed into comprehensive systems that now allow for completely paper-less radiotherapy clinics.

In the Radiotherapy Unit at Rambam Medical Center, 190 patients are treated daily (08:00–19:00) with four linear accelerators (linacs). During the last two years, three of our accelerators (ELEKTA Precise, VARIAN 600C and VARIAN 1800)\(^1\) have been connected to the IMPAC MultiAccess system. Because of technology differences between the accelerators, the implementation and connection to the IMPAC system was not identical for the different linacs. However, in all cases, recording and verification of treatment parameters were possible. Twenty palliative patients are treated on a Varian 6-100 machine that was not connected to the IMPAC system because of its old technology and planned replacement.

We also expected that administrative aspects, such as patient’s treatment scheduling, would be improved. The implementation of the system was not meant to replace our “paper” radiotherapy chart but to be used in parallel with it. As a result we expected an increase in the workload of the staff involved in the treatment planning and delivery process.

Until the introduction of the system, the workflow of the patient’s treatment parameters was as follows:

I - Treatment dose is prescribed by the physician and written in the chart

II - Treatment plan is performed (2D or 3D), and all treatment parameters (setup and dosimetry) are defined/calculated by the technologist/physicist or dosimetrist and written in the chart

III - Treatment dosimetric parameters are checked by a senior physicist

IV - Treatment setup parameters are checked by a senior technologist

V - Treatment is delivered and manually recorded.

In the above described process, we can find several weak links that, in a busy clinic like ours and for treatments with constantly increasing complexity, may induce treatment delivery errors. Among the most common errors were: prescriptions that were changed without

\(^1\) From Varian Medical Systems Inc., USA, and Elekta Ltd, UK.
physician approval; setup parameters such as SSD, collimator opening, beam modifiers such as blocks or wedges that were not clearly documented in the chart; mistakes during treatment delivery, such as wrong MU used for the irradiation, and wrong documentation of cumulative daily doses. These are the usual errors often presented in the literature and in public internet sites such as ROSIS [1].

The MultiAccess system requires electronic approval of the data entered to enable treatment delivery. Each of the users (physicians, physicists, technologists, secretaries) has security permissions that allow him/her to add/modify/approve a specific type of information. With implementation of the R&V system, the process had to be changed accordingly. Referring to the already described process the following was modified: data previously written in the paper chart is also entered in the e-chart and electronically approved by the authorized persons. For 3D plans, parameters are transferred directly from the Treatment Planning System. Treatment delivery is automatically recorded in the IMPAC system.

When comparing and analysing the new process, we can show improvement relative to the previous situation. Firstly, if the prescription is modified by an unauthorized person, it is not possible to irradiate the patient. The dose prescription entered by the physician prevents overdosing when trying to irradiate more fractions than the number prescribed. Secondly, treatment parameters approved by a senior physicist can be modified only by an authorized physicist and require approval. In the past, the technologist could change some of the geometrical parameters to compensate for an inaccurate patient setup. This is not possible anymore and requires physician’s and physicist’s intervention. For 3D plans the weak links described previously were resolved, while human errors are still present for 2D plans. Since 2D plans are becoming less common, can we say that this type of R&V system eliminates all errors? Unfortunately, the answer is NO, as new weak links have appeared.

When people work with computer driven systems, they tend to rely on them almost blindly. As a result, they will not criticize data appearing on the screen, preventing them from finding mistakes. Even more, especially for the advanced accelerators where data is directly transferred by the R&V system, a patient identification problem may arise when trying to speed the treatment process to accommodate more patients in the machine schedule.

In conclusion, our experience demonstrates that the R&V system allowed us to improve our QC process, reducing some common errors, but its implementation requires a change of attitude by the staff with respect to the treatment delivery process.

REFERENCE

In vivo dosimetry with silicon diodes for Co-60 beams

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A systematic characterization of semiconductor detectors for entrance dose (ED) measurements was initiated in order to implement in vivo dosimetry as a part of quality assurance (QA) programme for external beam radiotherapy in our department. The DPD-3 Scanditronix basic unit with three p-type silicon diodes EDE-5, designed for Co-60 beams, and calibrated Farmer type ionization chamber connected to a Unidos PTW electrometer were used.

Prior to calibration, diodes were checked for: reproducibility, stability of the signal and linearity [1]. The signal stability 5 min after irradiation was less than 0.5%, reproducibility within 0.5% and leakage negligible. Calibration is performed once per month for each diode under the reference conditions (10×10 cm$^2$ field size at isocenter, SSD = 80 cm, gantry angle (0°) using the white polystyrene phantom (RW3). The irradiation time is calculated by the treatment planning system (TPS, TheraplanPlus) to give 100 cGy at $d_{max}$. Calibration factors are then given by:

$$N_{cal} = \frac{D}{M \cdot k_{pl}} \left( \frac{SSD - d_s}{SSD + d_{max}} \right)^{-2}$$

where

- $D$ - represents dose measured by the ionization chamber placed at the reference depth (5 cm),
- $M$ - is signal from the diode placed at phantom surface,
- $k_{pl}$ - is plastic to water correction factor,
- $d_s$ - is effective distance of a diode centre to the surface of the phantom, and
- $PDD$ - is percent depth dose used to give dose at $d_{max}$ in the phantom [2,3].

A small 3 mm thick Styrofoam plate was put under the diode to prevent heating of diodes from the patient's skin in clinical studies. The same approach was applied to all correction factors and Alderson phantom measurements. Different correction factors were determined to compensate for non-reference conditions during the actual patient treatment: angle of beam incidence, SSD, field size, wedges, block and tray. Corrections less than 1% were neglected in further measurements. In addition, the diode perturbation of radiation field was measured to be about 3% at 10 cm depth on the central axis of the beam. The diode dose rate dependence was investigated as a comparison of the calibration factors at reference and extended SSD.

Entrance dose measurements were done on Alderson phantom for pelvic and head and neck localization. The CT scans of Alderson phantom were used for planning purpose. A three field arrangement with and without wedges for pelvis and two parallel-opposed fields with and without thermoplastic mask for head and neck treatments were investigated. Percentage differences between expected entrance dose, calculated either manually or with TPS, and measured dose were below 3%, which was satisfactory for commencing with patient in vivo dosimetry.
Patient measurements are performed for all localizations treated in the department, preferably in the first three fractions of the treatment. During the initial period of patient in vivo dosimetry, a total number of 293 fields were checked (Fig. 1). The mean percentage deviations (%Δ) between measured and expected (TPS) dose, for three particular sites, were +0.9% with 1.8% standard deviation (SD) for 87 pelvic fields, +1.0% (2.3% SD) for 66 head and neck fields and -1.8% (2.8% SD) for 37 breast fields. Diode measurements detected nine (9) cases where mean percentage deviation was larger than 5% among which the largest were due to the missing wedge, block not included in time calculation and wrong SSD.

The use of diodes to verify the radiation treatment delivery is effective and important step in implementation of a QA programme in a small radiotherapy department particularly when a record and verify system is not in place. Implementation of the optically stimulated luminescent (OSL) detectors for in vivo dosimetry in clinical radiotherapy is planned for future investigations. This should include measurements of physical properties, correction factors for non-reference conditions, evaluation of the build-up caps and eventually patient studies.

ACKNOWLEDGEMENT

This work has been supported by the IAEA under the Contract No. CRO-13115 under the coordinated research project CRP E2.40.14 on “Development of procedures for in vivo dosimetry in radiotherapy”.

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In vivo entrance dose measurements with TLD in pelvis and head and neck cancer treatment in radiotherapy

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The aim of this work is to implement an in vivo dosimetry programme in pelvis and head&neck radiotherapeutic patients treated in Co-60 or linac units in the National Cancer Institute, Brazil using chip thermoluminescent dosimeters (LiF:Mg;Ti). It is a part of an IAEA coordinated research project CRP E2.40.14 on “Development of procedures for in vivo dosimetry in radiotherapy”.

All irradiations were take on a plastic water phantom. The irradiation time was determined from the Co-60 source decay to deliver 100 cGy. The dose delivered to the ionization chamber followed the IAEA TRS-398 [2].

The first step has been the determination of the TLDs characteristics: non-linearity, energy, fading, angle, SSD, field size, tray and wedge dependencies [1]. Before their calibration, the TLDs have been irradiated in a Co-60 beam in five cycles of annealing and irradiation (100 cGy each) without reading their results. The annealing cycle performed was 400ºC/1 h plus 100ºC/2 h and, 12 hours later, the chips were ready to be used [3].

Non-linearity dose response correction factor (Fig. 1) is defined as the ratio of the detector response per unit dose measured at the reference dose to the detector response per unit dose measured at the different doses. For energy dependence, pairs were irradiated in \textsuperscript{60}Co and 6 MV energies. The reference calibration was normalized in regard to the \textsuperscript{60}Co energy.

For the angular incidence correction (Fig. 2), TLD pairs were irradiated with gantry moving from –60º to +60º. Figs 3 and 4 show the curves for the field size corrections.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1}
\caption{Non-linearity dose response correction.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig2}
\caption{Angular dependency.}
\end{figure}
The next step was making measurements in a RANDO Alderson anthropomorphic phantom, with the TLDs under an aluminum (for $^{60}$Co) or stainless steel (for higher energies) build-up cap. The calibration factor carried out the plastic to water correction and the effective distance of the centre of two TLD to the phantom surface.

The expected dose was calculated using the ECLIPSE treatment planning system considering the calculation point at the depth of maximum dose.

For phantom and patient measurements the ‘entrance dose’ (D) is defined as the dose at the depth of maximum dose. From the TLD reading it is calculated by:

$$ D = M \cdot N_{\text{cal}} \cdot (SSD - d_s / SSD + d_{\text{max}})^2 \cdot k_{\text{engy}} \cdot k_{\text{lin}} \cdot k_{\text{ang}} \cdot k_{\text{SSD}} \cdot k_{\text{wedge}} \cdot k_{\text{field}} \cdot k_{\text{chip}} $$

After validation using the RANDO Alderson phantom, we performed in vivo measurements in 19 $^{60}$Co treatment fields (nine patients). Fig. 5 shows the results of all in vivo measurements which were within the acceptable tolerance limit of ±5%.

**REFERENCES**


In vivo dosimetry in HDR brachytherapy of prostate cancer - Preliminary results

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Purpose. To evaluate the use of the MOSFET detectors for in vivo measurement of the dose delivered to the rectum during prostate HDR treatment.

Calibration procedure. The rectal probes composed of three MOSFET detectors (model TN-502 RD and TN-502 RDM) were used for measurements. The individual calibration for each detector was done in a water phantom in Co-60 beam and with $^{192}$Ir source.

Phantom measurements. Phantom measurements with the rectal probe were performed in a wax phantom using interstitial applicators. The treatment plan based on AP and LP radiographs taken with rtg mobile C-arm was prepared with Abacus TPS. Irradiation was done with $^{192}$Ir source using HDR Gammamed Plus unit. The measurement values were compared to the TPS calculations.

Patients studies. Between October 2003 and October 2005, comparison for Mosfet measurements and the inner rectum wall dose calculated in TSP were done for 192 measurements for 45 patients during 64 treatment fractions.

The comparison for Mosfet measurements and post clinical Mosfet dose TPS evaluation were done additionally for 78 measurements for 16 patients during 26 treatment fractions.

Patient studies were performed according to the following procedure:

1. Application of the rectal probe
2. AP and LP fluoroscopy
3. Dose measurement during the treatment
   3.1. Comparison between the doses measured by detector and calculated in TPS for inner rectum wall
   3.2. Reconstruction of the Mosfet position based on AP and LP fluoroscopy
       3.2.2. Dose calculation for Mosfet detector points according to the treatment plan
       3.2.3. Comparison between the dose measured by detector and dose calculated in TPS.

Result. The measured dose $D_m$ was smaller then the inner rectum wall dose calculated in TPS $D_{TPS}$ in all cases.
FIG. 3. The percentage differences between the measured dose in the rectum and the TPS calculated dose for inner part of rectum wall. Total number of readings equals 182.

Differences between the doses measured by Mosfet detectors and calculated in TPS can be caused by the

- extraction of the ultrasound probe from the rectum what causes increase of the distance between the basal needles and the rectal wall
- possibility of the prostate and the rectum movements
- uncertainty of the real geometry and the TPS reconstruction accuracy
- uncertainty of measurement: very high gradient causes uncertainty of measurement growing very fast with the increase in detector-source distance.

**Conclusions.** Mosfet detectors and the methodology are a useful tool to determine the dose received by the rectum during prostate HDR treatment.

In vivo dosimetry with Mosfets can be used in clinical applications to measure the dose received by critical organs as a standard technique and improvement of the safety of HDR brachytherapy application.

This work was done under the framework of the IAEA CRP on “Development of procedures for in vivo dosimetry in radiotherapy”, Research Project No. POL-13117 on “Using Mosfet detectors for in vivo dosimetry in HDR brachytherapy”.

FIG. 4. The percentage differences between the measured dose in the rectum and the post-clinical calculated values for Mosfet positions. Total number of readings equals 76.
Development of TLD procedure for in vivo dosimetry for photon beams in radiotherapy

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A TLD based in vivo dosimetry system was tested for the measurements of the entrance dose for radiotherapy with high energy photon beams. Prior to the measurements on patients, a rigorous procedure for the TLD calibration was conducted including the determination of several correction factors related to different beam and set-up parameters. These account for the changes in the field size, distance from source to skin, the angle of beam incidence, the wedge angle for wedged beams, and for the presence of a block and tray in the beam. Before the measurements on patients started, in vivo dosimetry tests were conducted using a Rando Alderson phantom.

TLD chips were used in this study. To initiate the chip selection process, new chips were irradiated and annealed without reading five times. The reproducibility measurements were conducted next. TLD chips were laid side by side in a plastic tray, irradiated and read out. The beam uniformity over the chip irradiation area was within 0.3%. This process was repeated three times. The chips showing a difference between the maximum and minimum measurement of the individual chip factor exceeding 3% were rejected.

The batch calibration factor, $N_{\text{cal}}$, for the selected TLD chips was derived. Ten chips were selected from the batch at random and irradiated on a solid phantom using build-up caps. Individual chip correction factors, $K_{\text{chip}}$, relative to the batch calibration were derived.

TLD fading correction factor, $K_{\text{fad}}$, was determined by irradiating the chips to 100 cGy in a $^{60}$Co beam and reading them out after 30 minutes, 4 hours, 1, 2, 3, 4, 5 and 7 days.

For the angle of incidence correction, $K_{\text{ang}}$, the chips with build-up cap were placed on the surface of the plastic phantom with the TLD at the isocentre and irradiated to 100 cGy at $d_{\text{max}}$ with the gantry at $\pm 60^\circ$, $\pm 45^\circ$, $\pm 30^\circ$, $\pm 15^\circ$, 0$^\circ$. All results differed by not more than 1% from the reference measurements.

For the SSD correction, $K_{\text{SSD}}$, measurements were performed at different SSDs of 70, 80, 90, 100 and 110 cm with a fixed collimator opening, the same as for the reference conditions. The dose was $D_0 = 100$ cGy at $d_{\text{max}}$, for each SSD, the same as for the calibration conditions.

Field size correction, $K_{\text{field}}$, was measured for the following fields: 6×6 cm$^2$, 8×8 cm$^2$, 15×15 cm$^2$, 20×20 cm$^2$, and 25×25 cm$^2$.

For the non-linearity dose response correction, $K_{\text{lin}}$, TLD chips were placed on the surface of the plastic phantom as for the calibration. The following doses were delivered to the TLD...
chips: 20, 50, 100, 150, 200, 300, 400 cGy. The non-linearity dose response correction factor was determined as: 

\[ K_{\text{lin}} = (1 + 0.0278 D - 0.000265 D^2)^{-1}. \]

Wedge correction factor, \( K_{\text{wedge}} \), was measured for 6×6 cm\(^2\), 8×8 cm\(^2\), 10×10 cm\(^2\) for 30°, 45° and 60° wedges. The results were within 1.0%. The block and tray correction measurements were performed similarly as for the wedge factors.

The dose is calculated from the TLD reading using the following formula:

\[ D = M \cdot N_{\text{cat}} \cdot \left(\frac{SSD - d}{SSD + d_{\text{max}}}\right)^2 \cdot K_{\text{energ}} \cdot K_{\text{lin}} \cdot K_{\text{ang}} \cdot K_{\text{SSD}} \cdot K_{\text{wedge}} \cdot K_{\text{field}} \cdot K_{\text{fad}} \cdot K_{\text{TLD}} \]

Two series of entrance dose measurements were performed on a Rando phantom, for pelvis and head and neck treatment. The pelvis measurements were done for a three-beam arrangement, anterior and two opposing lateral fields, with and without the wedge, for one beam at a time. Head and neck measurements were conducted for two parallel-opposed fields with and without the immobilization mask. The results are shown in Tables 1 and 2.

### TABLE 1. PERCENTAGE DIFFERENCE BETWEEN THE MEASURED AND CALCULATED (TPS) ENTRANCE DOSE FOR THE ANTERIOR-POSTERIOR (AP), RIGHT LATERAL (RL) AND LEFT LATERAL (LL) FIELDS AND RL\(_{\text{wedge}}\) AND LL\(_{\text{wedge}}\) WITH WEDGE 45° FOR THE PELVIS EXERCISE USING A RANDO PHANTOM

<table>
<thead>
<tr>
<th>Field type</th>
<th>Field size (cm×cm)</th>
<th>DTLD (cGy)</th>
<th>DTPS (cGy)</th>
<th>Dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL</td>
<td>10×10</td>
<td>96.81</td>
<td>98.2</td>
<td>1.4</td>
</tr>
<tr>
<td>LL</td>
<td>10×10</td>
<td>90.96</td>
<td>90.8</td>
<td>-0.2</td>
</tr>
<tr>
<td>AP</td>
<td>20×20</td>
<td>74.62</td>
<td>72.45</td>
<td>-3.0</td>
</tr>
<tr>
<td>LL-w</td>
<td>10×10</td>
<td>93.37</td>
<td>94.26</td>
<td>1.0</td>
</tr>
<tr>
<td>RL-w</td>
<td>10×10</td>
<td>105.75</td>
<td>101.8</td>
<td>-3.7</td>
</tr>
</tbody>
</table>

### TABLE 2. PERCENTAGE DIFFERENCE BETWEEN THE MEASURED AND CALCULATED (TPS) ENTRANCE DOSE FOR RL AND LL, RL-M AND LL-M FOR HEAD AND NECK EXERCISE USING A RANDO PHANTOM WITH AND WITHOUT A MASK

<table>
<thead>
<tr>
<th>Field type</th>
<th>Field size (cm×cm)</th>
<th>DTLD (cGy)</th>
<th>DTPS (cGy)</th>
<th>Dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL</td>
<td>6×6</td>
<td>127.21</td>
<td>127.60</td>
<td>0.3</td>
</tr>
<tr>
<td>LL</td>
<td>6×6</td>
<td>129.45</td>
<td>127.60</td>
<td>-1.4</td>
</tr>
<tr>
<td>LL-m</td>
<td>6×6</td>
<td>129.21</td>
<td>127.60</td>
<td>-1.3</td>
</tr>
<tr>
<td>RL-m</td>
<td>6×6</td>
<td>128.52</td>
<td>127.60</td>
<td>-0.7</td>
</tr>
</tbody>
</table>

The results of the Rando phantom exercises are mostly within 3% of the percentage difference between the measured and calculated (TPS) entrance dose. One measurement of a wedged beam for the pelvis case had a higher deviation. This is attributed to the uncertainty in the TLD positioning relative to the wedge.

**REFERENCE**

Comparison of performance and development of the home made phantom for evaluating the characteristics of the standard MOSFET and microMOSFET

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Purpose

To compare the dosimetric performance and develop the home made phantom which evaluates the characteristics of a standard MOSFET in comparison with a microMOSFET.

Method and materials

We developed the phantoms to perform a calibration and to analyse characteristics of standard MOSFET and microMOSFET dosimeters (Figs 1, 2). The phantoms are made of polystyrene (\(\rho = 1.05\)), which have the shape of semi-sphere with 10 cm diameters and flat slab of 30\(\times\)30 cm\(^2\) with 1 cm thickness. The flat slab phantom was used for calibration and characterization measurements such as reproducibility, linearity and dose rate dependency.

\textbf{FIG. 1.} The flatten slab phantom. The phantom was used for calibration and characterization measurements such as reproducibility, linearity and dose rate dependence of standard MOSFET and microMOSFET dosimeter.

\textbf{FIG. 2.} Semi-sphere phantom used for measurement of the angular and directional dependence.
The semi-sphere phantom was used for angular and directional dependence on the types of MOSFETs. The measurements were conducted at a depth of 1.5 cm under 10×10 cm$^2$ fields at 100 cm SSD for reproducibility, linearity, and dose rate dependence. For calibration and reproducibility measurement, five standard MOSFET and microMOSFETs were repeatedly exposed to 200 cGy three times. Doses ranging from 10 to 600 cGy were measured to evaluate linearity. The effect of dose rate was measured in exposure of 200 cGy varied from 100 to 600 MU/min. For angular and direction dependence, the measurements were performed between 0° and 90° gantry angles, while MOSFETs were placed at the center of semi-sphere phantom. The 50 cGy was irradiated repeatedly three times under the same setup.

**Results**

The average calibration factor was 1.10±0.95 for standard MOSFETs and 1.09±0.50 for microMOSFETs. The response of reproducibility in the two types of MOSFETs was found to be at the maximum 0.5% variation. The linearity showed good linear response with $R^2$ value of 0.997 and 0.999 relative to increase of irradiation dose. The effect of dose rate was not observed by changing the dose rate between 100 and 600 MU/min. The directional dependence was found to be within ±2% and ±8% to standard MOSFET and microMOSFET. The angular dependence was also found to be within ±5% and ±8%.

**Conclusion**

Standard MOSFET and microMOSFET were compared by the dosimetric characteristics with the home made phantom. For linearity, reproducibility and calibration factor, two types of MOSFETs showed similar results. On the other hand, standard MOSFET and microMOSFET were found to be remarkably difference in their detection area size in angular and directional dependence. Therefore, the microMOSFET can be used as a better in vivo dosimeter to verify the dose delivered to patient than the standard MOSFET.
Session 8b:

Radiation Imaging

BONE DENSITOMETRY AND DOSIMETRY
Quantitative measurements of body composition: State of the art and QA processes

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The human body is composed of fat, water, mineral, and protein, and body composition is an important indicator of health. Most reporting of body composition in the lay press and with respect to health guidelines have used Body Mass Index (BMI), the ratio of body mass to height squared, as a simple measure of fattiness. A BMI of 25 kg/m$^2$ is considered overweight.

This measure is simple yet flawed since it doesn’t take into account individuals with very high lean mass for their height and misclassifies them as obese. Other very simple techniques include skin fold analysis that assesses the thickness of subcutaneous fat at specific sites. Although practical, economical, and administratively feasible, the models are specific to body shape and may differ by ethnicity and age. Underwater weighing is also accessible to all with a water tank and a scale, and used to calculate the proportion of body weight that is fat and lean mass if the compartment densities are assumed to be constant. Anthropomorphy and underwater weighing are examples of two compartment models. However, more sophisticated models of three (DXA), four or more compartments (combinational methods) are available. In addition to fat, these models include direct measures of whole body bone mass, total body water, and water-free lean body mass and will be described in this paper.

The purpose of a quality assurance program in body composition measures is to assure that the resulting data is accurate and precise while the purpose of a quality control programme is to correct the data if inaccuracies are found. Accuracy can be absolute in terms of international standards or relative to a reference population or baseline measurements.

In general, absolute accuracy is beyond the scope of most research projects and clinics and not part of the QA/QC process. However an assurance programme for relative accuracy is essential and more easily obtainable. Baseline accuracy is established through comparative studies with like devices and stable test objects or phantoms. Measurements of phantoms over time as well as continuing education assure longitudinal accuracy. If inaccuracies are found, the biggest challenge is how to correct the data using phantom measures.

Precision measures are important for showing the least significant change between time points of measure and are largely affected by the expertise of the person acquiring the measure and analysing the result. We will discuss the strengths and shortcomings of current phantoms being used for QC.

A large multisite clinical trial to quantify the normal whole body % FAT across the entire US population as measured by Dual X ray Absorptiometry is presented as an example. The National Health and Nutrition Examination Survey (NHANES) has obtained over 22,000 unique whole body DXA measures over a six year period across the US. Three Hologic DXA systems were transported around the country stopping at new locations every eight weeks.
single set of cross calibration phantoms was circulated and scanned at each new location as well as semi-daily scans of system-specific whole body phantoms. We present the details and outcome of this large quality assurance and quality control programme, as well as examples from other trials using bioimpedance, and stable isotope measures, to act as templates for other investigators.
Bone mineral density (BMD) composite index scores developed from bone densitometry (DXA and QCT) simplifies correlative and predictive analyses in adolescent’s bone health

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Introduction and aim

Adolescence is a critical period to accumulate 50–70\% of adult’s bone mass. Hence, precise bone mass determination is important to monitor BMD development among adolescents in health and disease. It is uncertain at which skeletal site BMD is best predicted by bone-mass determinants. Besides, BMD measured at different sites of an individual can be condensed into a composite-index-score to simplify correlation, outcome prediction and data interpretation. This study describes the development of BMD composite index scores (BMD-CISs) to correlate with bone growth determinants in adolescents.

Subjects and methods

BMD measurements using DXA: Norland-XR36 (spine, femoral-neck, trochanter & Ward’s triangle) and pQCT: Denisiscan-2000 (distal-radius and tibia) were obtained from 101 healthy girls aged 12–15 years to develop the BMD-CISs. Adolescent bone growth predictors (weight, height, pubertal-status, weight-bearing physical-exercise and bone-turnover markers) were evaluated to correlate with BMD-CISs.

Factor and principle-component analyses were used to examine the internal structure of 11 BMD skeletal sites and variables, and to create new BMD-CISs which summarize the characteristics of parent BMD-variables. Correlations between the BMD-CISs and parent BMD variables were performed. Univariate and multivariate analysis were performed to associate BMD-CISs with bone growth predictors for examining the strength of correlations and predictions when compared with the original BMD variables.

Results

Two independent DXA-generated BMD-CIS and pQCT-generated BMD-CIS were obtained to summarize the 11 original BMD variables. Each BMD-CIS correlated highly with respective DXA or pQCT variable (r=0.32–0.92; P<0.05 – P<0.001). DXA generated BMD-CIS (r=0.24 – 0.73; P<0.05–P<0.001) and pQCT-generated BMD-CIS (r=0.24–0.39; P<0.05–P<0.001) were significantly correlated with most bone growth predictors. In multiple regression analysis, R-square of DXA-BMD-CIS (66.4\% vs. 36.3\%–66.1\%) and pQCT-BMD-CIS (25.1\% vs. 12.2\%–42.2\%) have similar predicting values when compared with parent BMD variables demonstrated that the two new BMD-CISs summarized well the
characteristics of the parent BMD variables. Furthermore, areal spinal BMD (by DXA) and volumetric tibial integral BMD (by pQCT) were the BMD sites better predicted by bone-mass determinants (R-squares 0.6-0.8) in multiple regression analysis.

Discussion and conclusions

The newly developed BMD-CISs correlated well with original variables and have similar predicting powers when compared with the original BMD variables. The use of BMD-CISs would reduce workload of data analysis and simplify correlation and comparisons between multiple BMD measurements and other predicting variables. Identification of 1–2 skeletal sites better associated with health predictive variables could help reduce the number of skeletal sites for BMD measurement, thus, reducing subject’s exposure to unnecessary X ray irradiation.

REFERENCES

IAEA code of practice for dosimetry in diagnostic radiology

F. Pernicka\textsuperscript{a,1}, G. Alm Carlsson\textsuperscript{b}, D.R. Dance\textsuperscript{c}, L.A. DeWerd\textsuperscript{d}, H.-M. Kramer\textsuperscript{e}, D.I. McLean\textsuperscript{a}, K.-H. Ng\textsuperscript{f}, P. Ortiz-Lopez\textsuperscript{a}

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Radiologists constantly face the dilemma of trying to minimize patients’ exposure whenever possible, while still using exposures that are high enough to produce images of good quality to be able to provide proper diagnosis. Quality assurance provides a framework for achieving this goal. Among the other activities like image quality assessment, film reject analysis and measurements of physical parameters of radiation generators, it also involves evaluation of patient doses. Various international documents on safety of medical exposures \cite{1,2} require that diagnostic reference levels (guidance levels) be established to provide guidance on what is achievable with current good practice. This again requires extensive dose measurements.

Several practical dosimetric quantities have been found useful for measurements in X ray diagnostic radiology. However, ambiguity exists in names of quantities and their use. The situation indicated the need for harmonization of dosimetric approaches in diagnostic radiology. This was recognized by the International Commission on Radiation Units and Measurements (ICRU) and the International Atomic Energy Commission (IAEA) who started the development of guidance documents \cite{3}. The ICRU report \cite{4} proposes a harmonized system of quantities and units, including terminology, for patient dosimetry in medical imaging using X rays, and provides information on methods of assessing the patient dose and methods of determining organ and tissue doses.

The International Atomic Energy Agency (IAEA) has been developing an International Code of Practice for dosimetry in X ray diagnostic radiology. The main objective of the Code of Practice is to help achieve and maintain a high level of quality in dosimetry, improve the implementation of traceable standards at the national level, and ensure control of radiation dose in X ray medical imaging worldwide. Compared to the ICRU report, the Code of Practice puts more emphasis on the practical aspects of calibrations at SSDLs and measurements in clinics.

The Code of Practice gives an extensive advice on clinical dosimetry in general radiography, fluoroscopy, mammography, CT and dental radiography. As far as possible, the methods described are based on well established techniques, but opportunity has been taken to introduce recent developments where this seemed appropriate. For each modality, the

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procedures for phantom measurements are described first followed by the procedures for measurements on patients. In each case the description of the method is preceded by a background discussion describing dosimetric quantities and the equipment used. An analysis of experimental uncertainties, worked examples and worksheets are provided for each modality. Users of the worked examples, worksheets and analysis of uncertainties should be aware that they require adaptation to local needs.

The need for high quality measurements in diagnostic radiology requires that high quality calibration services be provided by SSDLs. The Code of Practice discusses the equipment necessary for the SSDL to perform calibrations for diagnostic dosimeters and X ray tube voltage measuring instruments and gives details of the calibration set-up. A generalized protocol in a form of a checklist provides clear basic information on steps to be followed when calibrating the user’s instrument. It is followed by description of procedures preceding calibration, procedures to follow during calibration and procedures following calibration. These include an analysis of the calibration uncertainty and preparation of the calibration certificate. Special attention is paid to calibration of CT ionization chambers, the air kerma-area product meters and X ray tube voltage measuring instruments.

The main sections of the Code of Practice are followed by appendices. Some of them give an advice on specific procedures used throughout the document. These include the general advice on an uncertainty treatment, half-value layer measurements, procedure for calibration of X ray tube measuring instruments and field calibrations of diagnostic dosimeters, air kerma-area product meters and thermoluminescence dosimeters. Other appendices provide useful background material to the text in specific sections.

The Code of Practice went through a comprehensive two stage critical review process that involved about 40 international reviewers including representatives of manufacturers of dosimetry equipment. The document has been submitted to the IAEA Publications Committee and its publication is expected soon.

REFERENCES


A tandem calibration method for kerma-area product meters

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The kerma-area product (KAP) of an X ray beam is the surface integral of air kerma over a plane perpendicular to the beam. The quantity is commonly used in diagnostic radiology to evaluate radiation exposure to patients. It can be measured, closely according to definition, using a KAP meter with a transmission ionization chamber. To achieve adequate accuracy in measurements, appropriate calibration of the KAP meter is needed.

An uncertainty of lower than 7% (with a coverage factor \( k = 2 \)) is pursued in air kerma measurements in diagnostic X ray beams [1,2]. The same level of accuracy can be seen as a challenging goal also for KAP measurements [2]. According to international standard IEC 60580 [3] a combined standard uncertainty of 25% \( (k = 2) \) should not be exceeded in KAP measurements. The aim of this study was to investigate whether better accuracy can be achieved by improving the calibration procedures for KAP meters.

The KAP meter should indicate the kerma-area product of the X ray beam delivered through the chamber to the patient [3]. It is also generally recommended [2] that calibration of a KAP meter of an X ray equipment (field KAP meter) should be performed using the actual X ray stand and irradiation geometry, mainly because of the characteristics of extra focal and stray radiation specific to the X ray equipment. A portable KAP meter can also be calibrated in a calibration laboratory but the effects of extra focal and stray radiation should be tested separately with the X ray equipment in which the KAP meter is used.

In calibrations on user’s site the KAP reference value is usually determined by approximating the surface integral by the product of the X ray field area and the air kerma measured in the centre of the field [4]. This beam area method works well in uniform, sharp-edged X ray fields. Non-uniformities and irregularities of the field may cause distorted dependence on field size to the determined calibration coefficients. Another important source of uncertainty is the measurement of field size [5]. The accuracy of calibration can be improved by measuring the reference KAP value as an integral according the definition. Larsson, et al. [5] have used TLDs to measure this surface integral.

In this work a tandem calibration method was introduced in which the reference KAP value is measured using a KAP meter. In this approach the reference KAP chamber is placed in the X ray beam simultaneously with the field KAP chamber, using a distance of 30 cm between the chambers. The reference KAP meter has to be calibrated for the incident beam. In tandem method the measurement distance is not critical and field area measurements are not needed. As the reference KAP value is based on the measurement of the surface integral, the non-uniformities of the X ray field are inherently included. Because of remarkable dependence of the response on energy, the main uncertainties arise from the interpolation of the calibration coefficient of the reference KAP meter between X ray beam qualities.

For tandem method, preliminary results indicate that uncertainty of 5% or lower could be achieved in the calibration of a field KAP meter. However, to achieve this level of accuracy, a comprehensive calibration of the reference KAP meter is required. Independent of calibration
methods, the aim of 7% uncertainty in patient measurements is possible to achieve only in limited conditions of use and (or) by instruments of improved quality.

This work has a contribution to the IAEA Coordinated Research Project for Testing of the Implementation of the IAEA Code of Practice on Dosimetry in X ray Diagnostic Radiology.

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A proper method of kerma-length product measurement during QC procedures in panoramic radiography

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As a relevant dose descriptor in panoramic radiography, product of kerma and length $P_{KL}$ is used. The introduction of $P_{KL}$ was recommended by NRPB [1]. Anyway, NRPB termed this quantity dose-width product (DWP), the name product of kerma and length comes from a new dosimetry formalism being developed by IAEA and ICRU. The product of kerma and length in panoramic radiography is an integral of kerma profile created at a front side of the secondary collimator along a line perpendicular to the collimator. The $P_{KL}$ should be measured at a place of maximum intensity of the beam with respect to vertical direction. The signal is integrated over the whole exposure cycle as well. Currently, no dose descriptor in panoramic radiography is measured in the Czech Republic during the QC measurements. Therefore the measurement of $P_{KL}$ should be included in QC procedures as well.

A pilot study using three different methods [1,2] of $P_{KL}$ measurement is being done in the Czech Republic since 2005. The measurements are performed by an X ray film attached to the front side of a secondary collimator, by a column of thermoluminescent detectors (TLDs) and pencil ionization chamber placed perpendicular to the secondary collimator. The results obtained through the mentioned methods agree within 10% generally.

The film based method has a significant disadvantage. Air kerma in a profile maximum reaches values up to 30 mGy. Standard X ray films have no dosimetric properties for such a high dose, because the response lies in a region of plateau at a characteristic curve of the film. Therefore, a primary collimator has to be covered by a shielding material. It increases energy dependence of the detection system naturally. An advantage of the film based method is knowledge of a complete kerma distribution within an X ray field. This information is used for proper positioning of a CT pencil ionization chamber or a stack of TLDs within an X ray beam. In the study, monochromatic films Foma Medix XBU (18×24 cm) and a attenuating filter with thickness of 1 mm Cu were used. For film scanning, a laser scanner Lumisys LS50 was used, with scanning resolution 0.2 mm. Before each measurement, the scanner was calibrated by a PTW calibration film in a range of optical densities 0.08÷3.4.

The simplest and the fastest method is the pencil ionization chamber method. Pencil ionization chambers designed for CT dosimetry were used in the study, especially a type 10X5-3CT with an electrometer Radcal 9015 and a type CT 77336 with an electrometer PTW Nomex 7723. Dependent on a way of calibration of a relevant chamber and an electrometer, a quantity indicated by the electrometer is either integral of kerma profile along a chamber length (Nomex system), which is the required $P_{KL}$, or just air kerma (Radcal system). In the latter case, indicated air kerma is multiplied by a chamber effective length. Calibration factor of the chambers was verified for beam qualities relevant to panoramic radiography, which are different from those in CT. For a beam quality 50 kV, total filtration 1 mm Al and effective energy $E_{ef}$ 22.7 keV, there was only a 5% difference in calibration factor according to CT energy range.
For the TLD measurements, a column of 30 sintered pellets of LiF:Mg, Ti was used. Total length of the TLD column is 27 mm, which is a sufficient length to cover a useful part of the kerma profile. A manual TLD reader Harshaw 4500 was used for the readout of detectors. For routine measurements of several exposure settings at a given X ray unit, TLDs are not appropriate because of time consuming preparation and readout of the dosemeters.

The TLD and X ray film systems were calibrated using a reference X ray machine Planmeca Intra in a national reference laboratory for X ray dosimetry. Beam quality for calibration was 70 kV, total filtration 2,2 mm Al, E_{eff} 31 keV.

It seems to be most user-friendly and appropriate to measure P_{KL} by means of pencil ionization chamber, for which the calibration factor will be verified for beam qualities relevant to panoramic radiography. A radiographic film should be used simultaneously for determining of a chamber position for the measurement. It is desirable to include a measurement of P_{KL} in standard QC procedures for dental panoramic X ray units. A pilot dose survey performed by the National Radiation Protection Institute has already been started in October 2005. A national diagnostic reference level will be assessed after collection and evaluation of a sufficient amount of data and relevant recommendation for the P_{KL} measurement will be given. Preliminary results of P_{KL} for an adult male examination measured at five workplaces are shown in Table 1.

**TABLE 1: SUMMARY OF RESULTS OBTAINED BY TLD, FILM AND CT CHAMBER MEASUREMENTS**

<table>
<thead>
<tr>
<th>Type of X ray unit</th>
<th>Exposure parameters</th>
<th>P_{KL} (mGy.mm)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U (kV)</td>
<td>I (mA)</td>
<td>t_{exp} (s)</td>
<td>Q (mAs)</td>
<td>Radcal</td>
<td>Nomex</td>
</tr>
<tr>
<td>Gendex, Orthoralix 9200</td>
<td>82</td>
<td>12</td>
<td>12</td>
<td>144</td>
<td>84,7</td>
<td>91,2</td>
</tr>
<tr>
<td>Planmeca, Promax</td>
<td>68</td>
<td>7</td>
<td>16</td>
<td>112</td>
<td>57,5</td>
<td>55,9</td>
</tr>
<tr>
<td>Instrumentarium, Orthopantomograph OC 100</td>
<td>77</td>
<td>16</td>
<td>17,6</td>
<td>281,6</td>
<td>106,6</td>
<td>108,6</td>
</tr>
<tr>
<td>Instrumentarium, Orthopantomograph OP 100 D</td>
<td>70</td>
<td>16</td>
<td>17,6</td>
<td>281,6</td>
<td>90,9</td>
<td>86,2</td>
</tr>
<tr>
<td>Chirana, Avantex C</td>
<td>75</td>
<td>15</td>
<td>19</td>
<td>285</td>
<td>-</td>
<td>103,0</td>
</tr>
</tbody>
</table>

**REFERENCES**


Longitudinal tracking of bone mineral density (BMD) trajectory and its association with curve severity in adolescent girls (12–17 year old) with adolescent idiopathic scoliosis (AIS) - The use of DEXA and pQCT instruments

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Background. AIS is a three dimensional deformity of the spine affecting girls at 10–17 years mostly. Low bone mass in patients with AIS has been well reported in cross sectional studies\cite{1}. No large scale longitudinal study has been conducted to monitor bone-mineral-density (BMD) trajectory in peripubertal AIS with varying scoliosis severity using both DEXA and pQCT.

Aim. We evaluated the BMD trajectory longitudinally and the factors determining BMD accretion in AIS during peripubertal period by using both DEXA and pQCT.

Method. 196 newly diagnosed AIS girls with Cobb-angle >10° and 122 healthy girls, aged 12–15 years were followed up for 2 year olds. Cobb-angle on the coronal plane of the whole spine was measured in a standard standing X ray long film. Weight, height, leg length, menarche and Cobb-angle were determined\cite{2}. Areal lumbar-spinal BMD (LSBMD) and femoral-neck BMD (FNBMD), and volumetric distal-tibial BMD (TiBMD) were evaluated by dual energy X ray absorptiometry (XR-36, Norland) and peripheral QCT (Densiscan 2000, Scanco Medical), respectively. BMD growth models were fitted by multilevel modelling (mixed longitudinal design).

Results. At baseline, 93% participants were pre-menarchial or within 3 years of menarche. Average Cobb-angles at baseline and subsequent follow-ups were 26°, 23° and 26°, respectively. TiBMD of AIS (moderate and severe severity) was significantly lower than the controls from 13–16 year olds (ANOVA, P<0.05). Post hoc test showed that TiBMD of severe AIS was lower than moderate AIS at 15–16 years (P<0.05). LSBMD accrual was significantly lower among AIS (moderate and severe severity) than the controls from age 13-17 years (ANOVA, P<0.05). FNBMD of AIS (moderate and severe severity) was lower than the controls at 15 year olds (ANOVA, P<0.05). BMD trajectories of individuals differed interpersonally and intrapersonally over time and that BMD growth followed a curvilinear pattern. The rates of BMD accretion reduced with retarded growth across the peripubertal period. Weight and height were significant time varying predictors on BMD growth. BMD of AIS was persistently lower than the healthy girls throughout the study (P<0.05).

Conclusions. This large scale longitudinal study in AIS girls with moderate to severe curve severity showed for the first time that both the volumetric and areal BMD were persistently lower when compared to the age-matched healthy girls throughout 12-17 years. AIS with more severe curve severity was found to have much lower BMD throughout the peripubertal period.
period. Promotion of a higher bone mass is important for AIS to modify scoliosis progression and to achieve peak bone mass in order to reduce the risk of osteoporosis later in life. DEXA and pQCT are highly precise and reliable nuclear instruments to monitor areal and volumetric BMD status respectively in patients with bone diseases.

**FIG. 1.** Site-specific BMD accrual for AIS (moderate and severe curve severity) and controls by chronological age for mean Distal tibial BMD by pQCT.

[* p<0.05 comparison between AIS and Control by t-test; ^ p<0.05 – comparison among AIS moderate, severe and control by one-way ANOVA; Post hoc Bonferroni multiple comparison: a: p<0.05 (Control vs. Moderate), b: p<0.05 (control vs. severe), c: p<0.05 (moderate vs. severe)].

**REFERENCES**


Optically stimulated luminescent dosimetry material for QA in radiation medicine

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Optically stimulated luminescent (OSL) materials have been used for dosimetry in many applications. Aluminum oxide, doped with carbon (Al\textsubscript{2}O\textsubscript{3}:C), has been used successfully for personnel dosimetry since 1996, with over 1.3 million individuals being monitored worldwide. A recently developed dosimetry system using OSL is now being used for radiation monitoring in numerous other applications including patient dose measurements, area monitoring, research applications, and nuclear power generating facilities. In addition, this same material is being used for computed tomography (CT) dose and dose profile measurements, and for image quality and dose measurements in dental intra-oral radiography. This paper will cover these three new applications of OSL material for quality assurance in radiation medicine.

Dots of aluminum oxide doped with carbon (7 mm diameter) are placed in a specially designed holder (25×12 mm, approximately 2 mm thick) low density plastic holder. The dosimeters are virtually impossible to detect on adult patient radiographs so they will not interfere with patient diagnoses.

Each dot has a unique serial number which allows tracking of individual sensitivities. The dots are read in a portable reader with very low power consumption due its use of light emitting diodes (LEDs) as a light source. The luminescent signal is measured using a photomultiplier tube and photon counting statistics system.

Calibration over the diagnostic energy range (from 30 to 120 kVp) is carried out at 80 kVp, with an energy response of better than ±10% over that range. The response of the OSL material is linear from 10 µGy to in excess of 10 Gy.

Results of comparisons with ionization chamber dosimetry will be presented. In addition, the results of clinical trials carried out at medical institutions worldwide comparing OSL dots and thermoluminescent dosimeters (TLDs) will be described.

For CT dose and dose profile measurements, a strip of aluminum oxide OSL material (6 mm wide by 150 mm long) is placed in a small plastic cylinder (12 mm in diameter), designed to fit into the conventional US FDA CT Dose Phantom. A scan is made using clinical techniques with the dosimeter in either the head or body phantom, and at any position in the phantom.

The OSL strip is then read in a specially designed scanner which uses a laser as a light source and a photomultiplier tube (PMT) and photon counting system to quantitate the dose and dose profile. The data is scanned with a resolution of 0.1 mm so it is possible to evaluate the details of slices 1 mm thick.
Initial results have shown several anomalies in CT scanners. One scanner with a nominal slice width of 1.25 mm demonstrated a slice width of 4.45 mm, meaning that the patient was receiving a dose approximately 3.6 times greater than necessary. (This slice width discrepancy was confirmed using radiation therapy localization film.)

The OSL CT dosimetry OSL strips and reading system will be described in detail and the results of the clinical evaluation of CT scanners from five institutions worldwide with these strips will be presented.

For measurement of image quality and patient dose in dental intra-oral radiography, a conventional personnel dosimeter is placed on a holder 25 mm above a dental periapical film. The personnel dosimeter contains a mesh pattern and several filters. These objects, along with additional small filters, produce an image on the film.

The test device is mailed to a dental facility where it is imaged by a dental technician, who then processes the film in the photographic processor at the dental facility. The dosimeter is analysed to provide information regarding patient dose and radiographic beam quality. The film is digitized and the mesh pattern is analysed to provide a measure of image sharpness. In addition, the film is tested for retained sodium thiosulfate (hypo or fixer).

A total of nine image quality and dose values are reported, including image sharpness, film contrast, film density, film base-plus-fog level, effective film speed, film processor quality, residual sodium thiosulfate, patient dose, and half-value layer.

Dot dosimeters, CT dose and dose profile strips, and dental image quality and dose tools will be described and clinical results presented.
X ray beam quality specification for kerma area product meters

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The kerma area product (KAP) in a diagnostic X ray beam is usually measured with a plane parallel transmission ionization chamber. The response of KAP chambers depend significantly on the energy distribution of radiation, and KAP meters are commonly calibrated with a discrete set of radiation qualities. Appropriate specification of radiation quality is needed to allow interpolation between the measured calibration coefficients. This is especially evident when calibration coefficients for laboratory radiation qualities are converted to clinical qualities.

Radiation quality of an X ray beam can be specified explicitly by the tube voltage and total filtration, together with anode angle and material. The half value layer (HVL) of the X ray beam is a generally used beam quality specifier and depends on all these parameters. When a high quality cavity ionization chamber is used properly, the response of the chamber depends on energy rather smoothly and the HVL can be used to specify radiation quality and to interpolate the calibration coefficients between radiation qualities. This is not the case with KAP chambers, however.

The energy dependence of the response is affected by the materials and design of the KAP chamber [1]. IEC standard for KAP meters [2] sets a requirement of maximum overall uncertainty of 25% (2 SD) for the accuracy of KAP measurement, including the maximum deviation of ±8% arising from X ray tube voltage variation, in the range of 50 kV to 150 kV with a 2.5 mm aluminium filtration. No requirements for the response are stated in the standard for other filtrations. ICRU recommendations for diagnostic dosimetry [3] state a maximum overall uncertainty of 7% (2 SD) for KAP measurements. This also emphasizes the need for accurate beam quality specification.

In this work the energy dependence of KAP ionization chambers was investigated using a tungsten anode X ray tube (anode angle 20º) with a set of standard and clinical radiation qualities. Tube voltages of 40 kV–150 kV and filtrations from 1.3 mm to 5 mm Al, and 4 mm Al with 0.1 mm and 0.2 mm Cu were used. The HVL values ranged from 1 mm to 9 mm Al. A diaphragm providing a strictly defined radiation field was designed and the KAP measurements were performed at 5 cm distance from the diaphragm. The reference value for the kerma area product was determined as the product of air kerma measured in the field centre and the area of the field at the same distance. For a KAP meter the calibration coefficient was determined as a quotient of the reference value by the measured KAP value.

Calibration coefficients were expressed relative to different beam quality specifiers: HVL, tube voltage and filtration. For any individual KAP meter the variation of calibration coefficients was in the range of 20%–30% for the used beam qualities, yet the behaviour of the response relative to radiation quality was clearly different for KAP chambers of different design. For constant HVL values the variation of calibration coefficients ranged up to 10% among typical clinical radiation qualities used in this study, and thus the HVL alone cannot specify the radiation quality adequately. At least two beam quality specifiers need to be known to describe the response of a KAP meter.
For a KAP meter, it is not possible to interpolate calibration coefficients between different X ray qualities relative to the HVL alone. Adequate and convenient specifiers in practice are the tube voltage and total filtration or, if one of these parameters is not known, the HVL instead of that. To allow the interpolations, measured calibration coefficients should cover the range of all clinically used radiation qualities.

This work is part of the IAEA coordinated research project for testing the implementation of the IAEA Code of Practice on Dosimetry in X ray Diagnostic Radiology.

REFERENCES


National standards of effective dose calculation for diagnostic and interventional radiology procedures

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⁶General Faculty Hospital in Prague,
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Currently, national standards for diagnostic and therapeutic procedures using ionizing radiation are developed in the Czech Republic. The standards are divided into four main categories, three of them are clinical standards for procedures in diagnostic/interventional radiology, radiation therapy and nuclear medicine. The last one is a medical physics standard for dose assessment in diagnostic/interventional radiology and nuclear medicine. The diagnostic and interventional radiology part of the medical physics standard is discussed here.

The medical physics standard for diagnostic and interventional radiology involves a computation of risk related quantities, it means an effective dose and a mean glandular dose (MGD). The standard is divided into seven separate articles concerning general radiography, mammography, panoramic radiography, intraoral radiography, computed tomography, fluoroscopy and interventional radiology. Each part contains a list of exposure parameters of a given patient and a list of given X ray machine parameters, which are required for an examination reconstruction and dose calculation. Detailed instructions on how to compute the effective dose or MGD from the given data follows. For the calculation, PCXMC program [1] is recommended for radiography and fluoroscopy examinations and ImPACT spreadsheet with NRPB SR250 data is used for computed tomography. For mammography, a dose formalism suggested by Dance [2] is used for the calculation of MGD. Directly measurable quantities used as an input for the calculations are incident air kerma $K_i$ for mammography, weighted computed tomography kerma index $CTKI_w$ for computed tomography, entrance surface air kerma $K_e$ or product of kerma and area $P_{KL}$ for general radiography, fluoroscopy and interventional radiology. These directly measurable dose quantities are based on kerma instead of absorbed dose, as recommended by IAEA and ICRU [3]. The medical physics standard should help to implement this new “kerma formalism” into a practice in the Czech Republic as well.

According to the standard, first calculations have been made already. Thirty procedures chosen for the first calculations were determined by the clinical standard for diagnostic radiology. Unfortunately, representative surveys pertinent to doses applied to patients have not been available yet in the Czech Republic, except for mammography and dental intraoral radiography. Therefore, the values of effective doses were normalized to a relevant directly measurable quantities. The normalized data cover a complex procedure; contribution of fluoroscopy and all radiographic exposures made during the whole examination is included. For the calculations, a standard way of the procedures as performed by physicians was taken into account. Additionally, values of effective doses were calculated for selected examinations, for which national diagnostic reference levels (DRL) are given by a Czech legislation, to receive a conservative assessment of radiation burden from these frequent procedures (see Table 1). As a value of the input dosimetric quantity, DRL was used. The
lowest permissible voltage and filtration were used for these calculations to comply with the conservative approach.

Currently, exposure data are collected from the hospitals governed by Ministry of Health during clinical audits. Eleven particular examinations were chosen for this purpose, namely chest, abdomen, dental intraoral and panoramic radiography, mammography, CT of abdomen and pelvis, CT of brain without a contrast agent, liver biopsy under a control of CT, intravenous urography (IVU), brain angiography, coronaryography and endoscopic retrograde cholangiopancreatography (ERCP). The hospitals are required to provide exposure parameters for 20 patients for each procedure. In case of fluoroscopy procedures, data from fluoroscopy and radiography part of the examination have to be given separately. These data will be used for calculation of particular values of effective dose and MGD received by Czech population during the procedures.

### TABLE 1. SELECTED RESULTS OF EFFECTIVE DOSE CALCULATIONS BASED ON DRLS

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Tube voltage [kV]</th>
<th>Total filtration [mm Al]</th>
<th>Effective dose [mSv]</th>
<th>Effective dose UK [mSv] *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Abdomen</td>
<td>60</td>
<td>2.5</td>
<td>1,129</td>
<td>1,390</td>
</tr>
<tr>
<td>Hips</td>
<td>65</td>
<td>2.5</td>
<td>0.342</td>
<td>0.190</td>
</tr>
<tr>
<td>Head</td>
<td>60</td>
<td>2.5</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>Pelvis</td>
<td>65</td>
<td>2.5</td>
<td>0.720</td>
<td>0.160</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>70</td>
<td>2.5</td>
<td>0.478</td>
<td>0.805</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>70</td>
<td>2.5</td>
<td>0.447</td>
<td>0.459</td>
</tr>
<tr>
<td>Chest</td>
<td>125</td>
<td>2.5</td>
<td>0.010</td>
<td>0.017</td>
</tr>
<tr>
<td>Intraoral</td>
<td>50</td>
<td>1.5</td>
<td>0.0064</td>
<td>0.0064</td>
</tr>
<tr>
<td>IVU</td>
<td>60</td>
<td>2.5</td>
<td>1.772</td>
<td>2.625</td>
</tr>
<tr>
<td>Upper GIT</td>
<td>100</td>
<td>2.5</td>
<td>6.2</td>
<td>6.3</td>
</tr>
<tr>
<td>Irrigoscopy</td>
<td>110</td>
<td>2.5</td>
<td>7.1</td>
<td>10.8</td>
</tr>
</tbody>
</table>

* Data from [4].

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The Brazilian calibration network for radiodiagnostics

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Coordination of the Brazilian Calibration Network for the radiodiagnostic dosimetry and quality control is the responsibility of the National Ionizing Radiation Metrology Laboratory (LNMRI) of the Radioprotection and Dosimetry Institute (IRD). The LNMRI/IRD is the Institute working in metrology, dosimetry and radioprotection at the National Nuclear Energy Commission (CNEN). The IRD is designated by the Brazilian Government through the National Institute for Metrology (INMETRO) to maintain and disseminate the national ionizing radiation dosimetry standards and quantities related to the ionizing radiation.

The idea for that network is to establish partnership in the implementation of health improvement programmes – the primary goal of the Brazilian Government. Some of these programmes are related to the medical applications of the ionizing radiation and it is so important that it is part of the main strategic planning of the following institutions involved in this subject:

- National Sanitary Inspection Agency (ANVISA)
- National Nuclear Energy Commission (CNEN)
- Health Ministry (MS).

The Health Ministry of Brazil established the regulation named Portaria MS 453 in order to regulate the quality control and inspection in hospitals and clinics that use X ray for medical diagnostics. The National Sanitary Inspection Agency, in adherence to this regulation, is implementing at each State body the sanitary inspection compliance control. In parallel, there is a great demand for equipment acquisition and staff training all over Brazil.

Many universities are implementing graduation and post graduate courses in order to cover the lack of specialized personnel at ANVISA, hospitals and service companies for running this programme.

The LNMRI/IRD provides traceable standards in radiation therapy, diagnostic radiology and radiation protection and coordinates this Brazilian metrology network to develop all Brazilian diagnostic metrology centres, take care of the implementation of the legal dosimetric, kVp and exposure time measurement units in accordance with the scientific progress of metrology and international agreements.

In order to attend the great demand for calibration and type test of all equipment in use all over the country, it is necessary to have calibration and test laboratories preferentially located in those regions where there are higher number of instrument in operation, that means, the Southeast and Northeast regions. The Brazilian metrology centers are (Fig. 1):

- Radioprotection and Dosimetry Institute (IRD), Rio de Janeiro
- Radiologic Sciences Laboratory (LCR), Rio de Janeiro
- Nuclear Energy Research Institute (IPEN), Sao Paulo
- Electric Engineering Institute (IEE), Sao Paulo
- Nuclear Technology Development Center (CDTN), Belo Horizonte
- Regional Nuclear Sciences Center (CRCN), Recife
The Brazilian metrology network is connected to the latest developments in the respective areas. The technology and know-how were under the support of the IAEA technical cooperation project and FINEP project, investing in great part in equipment and training.

The network is being financed by the Brazilian Government Institution for Projects Funding (FINEP), International Agency Energy Atomic (IAEA) and CNEN itself. More than US$ 500,000.00 has been invested in equipment (ionization chambers, X ray systems, dynalysers, electrometers, among others) and training of the staff members involved has been given, through training courses, workshops, fellowships and scientific visits.

The goal to keep all groups of the laboratories united on the same objective is attained by holding strategic meetings, like the workshop based at IRD and other workshops together with the international metrology congress (IMEKO) in Rio de Janeiro. That metrology network is a success case of transferring technology and integrate research with technology involved to maintain and disseminate the national ionizing radiation dosimetry standards and quantities related to the ionizing radiation.

CNEN’s strategic planning, which is part of the Brazilian Government’s long term strategic plan, covers two items specifically directed to metrology and quality control of the use of ionizing radiation:

1. To make available in the market products and services which are adequate and technologically updated;
2. To improve the level of the nuclear measurements. This is an evidence of the importance of this subject for the Brazilian Government.

FIG. 1. The Brazilian metrology centers.
Patient dose measurements for establishing reference levels for medical exposure in diagnostic radiological procedures in Malaysia

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1. PATIENT DOSE MEASUREMENTS

At present, the demand for radiological services in Malaysia is growing rapidly, with the increasing use of computed tomography (CT) and other specialized fluoroscopic procedures including interventional techniques, and is anticipated to continue in the future. However, there has been very little study and published literature on radiation doses received by patients during diagnostic radiological examinations with regard to the Malaysian population.

The objectives of the measurements are to obtain a range of radiation doses received by patients undergoing diagnostic radiology examinations in the Malaysian context, to investigate the variability of patient doses in relation to X ray equipment, exposure technique factors and type of ancillary equipment used and to establish national reference levels for medical exposure for diagnostic radiological procedures. The results of patient doses measured were compared with NRPB and IAEA reference levels. The comparison shows that the values obtained are below or within the limits recommended by both bodies.

Patient dose measurements are divided into three categories of medical exposure, i.e. diagnostic radiology, nuclear medicine and radiotherapy. In diagnostic radiology, patient dose measurements are conducted for the following:

- Common radiographic procedures which include plain radiography of the chest, abdomen, pelvis, skull, extremities and intravenous urography (IVU)
- Fluoroscopic procedures including barium meal and barium enema
- Certain specialized radiological procedures such as CT and mammography.

For common radiographic procedures, doses will be assessed by direct measurements using lithium fluoride thermoluminescent dosemeters (TLDs), chip attached to the patient's skin at the centre of the entrance field. In this report, the results of radiation doses received by patients undergoing plain radiographic examinations are presented. A survey was carried out to include 50 hospitals in Malaysia. The measurements of patient dose for specialized radiological procedures such as CT is still ongoing and the result is not ready yet.

2. DOSE REFERENCE LEVELS

A summary of the results is given in Table 1, showing the range as well as the average entrance surface doses (ESD) for the different examinations. The same table further compares these results to the NRPB and IAEA documents on reference levels for exposures during diagnostic radiological procedures whose values are for conventional film-screen combinations in the relative speed range of 200.
TABLE 1. PATIENT DOSES IN PLAIN RADIOGRAPHIC EXAMINATIONS

<table>
<thead>
<tr>
<th>Examination</th>
<th>View</th>
<th>Min.</th>
<th>Max.</th>
<th>Average</th>
<th>NRPB 1992</th>
<th>IAEA 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measured</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>AP/PA</td>
<td>0.04</td>
<td>0.99</td>
<td>0.22</td>
<td>0.30</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>0.16</td>
<td>3.01</td>
<td>0.84</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Abdomen</td>
<td>AP</td>
<td>0.42</td>
<td>10.04</td>
<td>4.74</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Skull</td>
<td>AP/PA</td>
<td>0.33</td>
<td>5.42</td>
<td>2.30</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>0.25</td>
<td>4.19</td>
<td>1.55</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.16</td>
<td>5.37</td>
<td>0.73</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>AP</td>
<td>1.13</td>
<td>6.70</td>
<td>3.26</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>1.81</td>
<td>11.50</td>
<td>5.96</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.19</td>
<td>2.82</td>
<td>0.75</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>AP</td>
<td>0.43</td>
<td>15.30</td>
<td>4.20</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>0.93</td>
<td>64.40</td>
<td>10.43</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.60</td>
<td>18.50</td>
<td>13.38</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>AP</td>
<td>0.10</td>
<td>4.70</td>
<td>0.51</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>0.09</td>
<td>0.97</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.02</td>
<td>1.07</td>
<td>0.27</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Shoulder</td>
<td>AP</td>
<td>0.04</td>
<td>1.17</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>AP</td>
<td>1.19</td>
<td>7.96</td>
<td>2.83</td>
<td>10.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

3. Conclusion

More complete and extensive dose survey is required to obtain a representative range of radiation doses for the Malaysian population. The variability of patient doses in relation to the relevant parameters should be investigated and exposure technique charts could be drawn up for given examinations to ensure consistently correct exposures and good quality images. Further to this, reasons for such variations will be sought towards identifying the potential for patient dose reduction and the effectiveness of a QAP.

Finally, as an effort of reducing patient dose to as low as reasonably practicable without adversely affecting image quality, dose constraints or reference levels for the various radiological examinations should be formulated locally as recommended by the ICRP. In addition, regular patient dose monitoring should be incorporated as an essential part of a QAP, besides reject analysis and routine quality control (QC) works, to aid in the monitoring of any changes in equipment or technique employed.
Implementation of a QA programme at the diagnostic radiology calibration laboratory of IPEN

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The Calibration Laboratory of the Instituto de Pesquisas Energéticas e Nucleares (LCI) has, for over 25 years, has been calibrating instruments used in radiation protection, therapy and diagnostic radiology measurements belonging to hospitals, industries, clinics and other users. The number of annually tested instruments, about 2000, needs development and implementation of a quality assurance system to facilitate the management of the routine procedures and their improvement.

The LCI has already established a quality assurance programme in order to achieve accreditation of the calibration activities following the requirements of the ABNT ISO/IEC 17025 [2]. The quality manual and all procedures, including the uncertainty analysis, are ready. The Calibration Laboratory has undertaken three internal audits and an external audit performed by the Evaluation Committee of the Calibration Laboratories linked to the National Institute of Metrology, Normalization and Industry Quality (INMETRO), Brazil.

The quality assurance system of the LCI follows also the requirements of the Integrated Management Quality System of IPEN, and it can be described by its main characteristics:

**Organization.** The Calibration Laboratory of IPEN is part of the Radiation Metrology Center (CMR).

**LCI quality mission.** Calibration of radiation detectors in order to guarantee more accuracy in the measurements and in the radiation use.

**Documentation system.** It follows the hierarchy shown in the Table 1.

### TABLE 1. DOCUMENTATION HIERARCHY AT THE LCI QUALITY ASSURANCE SYSTEM

<table>
<thead>
<tr>
<th>Hierarchic level</th>
<th>Document</th>
<th>Number of documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estrategic</td>
<td>IPEN integrated management quality manual</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td>CMR quality manual</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td>CMR business plan</td>
<td>01</td>
</tr>
<tr>
<td>Tactician</td>
<td>CMR action plan</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td>IPEN management procedures</td>
<td>08</td>
</tr>
<tr>
<td></td>
<td>CMR management procedures</td>
<td>06</td>
</tr>
<tr>
<td>Operational</td>
<td>LCI operational procedures</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>LCI technical instructions</td>
<td>10</td>
</tr>
</tbody>
</table>
Technical requirements. (a) **Staff:** The technical manager of LCI authorizes and keeps the registers of all authorizations, professional and educational qualifications, training, abilities and experience of the staff. (b) **Main reference dosimetric systems:** PTW spherical ionization chamber, 1000 cm³, model LS01, traceable to LNMRI, Brazil (radiation protection level); NE cylindrical ionization chamber, 0.6 cm³, model 2505/3, traceable to LNMRI, Brazil (radiation therapy level); PTW parallel plate ionization chamber, 1 cm³, model 77334, traceable to PTB, Germany (diagnostic radiology level, conventional qualities), Radcal parallel plate ionization chamber, 6 cm³, model 20×5-6M, traceable to FDA, USA (diagnostic radiology level, mammography qualities). (c) **Traceability:** The LCI calibration programme of all instruments is traceable to the International Systems of Units (SI); therefore, all reference systems are periodically calibrated or intercompared to the standards of the Ionizing Radiation Metrology National Laboratory (LNMRI). If these procedures are not possible, the instrument has to be sent to an international secondary or primary laboratory. (d) **Calibration procedures and best measurement capacity:** The LCI uses adequate methods and procedures for all kinds of calibration services offered, including handling, transport and storage space; preparation of the items to be calibrated; and the determination of the measurement uncertainties. For the calibration of diagnostic radiology instruments, the radiation qualities recommended by the IEC 61267 standard [2] were established. Table 2 shows the best capacity of measurement for the calibrations applied to diagnostic radiology instruments.

**TABLE 2. BEST CAPACITY OF MEASUREMENT FOR THE CALIBRATIONS APPLIED TO DIAGNOSTIC RADIOLOGY INSTRUMENTS AT THE CALIBRATION LABORATORY OF IPEN**

<table>
<thead>
<tr>
<th>Calibration</th>
<th>Measurement range</th>
<th>Expanded uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qty. Instrument</td>
<td>Calibration method</td>
<td>Minimum energy value</td>
</tr>
<tr>
<td>Air Kerma Ionization chambers</td>
<td>Substitution</td>
<td>27 keV</td>
</tr>
</tbody>
</table>

**Calibration report.** A calibration report is issued for each calibration service realized by the LCI, which includes all the necessary information for the interpretation of the results, including the measurements traceability.

**REFERENCES**


Evaluation of usefulness of a metal oxide semiconductor field effect transistor (MOSFET) dosimeters for the measurement of entrance surface dose in diagnostic radiology

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Introduction. In vivo dosimetry system using MOSFET technology has been developed by Thomson and Nielsen Electronics Ltd as an alternative to thermoluminescent dosimetry (TLD) for radiation dosimetry in radiotherapy. The new MOSFET detector with increased sensitivity was designed. It allows measurements in diagnostic radiology. In this report we present the characterization of high sensitivity Mosfet detector used in our hospital for in vivo entrance dose measurements for diagnostic beams. For comparison purposes results for standard sensitivity detectors are also presented.

Methods and material. Two series of measurements were performed. In the first series of measurements one standard sensitivity MOSFET detector (TN-502RD) and two high sensitivity MOSFET detectors (TN-1002RD) were coupled to a high sensitivity bias supply. In the second series of measurements five high sensitivity MOSFET detectors were used. All calibration were made with water phantom with full backscatter condition. The actual doses were measured with Unidos-10001 dose-meter and Farmer type ion chamber (PTW 30013). Exposition was made with a Siemens Siregraph CF with generator Polidoros SX 50 and an X ray tube with 2,5mmAl inherent filtration. MOSFET detectors were always orientated to have the build-up “bubble” facing away from the X ray tube which, according to manufacturer recommendation, to give highest sensitivity. All measurements were repeated at least three times for each measurement set-up. The results were calculated as an average value of all measurements.

Detector sensitivity, linearity, and energy dependence were assessed. Also the appearance of the detector on radiographs was checked. The sensitivity of detectors was measured at 81kV, 200 mAs with a focus-to-skin distance (FSD) of 77.0 cm (first series of measurements) and 82.7 cm (second series of measurements). The sensitivity was assessed for one standard detector and seven high sensitivity detectors. Linearity was evaluated with a series of measurements for 81 kV exposures for variation in mAs ranging from 25 to 710 mAs ( doses in the range of about 4–115mGy).

– for one standard sensitivity detector and two high sensitivity detectors. The sensitivity of detectors was defined as the response of the system (mV) per unit of dose exposure (mGy).
– Energy dependence of all detectors was measured over a range of 50–137kV with 10kV intervals (first series of measurements) and a range 60–125kV (second series of measurements).

The visibility of detectors on radiographs of a phantom Normi 3 PTW-Freiburg, and on radiographs of anthropomorphic phantom (Alderson phantom) was evaluated. Also, some measurements for patients undergoing chest, pelvis, spine and urography examinations were made and appearance was assessed. It case of the measurements performed for patients the influence of the detectors on image quality was evaluated by diagnostic specialists.
Entrance surface dose was measured for chest LAT, lumbar spine LAT and AP, pelvis, and urography examinations with an anthropomorphic phantom. All measurements were performed with high sensitivity MOSFET detectors coupled to a high sensitivity bias supply.

**Results.** The sensitivity of one standard detector was 1.41±0.03 mV/mGy. Six high sensitivity detectors had an average sensitivity of 3.36±0.07 mV/mGy (range 3.25–3.47 mV/mGy). The seventh high sensitivity detector had lower sensitivity of 2.58 mV/mGy. All values were obtained for 81 kV. Linearity of the system was good over the range of exposure (Fig. 1).

The response of detectors depended on the energy of the beam either for standard and high sensitivity detectors. In Fig. 2, the sensitivity is presented. The data were normalized to 100% for 81 kV beam. Maximum difference between calibration factors did not exceed 6% for high sensitivity detectors and 4% for standard sensitivity detector for the energy up to 100 kV. For the energy up to 125 kV and up to 137 kV the difference did not exceed 10% for high sensitivity detectors and 12% for standard sensitivity detector, respectively. The detector was clearly seen through the radiograph of phantoms. The appearance of the detector on the radiographs was evaluated by radiologists so as not disturbing the process of diagnosis. The average entrance surface dose measured for anthropomorphic phantom was 2.15 mGy for chest LAT examinations (total number of measurements N=20), 3.29 mGy for lumbar spine AP examinations (N=20), 15.22 mGy for lumbar spine LAT examinations (N=20), 2.30 mGy for pelvic AP examinations (N=20) and 3.18 mGy for urography examinations (N=40), respectively.

**Conclusions.** Patient dose verification system MOSFET 20, Model TN-RD 50 (Thomson and Nielsen Electronics Ltd.) is performed admirably at diagnostic energy levels. The response of the detection system is found to be linear with dose. There is some energy dependence of the sensitivity, however, if measurements with accuracy of about 10% would be accepted, the calibration for only one middle energy might be enough.

The small size of the dosimeter compared to other detectors do not produce significant interference with the diagnostic image quality. Therefore real time monitoring of dose delivered to patients is possible with MOSFET dosimeters. These detectors are good candidates for use in a variety of dosimetry applications for diagnostic X ray systems.

![FIG. 1 The linearity of standard detector and a new high sensitivity detector plotted across a range of exposure times.](image1)

![FIG. 2. The sensitivity of Mosfet detectors at different tube potentials.](image2)
Quality assurance of dual energy X ray absorptiometry (DEXA) systems


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Introduction. DEXA scanning is currently the most widely used method to measure bone mineral density (BMD). DEXA systems are particularly important in the screening and management of osteoporosis, and the determination of fracture risk. Since the advent of DEXA in the 1960s, there has been rapid growth in their use in private and public medical institutions. Although DEXA scanners from different manufacturers are based on the same principle of X ray Spectrophotometry, most models vary in its implementation. Differences exist in the positioning of the X ray tube, the method of generating dual energy X ray beams and in the imaging geometry. The original DEXA systems (pencil beam) were low dose modalities and as such attracted little interest from the medical physics, engineering and radiation protection profession [1]. However, new developments in DEXA imaging technology (fan beam and cone beam) result in higher exposure levels [1,2], shorter scan times, increased patient throughput and increased shielding requirements. One of the recommendations of the EU Osteoporosis Consultation Panel (2004) was to investigate the cost/utility ratio of introducing screening programmes [5]. Furthermore, the patient population for DEXA scans is no longer just post menopausal women, DEXA scans are being prescribed for pre-menopausal women who are on certain types of contraceptives and people of all ages with eating disorders. Most DEXA scanners do not incorporate DAP meters, and Article 7 of the EU Council Directive 97/43 Euratom (MED) states that particular attention should be paid to RP for population screening systems, and the NRPB recommends that all X ray equipment should be subject to regular performance checks. However, there is limited published acceptance testing/QA guidelines for DEXA systems [1–4], and this provides a real challenge for QA testing in the field. This study presents the results of a DEXA equipment survey based on a QA protocol developed in-house [1].

Methodology. QA testing was performed on fourteen DEXA scanners. The following X ray equipment performance indicators were assessed: radiation output consistency, half value layer, patient entrance surface dose (ESD), patient effective dose [2], X ray field size, beam divergence, exposure mechanism, BMD accuracy and spatial resolution. In addition, scatter measurements and a radiation protection inspection of the facilities were performed.

Results. The effective patient dose for the latest generation cone beam and fan beam DEXA systems are far greater than that of the pencil beam scanners (Fig. 1). Total effective dose to the patient from a spine and femur DEXA examination on the latest generation DEXA systems is comparable to approximately one day of natural background radiation. Associated with the increase in patient dose and higher patient throughput with the latest generation DEXA scanners is a greater occupational hazard to staff from scattered radiation (Fig. 2). The use of a mobile lead screen for staff protection was necessary for the fan and cone beam systems; pencil beam systems did not give rise to such concerns. Scattered dose from newer generation systems may also exceed the exposure limits for the general public so structural shielding may be required. Considerable variation in the magnitude and repeatability of HVL was noted between different models of DEXA scanners. Results of a comparative study of
BMD accuracy using the European Spine Phantom displayed a difference of up to 7% in BMD values between scanners of different manufacturers.

**FIG. 1.** Average patient effective dose for a standard AP spine examination, derived from measured DAP$^2$.

**FIG. 2.** Annual dose to the operator (mSv) measured at 1m from DEXA scanner. Assuming twenty patients per day.

**Discussion.** Despite the dose increases associated with advances in technology, patient doses from DEXA remains low when compared with natural background and other common radiological examinations. However, any equipment that exposes patients to ionization radiation should be subject to regular performance checks. Comparative studies on QA results will assist with the ongoing development of QA testing guidelines, determination of required testing frequencies, the establishment of tolerances, and criteria of acceptability for DEXA X ray equipment.

**ACKNOWLEDGEMENT**

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**REFERENCES**


Session 8c:
Radiation Imaging
QUALITY ASSURANCE OF RADIOPHARMACEUTICALS AND RADIOACTIVITY MEASUREMENTS
QA of radiopharmaceuticals

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Radiopharmaceuticals are a specialized type of medicinal product and any QA system controlling their manufacture and use must deliver the same basic requirements as all other drugs, i.e. the products must be safe and fit for their intended purpose. However, the specialized nature of the product, in particular their short shelf-lives imposed by the radioactive decay of the incorporated radionuclide impose restrictions on the design of the QA system. This presentation will discuss the parameters that apply to the quality of radiopharmaceuticals, the difficulties that relate to short-lived radionuclides and the possible solutions to these problems.

Many of the issues that relate to the safety of conventional drugs also apply to radiopharmaceuticals. Thus they need to comply with the same requirements regarding pharmaceutical safety – for example, sterility and freedom from pyrogens as well as toxicity arising from the drug itself or any contaminants. However there are also issues that are specific to radiopharmaceuticals and these mostly relate to the radioactive component of the product. This radioactive component can impinge upon safety – since it affects the radiation dose received by the patient, and also on efficacy – since it determines the quality of the diagnostic information obtained or the effectiveness of any radiotherapeutic action.

For the purposes of this presentation, consideration will be restricted to intravenous radiopharmaceuticals since this route provides the great majority of administrations. The parameters with which these products must comply are: radionuclidic, chemical and radiochemical identity; and radionuclidic, radiochemical and chemical purity, sterility and freedom from pyrogens. Particulate radiopharmaceuticals must also comply with requirements for particle size. If the product complies with the set specification for each of these parameters then the user can have complete confidence that it will fulfil all the requirements for use in terms of safety and efficacy. The difficulty arises from the limited time that is available to check compliance. Radiopharmaceuticals incorporate radionuclides with physical half-lives ranging from a few seconds (e.g. Kr-81m: 13 secs) to several weeks or months (e.g. Sr-89: 50 days). The shorter the half-life, the greater the problems imposed on the QA system while for long-lived isotopes it is possible to apply much the same system as required for non-radioactive drugs. Consideration must also be given to radiation protection issues. If the execution of a quality control procedure imposes a potential radiation hazard to the operator, then the procedure should be modified in such a way as to reduce this potential hazard. Solutions to this problem range from relatively simple devices such as those which allow insertion of shielded radioactive syringes into dose calibrators for measurement of radiochemical purity, to the more complex use of automated HPLC devices to measure radiochemical purity in conjunction with PET synthesis modules.

In the past, great emphasis was placed on prospective QC testing of radiopharmaceuticals prior to supply but even then, it was recognized that some lengthy tests – sterility testing for example, could often not be performed prior to supply and use of the product. Efforts have been made to develop very rapid pre-release assays that do not result in lengthy delays prior...
to the release of the product. These developments can be very simple. Thus the use of miniaturized TLC strips, rather than conventional glass plates, for measuring radiochemical purity of $^{99m}$Tc-labelled agents allows the duration of this assay to be reduced to a few minutes. Sometimes a more high-tech approach is required. A good example is the Endosafe™ instrument (Charles River) for rapid pyrogen testing. This reduces the time taken for measurement of endotoxin from over an hour to 15 minutes.

Nevertheless, as the use of ultra-short-lived isotopes increases, parametric release arrangements have to be considered for many more of these parameters and therefore attention is being paid to other ways of ensuring compliance other than prospective testing. As described in the relevant European Guidelines [1], quality assurance is a wide ranging concept that covers all matters which individually or collectively influence the quality of the product. These matters include such diverse issues as personnel training, premises and equipment, documentation, production processes and quality control procedures. Increased consideration must therefore be given to all of these aspects if one is to be assured that the quality of the product that results from the manufacturing process is as reliable as possible. A question arises as to the way in which these broad GMP issues should be applied to the specialized manufacture of radiopharmaceuticals. The authorities do give some guidance (Annex III of the EC Guide) but these are quite ‘general’ and do not give detailed advice. The EANM Radiopharmacy Committee has produced guidelines which they consider to be appropriate for the small scale and specialized nature of radiopharmaceutical preparation in hospitals [2]. Compliance with these guidelines will ensure that the level of confidence in the quality of the product is enhanced and the level of reliance that needs to be placed on quality control testing of the final product is reduced.

Ultimately the decision on whether a radiopharmaceutical is suitable for clinical use must be made by a suitably qualified individual who checks its quality against a set specification for that particular product. The release criteria will include compliance with a combination of final QC checks and assurance that its manufacture has been undertaken in the controlled manner prescribed by Good Pharmaceutical Manufacturing Practice.

REFERENCES


Strengthening radiopharmacy related quality programmes
by the IAEA

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The International Atomic Energy Agency (IAEA) is actively involved in all activities related to the peaceful applications of nuclear energy, amongst others in nuclear medicine. Following recruitment of a specialist radiopharmacologist with extensive hospital based radiopharmacy experiences in March 2003, the Nuclear Medicine Section of the IAEA has accelerated efforts to strengthen all aspects of quality programmes related to clinical practice. These include all inclusive guidelines and programme referred to as “NUMQUM” that will play a vital role for self appraisal in improving QA/QC in clinical practice. However this paper will focus on quality programmes specific to hospital radiopharmacy. The overall aim has been to address Member State needs by improving practices in ‘hot laboratories’ and support the growing need for qualified staff for laboratories supporting hospital based PET and molecular imaging programmes.

With the assistance of various international consultants, a new set of operational guidelines has been created which include the following:

- Operational guidance on hospital radiopharmacy- A safe and effective approach
- Establishing norms and standards for clinical application of radiolabelled biological proteins, peptides, and antibodies
- Criteria for parametric acceptance of PET tracers for clinical applications.

These provide guidance at an international level in many aspects of hospital radiopharmacy practice including training, facilities, equipment, operations and quality systems. They take into consideration the skill mix, busy nature and limitations applicable at clinical practice level. These publications are not intended to override local guidance or provide comprehensive advice on all aspects of radiopharmacy practice.

Operational guidance on hospital radiopharmacy - A safe and effective approach

This guidance has been written with routine clinical practice in mind and therefore provides many practical points that should help the new and more developed nuclear medicine centres. In many centres the nuclear medicine physicians take responsibility, and routine service is provided with the aid of a medical scientist or technologist, in which case he/she clearly needs to know the safe level of operation.

In the larger nuclear medicine centres these are served by a qualified radiopharmacist who would find this guidance an aid to establishing and/or meeting international requirements. The new centres will find specific information essential for setting up the provision of the service and the more developed centres will find numerous updated protocols and suggestions on improving operational performance. The guidance is of interest to nuclear medicine physicians, radiologists, radiopharmacists, medical physicists, medical technologists, educationalists, diagnostic centre managers, and those engaged in quality systems in public health.
Establishing norms and standards for clinical application of radiolabelled biological proteins, peptides, and antibodies

Taking into account the complexity of radiolabelled peptides and biologicals it is essential that a proper set of norms and standards documents are provided on safe and effective use of radiolabelled biologicals in the clinical setting. After considerable discussion and debate the following were established:

Scope: The aim was to prepare a user friendly document for personnel involved in preparation of radiopharmaceuticals based on peptides, proteins and antibodies for human use. This document should cover all practical, methodological and ethical concerns relating to radiolabelled products mentioned above and should clarify the complicated roadmap that one has to follow in this area. This document does not cover the use of radiolabelled oligonucleotides, cells and other autologous products and does not provide technical protocols on actual methodologies.

Requirements: After extensive discussions on the contents of the guidance document, it was decided to focus the guidance on issues relating to requirements of the starting materials, radiolabelling conditions, quality assurance procedures and characterization studies including physico-chemical and biochemical testing. In addition, in vitro and animal studies and human clinical trials during different phases for the clinical development of radiopharmaceutical products were also included. This guidance should assist in pre-clinical and clinical settings.

Criteria for parametric acceptance of PET tracers for clinical applications

There is immense global interest in PET with accelerated investment in clinical setting. The time available for the labelling of PET molecules (including purification and quality control) is very limited, therefore presenting new challenges and needing for more proficient systems in place before clinical use. Bearing in mind the busy and demanding nature of the clinical setting, this adds to the complexities. Therefore, there is a need for establishing criteria for ensuring better PET systems acceptance practices and parametric acceptance of PET tracers for clinical applications.

Central to any quality programme is human resources development. Therefore the IAEA has various projects at different stages of development which will strengthen human resource capacity building in Member States to provide a more sustainable approach for the future. This includes the introduction of the first IAEA based, competency based – “Certificate in Safe Practices in Routine Hospital Radiopharmacy”. Another project will develop a master based programme for radiopharmacology and molecular imaging scientists. These activities are in addition to the traditional IAEA support to national and regional training courses for continuous professional development.

At an international level there is a need to strengthen the role of international pharmacopoeia mandated by WHO members. The last update on radiopharmaceutical chapters was done over twenty years ago. The group at the IAEA has taken on the challenge to update these monographs and deliver them to the international community. These monographs are fundamental for end users purchasing radiopharmaceuticals in a globalized world and for the numerous national laboratories which manufacture radiopharmaceuticals.

Summary

Numerous recent activities have been created to strengthen the quality programmes related to radiopharmacy practices which will have an impact at the international level.
Results of an international comparison of iodine-131 among national laboratories: Establishing measurement traceability for radioactivity in medicine

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The establishment of measurement traceability to national or international standards is an important component of ISO 17025 based Quality Management Systems for laboratories providing measurement standards and calibration services [1,2]. For applications impacting medical practice, such as the measurement of radioactivity for nuclear medicine, this is especially important since it ultimately plays a role in the quality of care that a patient receives. Because the dose delivered to both the diseased tissue and healthy organs is related to the amount of injected activity, the more accurately the radioactivity content of the administered drug can be determined, the more accurate the dose estimations will be. By establishing and maintaining traceability of the radioactivity measurement to national or international standards, the accuracy and consistency of the measurement results can be ensured.

Traceability is defined as “the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually international or national standards, through an unbroken chain of comparisons, all having stated uncertainties” [3]. Because traceability can be established only through direct comparisons, most radioactivity measurement laboratories must achieve this by participating in bi- or multi-lateral comparisons in which all participants measure an aliquot of the same master solution. Traceability to international standards, held by the Bureau International des Poids et Mesures (BIPM), can be established by national laboratories if at least one other participant has already established traceability through a previous comparison with either the BIPM itself or other national metrology institutes. Traceability to national standards is established through similar comparisons conducted by national measurement laboratories. In the case of radioactivity measurements for nuclear medicine, it is desirable for radiopharmacies and nuclear medicine clinics to be traceable to their national standards laboratory, thereby helping to ensure the accuracy of their results.

The difficulty that many developing countries face is that there is no national measurement laboratory to which traceability can be established. Moreover, a large number of developing countries are not signatories to the Metre Convention, thereby precluding them from directly participating in BIPM comparisons. In the area of dosimetry, the International Atomic Energy Agency (IAEA) assists these laboratories through its Secondary Standards Dosimetry Laboratory (SSDL) programme, in which national laboratories are able to have their standards calibrated or compared to IAEA standards that are directly traceable to the BIPM or other primary national laboratories. This enables laboratories in developing countries to establish the necessary traceability to international standards for dose measurement.

Currently, no such international secondary laboratory network exists for radioactivity, but requests from IAEA Member States for it are increasing. One part of the IAEA Coordinated
Research Project (CRP) entitled *Harmonisation of Quality Practices for Radioactivity Measurement in Nuclear Medicine* involves developing the necessary procedures, protocols, and guidance needed to expand the SSDL network to include radioactivity measurement and helping them to be able to establish traceability to international standards. The participants include laboratories from Brazil, Cuba, the Czech Republic, India, Iran, Romania, South Korea, and Turkey. The level of experience in the laboratories varies – some are primary national metrology institutes that have participated in several BIPM comparisons, while some have little experience in participating in or conducting radioactivity comparisons.

An important part of the CRP is the conducting of two interlaboratory and two national comparisons of two different radionuclides: $^{131}\text{I}$ and $^{67}\text{Ga}$. In the first Research Coordination Meeting held in June 2005, the participants developed draft protocols for these comparisons, the first of which will be an interlaboratory comparison (involving the participants only) for a solution of $^{131}\text{I}$. The comparison was held in April 2006.

The solutions to be compared were prepared by AEA Technology (Braunschweig, Germany), which itself has established traceability to the national metrology laboratory of Germany. Each recipient was provided 5 mL of solution containing nominally 185 GBq of $^{131}\text{I}$ in a Schott 10-R glass dose vial. According to the accepted protocol, each participant was required to report the activity concentration of the solution as measured in the dose vial. An optional exercise that several of the laboratories expect to perform involved the transfer of the solution into whatever “standard” measurement geometry (flame-sealed ampoule, other type of dose vial, etc.) is used by that laboratory in their routine measurements. In addition, the primary laboratories are expected to analyse the solution for possible radionuclidic impurities. Each participant’s results were due to the IAEA no more than four weeks after receipt of the solution. Because several of the participants have already participated in BIPM comparisons of $^{131}\text{I}$, an unbroken comparison chain between the BIPM and the other laboratories can be established.

This paper presents the results of the interlaboratory comparison of $^{131}\text{I}$ conducted between the participants of the CRP and will demonstrate how traceability to international standards for the measurement of this radionuclide was established for the laboratories. Potential ways of incorporating radioactivity measurement comparisons into the existing SSDL network will also be briefly discussed.

**REFERENCES**


Preparation, QC and biological evaluation of $^{177}$Lu-DOTA-Tyr3-Octreotate

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Somatostatin (SS) plays a major role in the physiological regulation of hormones and organs. Radiolabelled somatostatin analogues have been studied for targeted radiotherapy of neuroendocrine tumors and with other malignancies known to bear somatostatin receptor, such as lymphoma, breast cancer, small-cell lung cancer and melanoma [1–2].

Reactor produced $^{177}$Lu is emerging as an important radionuclide for cancer therapy since it decays with half-life of 6.71 d by the emission of $\beta^-$ particles with $E_{\beta}$ of 498 keV (78.6), 384 keV (9.1%) and 176 keV (12.2) to stable $^{177}$Hf. The $^{177}$Lu radionuclide has tissue mean range of 670 µm is considered to be more effective for the treatment of small tumour [3]. High specific activity $^{177}$Lu radionuclide (> 8 Ci/mg) prepared in our laboratory is considered to be appropriate for labelling peptides. Several experiments for obtaining optimum labelling yield of $^{177}$Lu-DOTA-Tyr3-Octreotate under different reaction parameters such pH, incubation time and reaction temperature were performed. Radiochemical purity of $^{177}$Lu-DOTA-Tyr3-Octreotate was determined by radio-TLC with C18 plates developed in 70:30 MeOH:10% NH₄OAc. Under these conditions $^{177}$Lu-DOTA-Tyr3-Octreotate appears at Rf 0.8 while $^{177}$Lu-acetate stays at the Rf 0. High labelling yield (>98%) of $^{177}$Lu-DOTA-Tyr3-Octreotate was obtained at pH 4.5 at a temperature of 90°C for 30 minutes incubation time.

The $^{177}$Lu-DOTA-Tyr3-Octreotate was further investigated for stability in acetate / ascorbate buffer and saline at room temperature (12–15 °C). The data showed that the labelled complex was stable in buffer and saline medium for a period >24 hours.

Animal study of $^{177}$Lu-DOTA-Tyr3-Octreotate was performed in ~200 g male Sprague Dawley rats. Two hundred microlitres of the labelled (80 µCi) were injected into the tail veins of rats and each rat was killed at 1 hour, 2 hours, 6 hours, 12 hours, 24 hours and 72 hours. Countings were performed using Capintec dose calibrator. The biodistribution study of $^{177}$Lu-DOTA-Tyr3-Octreotate in rats indicates (Table 1) that the critical organ was the pancreas and the excretion route was through kidney. All the rats during the study were found to show normal behaviour (movement, sleeping, eating).

For Internalization studies, AR42J cells were plated to a final concentration of 1x10⁶ cells into 35 mm culture dishes and incubated for 1 h at 37 °C. Cells (1x10⁶ cells/tube) were incubated with 1x10⁴ cpm /tube of $^{177}$Lu-DOTA-Tyr3-octreotate for 5, 20, 40, 80, 120 minutes at 37°C. Incubation was interrupted by removal of the medium and% internalized radioactivity was calculated. At the same time non specific binding (NBS) was evaluated by incubation of cells with tracer in the presence of a high concentration of unlabelled DOTA-TATE (150 µL of 10 µmol in each tube) The $^{177}$Lu-DOTA-Tyr3-octreotate showed more than 6% internalisation into AR42J cells after 80 minutes as shown in Fig. 1.
TABLE 1. BIODISTRIBUTION OF $^{177}$LU-DOTA-TYR3-OCTREOTATE IN MALE RATS AT VARIOUS INTERVALS POST INJECTION [% INJECTED DOSE (ID) PER ORGAN ± SD (N=4)]

<table>
<thead>
<tr>
<th>Organs</th>
<th>1 hour</th>
<th>2 hours</th>
<th>6 hours</th>
<th>12 hours</th>
<th>24 hours</th>
<th>72 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood</td>
<td>2.12 ± 0.38</td>
<td>0.81 ± 0.21</td>
<td>0.08 ± 0.03</td>
<td>0.05 ± 0.04</td>
<td>0.04 ± 0.02</td>
<td>0.03 ± 0.01</td>
</tr>
<tr>
<td>Lungs</td>
<td>0.21 ± 0.02</td>
<td>0.12 ± 0.02</td>
<td>0.07 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td>0.03 ± 0.00</td>
<td>0.01 ±0.00</td>
</tr>
<tr>
<td>Liver</td>
<td>0.61 ± 0.08</td>
<td>0.49 ± 0.04</td>
<td>0.32 ± 0.08</td>
<td>0.29 ± 0.07</td>
<td>0.26 ± 0.09</td>
<td>0.25 ± 0.06</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.04 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.01 ± 0.00</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.00</td>
</tr>
<tr>
<td>Kidney</td>
<td>2.7 ± 0.09</td>
<td>2.4 ± 0.12</td>
<td>1.95 ± 0.09</td>
<td>1.82 ± 0.11</td>
<td>1.71 ± 0.08</td>
<td>1.65 ± 0.06</td>
</tr>
<tr>
<td>Heart</td>
<td>0.05 ± 0.01</td>
<td>0.03 ± 0.01</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.00</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.00</td>
</tr>
<tr>
<td>Bone</td>
<td>2.65 ± 1.10</td>
<td>2.15 ± 0.99</td>
<td>1.55 ± 1.22</td>
<td>1.21 ± 1.25</td>
<td>0.75 ± 2.10</td>
<td>0.22 ± 0.88</td>
</tr>
<tr>
<td>Adrenal</td>
<td>0.42 ± 0.05</td>
<td>0.32 ± 0.06</td>
<td>0.29 ± 0.07</td>
<td>0.25 ± 0.04</td>
<td>0.24 ± 0.05</td>
<td>0.19 ± 0.04</td>
</tr>
<tr>
<td>Intestine</td>
<td>5.38 ± 1.25</td>
<td>5.12 ± 1.32</td>
<td>4.75 ± 1.50</td>
<td>4.25 ± 1.23</td>
<td>3.28 ± 1.10</td>
<td>2.25 ± 0.88</td>
</tr>
<tr>
<td>Pancreas</td>
<td>8.85 ± 1.25</td>
<td>7.15 ± 1.32</td>
<td>6.35 ± 1.95</td>
<td>4.85 ± 0.86</td>
<td>3.38 ± 1.10</td>
<td>1.55 ± 0.41</td>
</tr>
<tr>
<td>Feces</td>
<td>0.005±0.001</td>
<td>0.004±0.001</td>
<td>0.01±0.02</td>
<td>2.56±0.11</td>
<td>6.89±1.25</td>
<td>4.34±0.89</td>
</tr>
</tbody>
</table>

**FIG. 1.** Internalization of $^{177}$Lu DOTA-Tyr3-Octreotate into AR42J cells.

**REFERENCES**

Installation of a biomedical cyclotron: acceptance tests and QA procedures

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Positron emission tomography has gained an enormous role as a clinical tool in oncology, cardiology and neurology. At the same time its importance has grown also in research, both in pharmaceutical development and in pre-clinical studies. Due to the increased need for PET radiopharmaceuticals, numerous new installations of cyclotrons have been recently completed or are in realization. In medical facilities these costly accelerators are expected to undergo acceptance tests and QA procedures, not differently from other biomedical equipment. We report here on the acceptance test and QA protocol adopted for the installation at our institution.

A decision was taken to install a medium energy unshielded cyclotron, due to the trade off between characteristics (e.g. dual particle operation), performance (in terms of activity produced in typical runs), flexibility (easy of access to all subsystems, both for maintenance and for research purposes) and shielding and other radiation protection issues. The final choice was for a PETtrace (GE Healthcare), a negative ion compact cyclotron capable of accelerating $^1$H $^-$ ions up to 16.5 MeV with an extracted current of up to 80 $\mu$A and $^3$D $^-$ ions up to 8.4 MeV with an extracted current of up to 60 $\mu$A. The system can fit up to six targets for the production of the most important PET radionuclides and allows simultaneous dual beam irradiation.

The acceptance test program was agreed with GE and performed in two steps: tests on the accelerator were initially performed jointly at the factory and then repeated at our site; after installation it was also possible to perform tests for the targetry and sample production runs. The test program was as follows:

- $^1$H $^-$ single beam bombardment for 120 minutes (min) at 75 $\mu$A on a Faraday cup (“dummy” target)
- $^1$H $^-$ dual beam bombardment for 120 min at 75 $\mu$A on dummy targets
- Switching from $^1$H to $^3$D operation in a predefined, short time
- $^3$D $^-$ single beam bombardment for 120 min at 60 $\mu$A on a dummy target
- $^3$D $^-$ dual beam bombardment for 120 min at 60 $\mu$A on dummy targets
- Venting the cyclotron chamber to ambient pressure, start the vacuum system and measuring the time to get operational vacuum
- Check tightness of the targets and of the radioactivity delivery lines
- Test irradiations and check of activity produced and saturation yield.

Production tests of $^{18}$F were made using as target material 95% enriched $^{18}$O water (Cambridge Isotope Laboratories); the activity produced was delivered to hot cells specifically designed for PET radiopharmaceuticals synthesis and manipulation (TEMA Sinergie), and measured using a radionuclide activity calibrator (CRC15PET, Capintec). $^{13}$N was produced bombarding purified $^2$H$^1$O; the water bolus was delivered in an empty vial, inside the chamber of the activity calibrator while trapping of $^{11}$CO$_2$ and $^{18}$F$_2$ gases were made
respectively in Ascarite and soda lime traps, put directly inside the chamber of the activity calibrator. After completion of acceptance tests and the start of routine activity, we developed a regular QA protocol. For $^{18}$F targetry this comprises regular short time, low current pre-irradiations on H$_2^{16}$O before production, to condition targets and check yield. Rinsing of the target, post irradiation with H$_2^{16}$O and careful drying with inert gas are also performed. The quantity of enriched $^{18}$O water is weighed to control consumption and proper operation of the target filling stations. As regards the accelerator, QA routine comprises regular daily check of beam transmission, current on collimators and extraction system, vacuum levels and other operational parameters.

All the tests on the accelerator were regularly terminated, both at the factory and after installation. During long time bombardments, system parameters were visually checked and automatically recorded. The following analysis showed that current on target was stable within less than 1% standard deviation for H$^+$ irradiations and less than 1.5% s.d. for D$^+$ in both cases we requested less than 5% stability. The time for switching from H$^+$ mode to D$^+$ resulted to be 2.5 min (expected <5 min). The time to reach a pressure of 1·$10^{-6}$ mbar from atmospheric pressure was 70 min, starting with the diffusion pump already at operational temperature. Activity in $^{18}$F$^-$ production tests was measured for up to three hours, in order to correct for contamination of $^{15}$N produced in residual $^{16}$O in the enriched water. Corrected calculated $^{18}$F$^-$ activity at the end of bombardment resulted in more than 2500 mCi after 60 min irradiation at 38 µA, for each of the $^{18}$F$^-$ target stations installed in our cyclotron, giving a saturation yield >200 mCi/µA. In $^{11}$CO$_2$ production, bombarding a gas mixture of N$_2$+1.0% O$_2$ we obtained a saturation yield of 92 mCi/µA, that allows us to produce about 2 Ci of $^{11}$C in a 30 min irradiation at 35 µA. As regards $^{18}$F$_2$, our system is equipped for the production via the $^{20}$Ne(d,α)$^{18}$F reaction. After tedious work of conditioning the target to release the activity, due to high chemical reactivity of fluorine, we were able to obtain relatively stable yields of the order of 22–29 mCi/µA that allows us to obtain about 450 mCi in a 120 irradiation at 35 µA on a Ne+0.3% F$_2$ mixture. Exploiting regular QA procedures, we obtained reliable performance of the system, stable targets yields and early detection of deviation from normal operation. This allowed fixing minor problems and proper planning of preventive maintenance with minimal influence on the uptime.

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Establishment of a national programme for QC of nuclear medicine instruments in Cuba

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A national programme for the quality control of nuclear medicine instruments has been organized and established. It is the result of a multi-institutional project during three years. The work was participated in by an expert group of experienced medical physicists working in the nuclear medicine field: from the national regulatory authorities, research centers, hospitals, and other local institutions.

The programme for the quality control of nuclear medicine instruments included the following aspects: implementation of national protocols and regulations according to the local conditions and resources, education and training, organization and implementation of a phantom bank, evaluation of the current state of the nuclear medicine instruments, and establishment and registration of an audit service to be performed annually by the national regulatory authority.

It created the document “National protocols for quality control of nuclear medicine instruments”. The objective of this workbook was to propose standardized and homogeneous quality control procedures, taking into account the technical features of the local instrumentation and availability of complementary resources (phantoms, sources, etc). These protocols are mainly based on international publications such as the IAEA-TECDOC-602, the NEMA standards, etc. [1–3]. The document contains 84 pages, and includes topics related to the quality control of gamma cameras, SPECT systems, whole body systems, directional detectors, etc. Descriptions of the proposed tests such as the objectives, materials, procedures, periodicity, range of normal values and other information, are included. This document was evaluated and approved by the Cuban authorities (CCEEM) to be used as the basic protocol for the quality control of local nuclear medicine instruments.
A national course about quality control of nuclear medicine instruments was organized and established. It was mainly addressed to educate and train the responsible persons in this activity in all the nuclear medicine departments. The course was held at the National College of Health and it is going to be conducted every two years. Forty hours of theoretical and practical sessions were planned, 20 hours of lectures and 20 hours of laboratory activities. Two pilot courses have already been delivered during 2002 and 2004. More than 45 students from the whole country attended these educational activities.

A database of phantoms and accessories for quality control of nuclear medicine instruments was organized and published on the internet. Firstly, all the interested institutions provided the description and technical information of the phantoms and also their formal agreements to share these resources. A methodology for the exchange mechanism was promoted and headed by the CCEEM. Finally, a website was created with the details of the available resources, which included clinical phantoms (anthropomorphic torso phantom, cardiac inserts, dynamic cardiac phantom, etc), total performance phantoms (Carlson and Jaszczak phantoms), calibrated flood and point radiation sources, linearity and contrast/resolution phantoms, etc.

The current state of the Cuban nuclear medicine instruments was evaluated. Firstly, a survey was organized and performed by the CCEEM on all the national nuclear medicine services, in order to collect specific data about the equipment and the institutional quality control programmes. Later on, in situ measurements were performed in the majority of the services using a selected set of quality control tests. All the gamma cameras and SPECT systems were evaluated as well as the complementary equipment. The processing and evaluation of the measurements were performed by the expert group and the results were discussed with the local staff and authorities. Abnormal outcomes and the suggestions to fix them were reported in a formal report.

Finally, an audit service headed by the CCEEM was organized, which was licensed and registered by the National Centre of Nuclear Safety (CNSN). This service was created in order to control periodically the state of the instrumentation in all the nuclear medicine departments. It will allow checking of the usefulness and effectiveness of the established quality control programmes at each institution. Four nuclear medicine departments were audited in order to perform a practical evaluation of this service.

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QC of multiple detector SPECT systems at King Chulalongkorn Memorial Hospital

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The dual and triple detector SPECT systems were clinically available at King Chulalongkorn Memorial Hospital, Thai Red Cross Society, Bangkok, Thailand in 2000. The acceptance test was performed according to NEMA NU-1 standard for each and every detector. The scatter and attenuation corrections were available using both the hardware and software parts. The gadolinium line source was attached to the system gantry to create the transmission map for the attenuation correction, mostly in myocardial SPECT.

The dual head is the workhorse for the whole body bone imaging while the triple detector is mostly used for the myocardial and brain perfusion studies.

The quality control programme is continuously performed to assure that the systems are displaying correctly and accurately for both qualitative and quantitative studies.

The routine test consists of the mechanical test of all motion, detector performance such as the intrinsic and extrinsic uniformity, detector sensitivity, center of rotation calibration and the overall performance using JASZCZAK phantom. The anthropomorphic torso phantom imaging is acquired annually.

The results were considered in all items from the safety in the detector and gantry motion, the detector uniformity – the UFOV of less than 2.5% for each detector and 2.0% for CFOV. The intrinsic spatial resolution is obtained in the range of 3.8–4.0 mm for the FWHM and 7.4–7.8 for FWTM.

The intrinsic spatial linearity was between 0.4–0.6 mm for the absolute value and 0.2–0.25 mm for the differential values. The intrinsic energy resolution was less than 10% for $^{99m}\text{Tc}$. The COR offset is less than 0.25 mm per detector, the sensitivity difference between detector is less than 2.0%. JASZCZAK phantom studies showed the contrast variation for solid spheres between detectors. All spheres were visualized from the tomographic display with the 12.7 mm of minimal size. The minimum diameter of rod of 9.5 was visualized.

The system is maintained quarterly by the manufacturer in the USA under a service contract.

The system downtime was less than 10 days per year.

It is very important to perform the test and record the results regularly and, prior to the daily use, to make sure of the correct and accurate data for all nuclear medicine imaging.
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Swiss requirements concerning gamma camera acceptance and status testing

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Like in the field of radiology, digital systems are also becoming the standard in the field of nuclear medicine. This offers not only the possibility to process, transmit and archive data from patients more easily but also to introduce quantitative measurements for quality controls. In this framework standards concerning the qualification of gamma camera systems have been updated and appeared to be useful to set legal requirements, in spite of the fact that this is not their goal. The aim of this study was first to choose a set of tests described in standards to define measurements to be performed at the acceptance of the systems, after the regular maintenances (at least once every six months; status test) and for assuring the stability of the systems. To verify the feasibility, from the point of view of technical and a time requirements, the quality assurance programme proposed has been applied on three gamma camera systems. The results of this study show that, based on international standards, new requirements concerning the quality assurance of the gamma camera of the Swiss Public Health Authority make it necessary to slightly modify some procedures to reduce the time required for the acceptance and status tests.

\textbf{Introduction.} In the Ordinance related to the use of unsealed radioactive sources (November 1997) the Swiss Public Health Authority requires the supplier to carry out a reception test on all imaging devices used in the field of nuclear medicine before they can be used on patients. Moreover, a maintenance procedure of the imaging device has to be performed at least every six months by properly trained staff. This maintenance has to be followed by a status test that assures the integrity of the system before it can be used for further clinical applications. Daily and weekly stability tests, under the responsibility of the users of the system, are also defined. According to the Swiss Ordinance, all the measurements required for the acceptance and status tests should follow International standards set by either the National Electrical Manufacturers Association (NEMA) or the International Electrotechnical Commission (IEC) \cite{1, 2}. In practice, it appeared that the standards available at that time were not sufficiently precise to allow the technical staff from the manufacturers to perform these tests. Thus, acceptance and status tests performed were manufacturer dependent and could not allow the comparison of performances of different systems. This study presents these recommendations, shows their feasibility, evaluates the time and the material required and proposes slight modifications to simplify a few measurements.

\textbf{Content of the tests.} The background document of this work is the standard NEMA NU-1. Table 1 summarizes the tests required in the framework of reception and status test (RT: acceptance (or reception) test and ST: Status test (six month frequency).
TABLE 1. PARAMETERS AND MINIMAL FREQUENCY REQUIRED FOR GAMMA CAMERA SYSTEM IN SWITZERLAND

<table>
<thead>
<tr>
<th>Ref</th>
<th>Parameters to verify</th>
<th>Periodicity</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>Intrinsic flood field uniformity</td>
<td>RT + ST</td>
<td>NEMA 2.3</td>
</tr>
<tr>
<td>Z2</td>
<td>Homogeneity of the system</td>
<td>RT</td>
<td>Control of all the collimators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RT + ST</td>
<td>Visual monitoring</td>
</tr>
<tr>
<td>Z3</td>
<td>Intrinsic energy resolution</td>
<td>RT + ST</td>
<td>NEMA 2.2</td>
</tr>
<tr>
<td>Z4</td>
<td>Intrinsic resolution</td>
<td>RT or if Z5 is out of the tolerance</td>
<td>NEMA 2.1</td>
</tr>
<tr>
<td>Z5</td>
<td>System spatial resolution</td>
<td>RT</td>
<td>NEMA 2.4 with collimator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RT + ST</td>
<td>Phantom with bars, visual comparison with reference</td>
</tr>
<tr>
<td>Z6</td>
<td>System planar sensitivity</td>
<td>RT + ST</td>
<td>NEMA 3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RT with all the collimators, SC only with the more used</td>
</tr>
<tr>
<td>Z7</td>
<td>System count rate performance with scatter</td>
<td>RT</td>
<td>NEMA 3.4</td>
</tr>
<tr>
<td>Z8</td>
<td>Pixel size</td>
<td>RT + ST</td>
<td></td>
</tr>
<tr>
<td>Z9</td>
<td>Spatial linearity</td>
<td>RT</td>
<td>NEMA 3.1</td>
</tr>
<tr>
<td></td>
<td>System linearity</td>
<td>RT + ST</td>
<td>Visual comparison</td>
</tr>
<tr>
<td>Z10</td>
<td>System documentation</td>
<td>RT + ST</td>
<td>Specific to the manufacturer</td>
</tr>
<tr>
<td>Z11</td>
<td>Wholebody system spatial resolution</td>
<td>RT</td>
<td>NEMA 2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RT + ST</td>
<td>Phantom with bars</td>
</tr>
<tr>
<td>Z12</td>
<td>Correction values for the centre of rotation</td>
<td>RT + ST</td>
<td>Specific to the manufacturer</td>
</tr>
<tr>
<td>Z13</td>
<td>Quality of the slice image</td>
<td>RT + ST</td>
<td>According to manufacturer, Jaszczak phantom</td>
</tr>
<tr>
<td>Z14</td>
<td>Transmission sources</td>
<td>RT + at the change of source</td>
<td>According to data of the manufacturer</td>
</tr>
</tbody>
</table>

**Conclusion.** These new requirements will permit a uniform qualification of the gamma camera systems. A set of minimal acceptance tests is now available and requires two and a half hour acquisition time per head. For status test, the acquisition time can be reduced to one hour and a half per head, taking into account that the longer test (intrinsic homogeneity) is often required in the process of the maintenance. The main problem encountered during this study is the manipulation of very high activities when dealing with the assessment of the counting rate behaviour. To reduce exposure, manufacturer staff should be properly trained and the strict respect of the standard (let the source decrease) should be preferred since this test is only required for reception of the unit where time constraint is less of a problem. Concerning stability tests, one should control the homogeneity at least weekly and should check the picking and contamination of the system on a daily basis.

**REFERENCES**


Acceptance tests of a new gamma camera

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For best patient service, a QA programme is needed to produce quantitative/qualitative data and keep records of the results and equipment faults. Gamma cameras must be checked against the manufacturer’s specifications. The service manual is usually useful to achieve this goal. Acceptance tests are very important not only to accept a new gamma camera system for routine clinical use but also to have a role in a reference for future measurements.

In this study, acceptance tests were performed for a new gamma camera in our department. It is a General Electric MG system with two detectors, two collimators. They are low energy general purpose (LEGP) and medium energy general purpose (MEGP). All intrinsic calibrations and corrections were done by the service engineer at installation (PM tune, dynamic correction, energy calibration, geometric calibration, energy correction, linearity correction and second order corrections). After installation, calibrations and corrections, a close physical inspection of the mechanical and electrical safety aspects of the cameras were done by the responsible physicist of the department. The planar system is based on measurement of system uniformity, resolution/linearity and multiple window spatial registration. All test procedures were performed according to NEMA procedures developed by the manufacturer.

**Intrinsic uniformity:** NEMA uniformity was done first by using service manual and then other isotope uniformities were acquired with $^{99m}$Tc, $^{131}$I, $^{201}$Tl and $^{67}$Ga. They were evaluated qualitatively and quantitatively, but non-uniformities were observed, especially for detector II, The service engineers repeated all tests and made necessary corrections. We repeated all the intrinsic uniformity tests.

$^{99m}$Tc intrinsic images were also performed at “no correction”, “no energy correction”, “no linearity correction”, “all correction” and “±10% off peak”, and compared.

**Extrinsic uniformity:** At the beginning, collimators were checked for defects visually and Co-57 sheet source check was done, LEGP, MEGP collimators, 128×128 matrix, 120M counts. Single defect was observed in one of the LEGP collimators. This collimator has been replaced by the manufacturer. A collimator test was also done by a point source at 10 million counts for each collimator. Images from both collimators show the expected pattern of counts, indicating that the holes are perpendicular and parallel.

**Resolution and linearity:** Quantitative measurement of intrinsic resolution and linearity were done by NEMA linearity phantom. Resolution and linearity values were good and it was within the manufacturer’s specifications limits. These are given in Tables 1 and 2. Qualitative intrinsic and extrinsic resolutions were done using bar quadrant phantom with point source and Co-57 sheet source respectively. Quantitative resolution was done by using two capillary tubes with 512×512 matrixes, zoom: 2. FWHM was then calculated.
Multiple window spatial registration, quantitative analysis was performed using the NEMA method in the acquisition system which was developed by the manufacturer. Sensitivity was obtained by using a Petri dish and then it was calculated in the units of (count/second)/MBq.

Whole body scan was done with Co-57 sheet source. The poor images obtained at the beginning became better after the PMT gain adjustment and corrections were done by the service engineer. Pixel size was obtained by using line source, and it was calculated.

Tomographic system is based on measurement of resolution, uniformity and centre of rotation. Centre of rotation was done with point source and was within the acceptable limits. An overall assessment of system performance was obtained by Jaszczak phantom. The phantom was filled with 444 MBq $^{99m}$Tc. It was imaged under ideal conditions, i.e. minimum radius of rotation, LEGP collimator, and 128×128 matrices, with 120 views, zoom 1.0 and zoom 1.33. All conditions were taken from the service manual. After acquisition, optimal good image and attenuation conditions were determined. Finally, reconstructions were done by using ramp, Hanning filter with cut-off 1.0. Chang’s attenuation correction was used at threshold: 20, and coefficient: 0.105 setting and single pixel thick slices through the uniform section of the phantom was evaluated. In spite of uniformity correction, ring artefact was observed. Resolution elements were evaluated for tomographic resolution. It was evaluated for zoom 1.0. But for zoom 1.33 “+” shaped artefact in the sagittal and coronal slices was observed. Uniformity was performed with Co-57 sheet source at zoom 1.33. “+” shaped artefact insisted. The service engineer could not help and the production manager decided that they had a software problem for zoom 1.33. After they developed a new software, all tomographic acquisitions were repeated. No artefacts were observed.

<table>
<thead>
<tr>
<th>Table 1. NEMA Resolution Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEMA Resolution</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>CFOV FWHM</td>
</tr>
<tr>
<td>CFOV FWTM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. NEMA Linearity Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEMA Linearity</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>CFOV Absolute</td>
</tr>
<tr>
<td>CFOV Differential</td>
</tr>
</tbody>
</table>

The acceptance tests performed on a General Electric MG system gamma camera were found within specified limits by the manufacturer except a “+” shaped artefact due to a software problem. This study emphasizes the importance of a newly acquired gamma camera in a Nuclear Medicine department for acceptance tests in the QA programme.

REFERENCES

[1] INSTRUMENTATION AND RADIATION SAFETY COMMITTEE, Quality Control (draft).
Comparison for QA of $^{99m}$Tc activity measurements with radionuclide calibrators

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Braunschweig, Germany

The radioactive isotope $^{99m}$Tc is frequently used in nuclear medicine for diagnostic purposes. Before a radiopharmaceutical labelled with $^{99m}$Tc is administered to a patient, the activity is determined with the aid of radionuclide calibrators (activimeters) in order to obtain a reliable diagnostic result while keeping the unnecessary exposure of the human body as low as possible.

At the end of 2005 the Physikalisch-Technische Bundesanstalt (PTB) and the company AEA Technology (now: QSA Global) organized a joint national comparison of $^{99m}$Tc solutions in order to obtain information on the quality of routine activity measurements in nuclear medicine in Germany. The participants were asked to measure the activity in P6-type glass ampoules and in syringes. The results and supplementary information on the instrument characteristics, uncertainties, radionuclidic impurities and steps for quality control had to be stated in a questionnaire prepared by the organizers.

The distribution of the deviations ($A_i/A_{i,\text{ref}}$) with the activity $A_i$ stated by the participants and the reference activity $A_{i,\text{ref}}$ measured at PTB is shown in Fig. 1 for the measurements with glass ampoules. About 92% of the results fulfil the limitations prescribed by the European Pharmacopoeia [1], i.e. the deviation to the reference value is less than ±10%.

Table 1 shows some important results not only of this work but also from previous comparisons in Germany [2,3]. The data clearly indicate a considerable reduction of the deviations. In spite of this improvement there is still a considerable number of results which do not comply with the ±10% criteria.

In this contribution, the $^{99m}$Tc comparison results for two different geometries are presented and compared with results of previous comparisons. The data were also carefully analysed to detect potential causes for discrepancies and to find steps for further improvements of the quality in nuclear medicine.

| $|A_i/A_{i,\text{ref}}|$ | 1983 | 1987 | 1994 | 2005 |
|----------------------|------|------|------|------|
| No. of participants  | 83   | 62   | 192  | 52   |
| No. of reported results |          |      |      |      |
| ≤0.1                 | 80%  | 76%  | 78%  | 92%  |
| ≤0.2                 | 94%  | 94%  | 94%  | 100% |
| >0.2                 | 6%   | 6%   | 6%   | 0%   |
| >0.5                 | 0%   | 0%   | 1%   | 0%   |

TABLE 1. RESULTS OF $^{99m}$Tc COMPARISONS IN GERMANY. $A_i$ ACTIVITY STATED BY THE PARTICIPANT; $A_{i,\text{ref}}$ ACTIVITY MEASURED AT PTB
Syringes: number of reported results

<table>
<thead>
<tr>
<th>Deviation ≤</th>
<th>Result Count</th>
<th>Reporting Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.1</td>
<td>98</td>
<td>70%</td>
</tr>
<tr>
<td>≤0.2</td>
<td>61</td>
<td>90%</td>
</tr>
<tr>
<td>&gt;0.2</td>
<td>193</td>
<td>10%</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>95</td>
<td>0%</td>
</tr>
</tbody>
</table>

*) one extreme value unconsidered;
**) two extreme values unconsidered.

FIG. 1. Distribution of the deviations \((A_i - A_{i, ref})/A_{i, ref}\) for measurements of \(^{99m}\)Tc solutions in P6-type glass vials. The activity \(A_i\) was reported by the participants. The reference activity \(A_{i, ref}\) was measured at PTB.

REFERENCES

QC of $^{99}$Mo/$^{99m}$Tc generator between 2003 and 2005 in two nuclear medicine laboratories in Brazil


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Centro de Radioimunooensaio e Medicina Nuclear do Paraná Ltda (CERMEN), Brazil

Technetium-99m is the most used radionuclide in nuclear medicine diagnostic procedures due to, among other characteristics, the uncomplicated and flexible way of obtaining it from $^{99}$Mo/$^{99m}$Tc generators. Despite the appropriate characteristics of the product and attainment process, occasionally the eluate can be contaminated with undesirable proportions of $^{99}$Mo or Al$^{3+}$, and control of this was the object of study by several authors [1,2]. In this work are presented the results of a quality control programme of a $^{99}$Mo/$^{99m}$Tc generator in two Brazilian nuclear medicine laboratories during the years 2003 and 2005.

A total of 488 $^{99}$Mo/$^{99m}$Tc generators were evaluated, with calibrated activities of 37 GBq (37 units), 55.5 GBq (355 units) and 74 GBq (74 units). All of them were produced by the same manufacturer (IPEN-CNEN/SP, Brazil). The radioisotopic purity was performed using 6 mm of lead shield, the chemical purity was done with an aluminum spot test kit produced at CMN-FMUSP, the radiochemical purity was accomplished by chromatographic analysis using a W1 paper/methanol 85% system, and the pH, using a pH indicator paper. Systematic analyses were performed just in the first elution, except for the radioisotopic purity that was evaluated in the first and in the subsequent elutions, and the chemical purity that was also evaluated in the second elution. The thresholds established in United States Pharmacopoeia (USP-XXIII) [3] were used as standard values. The number of tests performed in each group of generators is shown in Table 1.

**TABLE 1. NUMBER OF TESTS PERFORMED IN EACH GROUP OF GENERATORS**

<table>
<thead>
<tr>
<th>Generator type (GBq)</th>
<th>Number of generator</th>
<th>pH</th>
<th>Number of analysis performed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Radionuclide purity</td>
</tr>
<tr>
<td>37</td>
<td>37</td>
<td>37</td>
<td>161</td>
</tr>
<tr>
<td>55,5</td>
<td>355</td>
<td>355</td>
<td>2081</td>
</tr>
<tr>
<td>74</td>
<td>74</td>
<td>74</td>
<td>444</td>
</tr>
</tbody>
</table>

All elutions assessed showed an average pH = 5 and radiochemical purity over 95%, which are in agreement with USP-XXIII limits. However, eluates from some generators presented radionuclide and chemical purities that are below the values established in USP-XXIII, as shown in Figs 1A and 1B.
Although Morengo [2] did not find any value in disagreement with USP, our results proved the importance of performing quality control in generators, especially for radioisotopic and chemical purities. Moreover, generators with higher activities are more prone to show QC problems.

REFERENCES


Comparison of two systems of paper chromatography for a fast determination of radiochemical purity of $^{99m}$Tc-MAG3

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The $^{99m}$Tc-mercaptoacetyltriglycine ($^{99m}$Tc-MAG3) was introduced in the medical practice as an alternative to $^{131}$I-Hippuran for the determination of the renal function [1].

Since the appearance of the $^{99m}$Tc-MAG3, its radiochemical impurities have been reported as a handicap (2,3,4). The $^{99m}$Tc-impurities in a final product and the accumulation of the radiolabeled lipophilic impurities in the liver are a source of complications in the quantitative renal function studies.

Several methods [51] have been used for the $^{99m}$Tc-MAG3 radiochemical purity (RP) quality control. Nowadays, the HPLC is the most reliable method. However, its high cost and the time this method consumes have limited their use for the RP routine controls in the hospital radiopharmacy laboratory. The use of alternative methods, such as solid phase extraction chromatography (SPEC), instant thin layer chromatography (ITLC) and ascending paper chromatography (APC) allows reduction in cost and duration of the quality control test, but in turn they introduce some errors that can overestimate or underestimate the real values of the $^{99m}$Tc-MAG3 RP.

In this paper we evaluate two solvent mixtures as mobile phase for APC using strips (1×18 cm, Whatman 1) for determining the RP of $^{99m}$Tc-MAG3 (UJV, Hungary) just before it is injected. The solvent mixture 1 (System A) was composed of Acetonitrilo/H2O (70:30) and it is the system recommended by the supplier. The solvent mixture 2 (System B) was composed of Acetone/Chloroform/Acetic Acid (13:3:2) [6].

Our goal is to demonstrate the existence of significant differences in the RP values obtained for the two systems.

Comparative studies of two quality control systems were carried out six times. The values of RP obtained differed notably for both methods. System A showed a mean value of $^{99m}$Tc-MAG3 (hydrophilic fraction) RP of (98.7 ± 0.7 %) and the System B showed a RP mean value of (90.2 ± 2.5 %). The substantial differences found showed that the System A overestimate the RP value of $^{99m}$Tc-MAG3.

Images of the analysed patients confirmed the differential behaviour of two chromatographic systems. We found that when the RP values obtained by the System A were high and the values obtained by System B were in the limit or below the accepted RP values, we observed an appreciable and sustained liver uptake (Fig. 1).

Our results revealed that System A is unable to separate efficiently the $^{99m}$Tc-MAG3 lipophilic fraction from the $^{99m}$Tc-MAG3 hydrophilic fraction and, because of this, an overestimation of the real RP values of $^{99m}$Tc-MAG3 occurred. We conclude that it is not possible to use system A in the rapid quality control of the $^{99m}$Tc-MAG3 just before its clinical use.
FIG. 1. Differential liver uptake in studied cases.

REFERENCES


Radiopharmaceutical quality of $^{18}$F-FDG QA/QC produced by the Cyclotron Laboratory, Chilean Nuclear Energy Commission

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The cyclotron technology for production of neutron deficient radionuclides is rather new in Chile. Positron emitter tomography (PET) has been introduced since 2003 with $^{18}$FDG as the contrast medium triggering the most significant revolution in non-invasive, ambulatory, prognosis procedure with all known tremendous benefits for patient’s quality of life.

Written procedures and checklist regarding the production process were created in order to introduce QA normatives to warrant the desired final product quality to be administered on human patients [1,2].

Therefore, production, maintenance programmes, document registry and quality controls have been adopted as SOPs.

Physical chemistry and biological assays are performed at the same time the product is released.

Results are electronically communicated to hospitals and PET centers where the $^{18}$FDG is finally injected upon QC results.

The aqueous fluoride anion, $^{18}$F, is produced by the classical nuclear reaction channel $^{18}$O(p, n)$^{18}$F used with a medium-low energy accelerator (such as IBA’s Cyclone 18/9 cyclotron). Oxygen-18 enriched water is the target to be irradiated.

For radiosynthesis, an automated $^{18}$FDG labeling module has been used during the past three years producing more than 337 production runs. $^{18}$FDG is thus produced by nucleophilic substitution on protected mannose triflate. Currently, $^{18}$FDG is produced four days per week, fifty-two weeks per year. The total number of patients since April 2003 is more than 1,600$^{(3)}$.

Quality controls are performed mainly to cover pH determination, radiochemical and radionuclidic purities as well as K222 traces and LAL tests. Radiochemical controls are performed by TLC-SG using acetonitrile:water (95:5) while Kryptofix is assayed with TLC-SG on methyl alcohol: Ammonium hydroxide (9:1) and Iodine are used as developer.

Every batch of $^{18}$FDG produced since 2003 shows radiochemical purities over 99%. Kryptofix content, through spot test, has been consistently below 0.017 mg per ml of product. LAL test resulted negative in all cases with the exception of two runs. Specific $^{18}$FDG activity runs from 20 to 50 mCi/ml. pH runs from 5.0 to 5.5. These figures, when compared with actual USP accepted values, correlate quite well (radiochemical >90%, LAL <175/V (UE/ml), with pH range from 4.5 to 8.5.
REFERENCES


Count-rate analysis from clinical scans in PET with LSO detectors

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$^b$Radiographer Corse, Faculty of Medicine, University of Udine,

$^c$Nuclear Medicine Department, S. Maria Hospital, Udine, Italy

The optimization of the acquisition parameters in Positron Emission Tomography has the purpose to improve the quality of the diagnostic images. Optimization parameters are a function of the administered activity, the time between the radiopharmaceutical injection and the PET scan, the duration of the scan and the patient size. Optimization can be done maximizing the signal-to-noise ratio (SNR) which leads back to the noise equivalent count rates (NECR) calculation, that in turn depends on the coincidences rate. As already proposed in literature [1,2] it is possible to set personalized values of the acquisition parameters for each patient.

In this work we present the results from a retrospective analysis of the clinical coincidences rates collected from 500 scans performed with a LSO based PET/CT scanner (Biograph Duo, Siemens). For each bed the scanner records in a log file the coincidences and the singles counts that have been analysed off line later. In order to optimize the injected activity, for each patient we figured out the functions $T=T(s)$, $R=R(s)$, $S=S(s)$ (where $T,R,S$ and $s$ are the true, random, scattering and single count rates, respectively) fitting the NEMA 70 cm phantom count rate curves on the measured clinical points, in order to analytically calculate the personalized PseudoNECR(s) curve [1]. The PNECR(s) curves relative to the central bed are reported in Fig. 1 where the single count rates are pretty far from the PNECR maximum. Assuming that the ratio between the activity at the PNECR_max and activity actually administered is the same for patient and phantom, it is possible to calculate the required activity to get the PNECR_max. For each bed, the Fig. 2 shows the percentage of missing activity to get the PNECR_max.

**FIG. 1.** Clinical PNECR and coincidences rates for patients with 52–62 kg weight and 155–170 cm height.

**FIG. 2.** percentage of missing activity to get the maximum PNECR value.
For central beds we estimate a missing activity of ~70%: but the improvement of the PNECR that we could get using such activity is around 15%. Since the gain in terms of PNECR is so low, it could appear not justified from the patient exposure point of view to inject higher activities than those currently administered.

As proposed in [1], it is also interesting to estimate the correlation between the patient weight and the PNECR_max. Such correlation allows us to estimate which should be the scan duration of a single bed in function of the patient weight to acquire the same PNEC. If we normalize the counts at the PNECR_max for the 70 Kg patient, we find that as the patient weight increases, the duration of the single bed has to increase proportionally (Fig. 3). Based on this analysis, the bed duration for a 90 kg patient should be of 230s, ~30% bigger than the 180s bed duration conventionally adopted. Finally, in Fig. 4 we show the measured correlation between the % distance of the measured PNECR from the PNECR_max and the time between the activity injection and scan (patients weight between 60 and 70 kg, with a mean injected activity of 363MBq, s.d.=22MBq). Being a direct proportionality between single counts and activity, one expects the PNECR gets worse at the time with the law PNECR(s[A(t)]) as shown in dashed line. It seems useful to us to interpret the diagram of Fig. 4 as an indication of how much the SNR goes away from the its maximum value as the time between the activity administration and the scan increases.

**Conclusions**

Although the analysis indicates that the fast electronics implemented in the scanner allows the use of higher administered activities, we found that this would involve poor improvement in terms of NECR. Attention can instead be addressed on the usefulness of higher bed duration for heavier patients.

**REFERENCES**


Radionuclide calibrator comparisons and quality improvement in nuclear medicine

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⁹Czech Metrological Institute, Prague, Czech Republic
¹⁰Comissão Nacional de Energia Nuclear (CNEN), Rio de Janeiro, Brazil

This paper presents and discusses the evaluation over time of the quality of activity measurement results obtained in Cuban nuclear medicine, on the basis of statistical samples taken during the radionuclide calibrator comparison programme that has been operating since 2000. Particularly, results of Cuban comparisons have demonstrated that the relative standard combined uncertainty of Cuban radionuclide calibrator activity measurement results performed in accordance with adequate quality control measurement procedures, can be ascertain as equal to 3.3 % for employed in comparisons nuclides namely, $^{131}$I, $^{99m}$Tc and $^{201}$Tl. Therefore, this is also a confirmation of that CENTIS-DMR Calibration and Measurement Capabilities for $^{131}$I, $^{99m}$Tc and $^{201}$Tl radionuclide calibrator calibration services also satisfy established in Cuban regulations ± 10 % accuracy limit.

On the other hand, an attempt has been made to evaluate the role played by radionuclide calibrator comparisons in quality measurement improvement in nuclear medicine, on the basis of comparisons results obtained in a number of countries and published by several authors over a period of time. Data of gamma-emitters such as $^{99m}$Tc, $^{201}$Tl, $^{67}$Ga and $^{131}$I are employed for this analysis. A $\chi^2$ test is applied to determine the character of association between the observed performance and the period of time when the exercises were organized at a significance level $\alpha$=0.05. Specifically, improvements of the measurement performance over time assessed by such exercises were found dissimilar in magnitudes in different countries Two moments could be distinguished in the improvement process over time. Firstly, a fast improvement can be obtained resulting from the improvement in measurement accuracy of devices. After that, the achievement of new and sustained improvements goes slowly and requires the application of quality assurance programs where the qualification upgrading of personnel become an essential point.

TABLE 1. COMPARISON OF OVERALL PERFORMANCES ACCORDING THE ±10 % ACCURACY LIMIT, SHOWN IN DIFFERENT COUNTRIES DURING RADIONUCLIDE CALIBRATOR COMPARISONS

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of acceptable results</th>
<th>No. of non-acceptable results</th>
<th>Totals</th>
<th>$\chi^2$</th>
<th>$\chi^2_{c}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First organized in countries comparison exercises</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina/1980/$^{131}$I (Furnari, et al., 1992)</td>
<td>8</td>
<td>3</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany/1985/$^{131}$I (Debertin &amp; Schrader, 1992)</td>
<td>77</td>
<td>17</td>
<td>94</td>
<td>4.22</td>
<td></td>
</tr>
<tr>
<td>Czech/1991/$^{131}$I (Olšovcová, 2004)</td>
<td>33</td>
<td>8</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuba/2000/$^{131}$I, $^{201}$Tl</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>186</td>
<td>53</td>
<td>239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>No. of acceptable results</td>
<td>No. of non-acceptable results</td>
<td>Totals</td>
<td>$\chi^2$</td>
<td>$\chi^2_{c}$</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------</td>
<td>-------------------------------</td>
<td>--------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>UK/$^{131}$I, $^{99m}$Tc, $^{201}$Tl (Woods, 1987; Baker, 2001)</td>
<td>299</td>
<td>18</td>
<td>317</td>
<td>8.39</td>
<td></td>
</tr>
<tr>
<td>Cuba/$^{131}$I, $^{99m}$Tc, $^{201}$Tl /2002–2004</td>
<td>129</td>
<td>16</td>
<td>145</td>
<td>24.41</td>
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<tr>
<td>Totals</td>
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<td>45</td>
<td>764</td>
<td>9.70</td>
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</tr>
<tr>
<td>Cuba/$^{131}$I, $^{99m}$Tc, $^{201}$Tl /2002–2004</td>
<td>129</td>
<td>16</td>
<td>145</td>
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<tr>
<td>Totals</td>
<td>300</td>
<td>104</td>
<td>404</td>
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</tbody>
</table>

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**BIBLIOGRAPHY**


Alternative fast methods for calculation of non-uniformity in nuclear medicine images: Comparison with conventional method

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Background. Non-uniformity test is the most essential in daily quality control procedures of nuclear medicine equipment. However, the calculation of non-uniformity is hindered due to high level of noise in nuclear medicine data. Non-uniformity may be considered as a type of systematic error while noise is a random error. The present methods of uniformity evaluation do not distinguish between the two and produce incorrect results when noise is significant. In the present study, two hypothetical methods were examined for evaluation of non-uniformity in nuclear medicine images. In the first method it is assumed that significant non-uniformity in the image significantly deviate the distribution of pixel counts from the Gaussian one. In the second method, a white frequency spectrum was assumed for noise spectrum in frequency domain. It was also assumed that significant non-uniformity in a flood image significantly increases the amplitude of the noise at some related frequencies.

Methods and materials. Statistical analysis. From the statistical point of view, pixel counts in a uniform flood image may be considered as a set of random values. This is because several physical phenomena involved in the formation of the image have statistical nature. Each phenomenon has its own probability distribution mainly of Poisson type. Based on the central limit theorem the overall distribution tends toward the Gaussian one. However the main characteristic of Poisson distribution (variance=mean) remains almost valid for overall distribution. Based on this assumption, in the absence of non-uniformity, pixel values in a uniform flood image follow a Gaussian distribution of known mean and variance. We further assumed that significant non-uniformity in the image significantly deviate the distribution from Gaussian. Kolmogorov-Smirnov test was examined as a possible means in measuring non-uniformity of flood images.

Fourier analysis. A uniform flood image is composed of two components; a constant mean counts in all pixels and noise that randomly and independently changes the pixel values around the mean. Fourier spectrum of such flood image is composed of very high amplitude at zero frequency reflecting the average count and small amplitudes at all other frequencies (reflecting the random noise). Noise in nuclear medicine is quite a random process, therefore no frequency component of the noise outweighs. It can be assumed that the frequency amplitudes of the noise are also random variables having a probability distribution. We further assumed that significant non-uniformity in a flood image significantly increases the amplitude of the noise at some related frequencies. In order to verify this hypothesis the highest frequency amplitude of the noise were compared to the average amplitudes.

Simulation. Using the Monte Carlo method, uniform and non-uniform flood images of different matrix sizes (64×64 ...1024×1024) and different counts (5, 10, 15....200 million) of Gaussian distribution were generated. To simulate the non-uniformity, the following two-dimensional sinusoidal function was used.

\[ NU(i, j) = D \times 0.5 \times (\text{Sin}(\frac{n\pi i}{m}) + \text{Sin}(\frac{n\pi j}{m})) \]

where m is the matrix size, “i” and “j” are the pixel numbers. The n in this equation determines the extent of non-uniformity. We used the values from 11 to 20 to simulate different forms of uniformities. The “D” in this equation reflects the degrees of non-uniformity in the image.
Uniformity of the images was calculated using the conventional method and proposed methods. The results were compared with the known non-uniformity of simulated images.

**Results.** The study showed that the value of integral uniformity is exponentially dependent on count density, preferable matrix sizes for calculation of integral uniformity is $128 \times 128$, and minimum count density required: 3000. (Fig. 1a). The value of differential uniformity is always less than the values of integral uniformity in similar conditions. Minimum required count density to calculate differential uniformity in matrix $128 \times 128$ is 9800 (Fig. 1b). *Kolmogorov-Smirnov test:* Results showed that it has very stable values even in low counts. Minimum required count density for Kolmogrov-Smirnov test in matrix $128 \times 128$ is 3000 (Fig. 1c). *FFT test:* This parameter could perfectly reflect the non-uniformity even in very low counts. Minimum required count density for using Fourier analysis in matrix $128 \times 128$ is 400 (Fig. 1d).

**Conclusion.** Both proposed methods were more sensitive to the non-uniformity at much lower count densities. Table 1 shows this conclusion.

**TABLE 1. COMPARISON OF CURRENT AND PROPOSED METHODS FOR EVALUATING NON-UNIFORMITY**

<table>
<thead>
<tr>
<th>Test</th>
<th>Counts per pixel</th>
<th>Critical value</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT</td>
<td>400</td>
<td>$809.89 \pm 0.8$</td>
<td>5</td>
</tr>
<tr>
<td>Integral Uniformity</td>
<td>3000</td>
<td>$0.018 \pm 0.003$</td>
<td>40</td>
</tr>
<tr>
<td>K-S</td>
<td>3000</td>
<td>$1.055 \pm 0.68$</td>
<td>40</td>
</tr>
<tr>
<td>Differential Uniformity</td>
<td>9800</td>
<td>$0.014 \pm 0.002$</td>
<td>134</td>
</tr>
</tbody>
</table>

*FIG. 1. Results of the study and tests.*
Correlation of QA and radiation safety problems in nuclear medicine

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As a rule, these problems are considered independently of one another when practical recommendations on quality assurance (QA) and patient radiation safety in radionuclide diagnostics and therapy are developed and formulated. International standards and recommendations, the IAEA standards including guidelines on QA and radiation safety are independently elaborated, officially approved and used in clinical practice.

Nevertheless, the adequate level of radiation safety can not be achieved without observance of all QA requirements. For different QA technologies the relation between patient radiation exposure and overall patient radiation safety can be direct and indirect.

The organizational and purely medical activities entering the overall QA system for radionuclide diagnostics and therapy, influence the radiation safety by binary logic principle: under successful nuclear medical procedure delivery and reliable radiation accident prevention, radiation treatment is considered to be justified and clinically efficient and vice versa.

These activities include:

\begin{itemize}
  \item radionuclide diagnostics or radionuclide therapy prescription (case history records, medical documentation, suggested diagnosis, indication and contra-indication, nuclear-medical procedure tolerance forecast);
  \item radionuclide diagnostics or radionuclide therapy planning (information and preliminary patient preparation essential for most of the radionuclide therapy techniques, choice of the necessary radiopharmaceutical and its introduction);
  \item radiopharmaceutical introduction (absence of the extravascular injection during the intravenous introduction and the skin radioactive contamination during the oral introduction);
  \item objective assessment of radionuclide diagnostics (valid diagnostic decision determination) or radionuclide therapy results (patient supervision in dynamics);
  \item software functional capabilities and reliability in measurement results processing during radionuclide diagnostics or absorbed dose distribution estimate in pathologic centres and critical organs by radiosensitivity during radionuclide therapy;
  \item staff basic qualification and personnel practical skills in all QA and radiation safety aspects.
\end{itemize}

QA of the selected radiopharmaceutical, research procedure (protocol) and physical and technical characteristics of the equipment greatly influences patient radiation safety. Sterility, anti-inflammation, chemical toxicity, isotonicity, pH index for the pharmaceutical (if they only meet the established requirements and restrictions) just slightly determine the concrete values of effective radiation dose of the patients. Similarly, the same should be mentioned
about QA of the measurement procedures and characteristics of gamma camera and SPECT systems which merely determine the quality and self descriptiveness of the registered images (background, energy window, registration efficiency, sensitivity heterogeneity, image scale, spatial resolution, active linearity, contrast resolution, rotation centre deviation for SPECT system, etc.).

Finally, the introduced radiopharmaceutical activity and the equipment sensitivity highly influence the patient radiation safety. The activity could be slightly reduced without the loss of diagnostic information of the received images under high sensitivity and accepted spatial resolution. This principle is the basis of the section “Medical Radiation Treatment” of the ICRP publications and Radiation Safety Standards in Russia (RSS-99): maximum permissible radiation doses are not specified as the priority is given to the reliable diagnostic data acquisition (radionuclide diagnostics) or the pronounced therapeutic effect (radionuclide therapy) under the minimum overall radiation exposure level of the patient.

In IAEA BSS-155 Standard under radionuclide diagnostics, it is recommended to choose such a radiopharmaceutical activity that will not exceed the reference value of radiopharmaceutical indicated in the standard. This approach is convenient for the routine clinical practice of radionuclide diagnostics but could be incorrect or even erroneous if the radiopharmaceutical supplier and the case study protocol is changed or new equipment with different sensitivity is used.

Therefore, a special procedure based on the choice of optimal activity of radiopharmaceutical was developed. (V.I.Trushin, 2003). The concrete activity value of a radiopharmaceutical is specified for each concrete radionuclide diagnostics technique and every specific equipment (gamma camera and SPECT system) by a set of phantom and clinical measurements on the apparatus. This allows provision of reliable and unequivocal image interpretation, including rare clinical cases, and minimum patient radiation exposure. When the research protocol is changed, the optimal value of the introduced radiopharmaceutical activity for the next patient could be easily specified.

For radionuclide therapy the optimal activity choice procedure is based on the same QA principles and technologies which are standard for the external beam therapy and brachytherapy.

REFERENCES


Training of nuclear medicine technical staff by the Brazilian Society of Nuclear Medicine and Biology

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\textsuperscript{b}Centro de Medicina Nuclear, Hospital das Clínicas-FMUSP,

\textsuperscript{c}Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear,

\textsuperscript{d}Grupo de Trabalho de Cursos, Sociedade Brasileira de Biologia, Medicina Nuclear e Imagem Molecular,

São Paulo, Brazil

Nuclear medicine was introduced in Brazil in 1949, at the University of São Paulo. Despite being a pioneer in South America and the existence of about 280 clinics of this medical specialty in the whole country serving around 185 million inhabitants, there is not any dedicated course forming its technical staff. Another shortcoming lies in the fact that there are not any basic requirements established for these professionals by an official medical or nuclear entity. As result, one can find persons ranging from university graduates (biomedics, radiology technologists, biologists, pharmacists, chemists, physicists, etc.) to secondary school graduates or radiology technicians working in nuclear medicine centres, preparing patients, labelling and injecting radiopharmaceuticals, obtaining images and processing studies.

Due to the high heterogeneity of the technical staff and lack of a formal preparation, the Brazilian Society of Nuclear Medicine and Biology (SBBMN) organized during 2004 and 2005 short courses conducted in different regions of Brazil in order to supply organized basic knowledge and practice on:

1. Quality control of \textsuperscript{99m}Tc\textsubscript{99m}Mo and labelling and checking of dose calibrators
2. Fundamentals of radiation protection, area monitoring and decontamination
3. Quality control of scintillation cameras.

Six courses were given during these two years in four cities in the South Eastern region and two in the North Eastern region. The first two topics were delivered during one weekend and the participants were presented with a lecture in the morning and, in the afternoon, a hands-on practice on the same subject. As QC of eluates and labelling and checking of dose calibrators were less practised in most clinics, this was the first time that the majority of the participants performed these activities. In one course, offered during a national congress, all three topics were included and the practical part was replaced by many examples from routine checkings, as well as extracted from the IAEA Quality Control Atlas [1].

A total number of 200 people attended the courses, 145 of which were effectively working in nuclear medicine and related areas, and 55 were university students, mainly taking medical physics and biomedicine courses. About half of the active personnel were technicians in radiology (from a professionalized secondary school), 17% were either technologists in
radiology or biomedics, 20% were biologists and pharmacists and 13% were physicists, chemists and engineers.

The above numbers are coherent with the real scenario of the technical staff working in nuclear medicine clinics in Brazil, although the distributions are probably not the same in different regions and between large and small cities.

Five courses with practical activities took place either in federal research institutions or in state universities. The lecturers (all volunteers) were experienced physicists, chemists and pharmacists from those institutions. Due to the practical part, a maximum number of participants was set in each course, depending on the installations of the hosting site. The participants paid a small fee for used materials and hand-outs. Teaching material [2–4] was made available in the Society’s web site.

Each course was evaluated and comments and suggestions were requested from the participants. The general opinion on the course was good or excellent. On the average, all topics contents were considered appropriate, except for a few experienced participants that classified them superficial. The majority suggested increasing the course length, so each topic could be made comprehensive, with more practices included. The more experienced professionals also proposed dividing the course in introductory and advanced parts, in order to suit better groups with different degrees of experience.

The participants listed many topics as possible subjects for future courses. Most wanted topics include:

- clinical protocols, specifying frequent mistakes, care to be taken, etc.
- kits labelling
- QC/QA of cameras with practice
- PET, PET/CT
- radiation protection in $^{131}$I therapy and PET installations
- theoretical basis in NM (physics, chemistry)
- image processing in clinical routines
- ethics and good practice for NM technologists.

From the results, comments and suggestions, it is possible to confirm the necessity of this type of courses, especially outside the large cities. As it is not feasible, in a short term basis, to create graduate courses of technology in nuclear medicine, the Society is planning to continue this activity in order to enhance and assure the quality of nuclear medicine technical human resources in Brazil.

ACKNOWLEDGEMENT

SBBMN would like to thank Activa, Amersham, MRA and REM for their financial support in the six courses.

REFERENCES

Patient-specific dosimetry in radioiodine therapy for thyroid disease: Optimization of computational procedure


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Treatment of benign and malignant thyroid disease with radioiodine is under strict regulatory control in Germany. Pre-therapeutic treatment planning and peri-therapeutic dosimetry are mandatory. A medical physics expert has to be involved to ensure that the desired dose is delivered to the thyroid while keeping exposures to non-target tissues as low as achievable.

We have devised a computer-based procedure to support physician and medical physicist in performing the required optimization. It is based on an Excel spreadsheet which collects data from a number of databases and makes the necessary computations. Its main features are:

- Calculation of the activity required to achieve a given thyroid dose from pre-therapeutic measurements of thyroidal radioiodine uptake (RIU) according to the “Procedure guideline for radioiodine test” [1].
- Displaying the time activity curve (TAC) for thyroid and whole body of the patient during the time of patient hospitalization (at least two daily measurements are performed on each patient) together with a prediction of this TAC from the above-mentioned radioiodine test.
- Prediction of dose committed to the target organ from numerical integration of the TAC and its extrapolation to infinity using the patient-specific observed effective half-lives.
- If the peri-therapeutic target dose falls short of the desired value, the spreadsheet computes the necessary amount of radioiodine for a second application but also lets the physician model the effect of giving the patient stable iodine in order to achieve a longer effective half-life in the thyroid [2], thus possibly avoiding a second application.
- The “time to release”, i.e. the time until the patient meets the regulatory criteria for release from the hospital (e.g. dose to members of the public not to exceed 1 mSv), is updated with each measurement and allows bed planning.
- Upon release of the patient from the nuclear medicine therapy ward, “discharge forms” are automatically generated which contain the relevant information - for the doctor: dose to thyroid, doses to gonads and other non-target tissues, statistical robustness of the dose computations; - for the patient: a set of advice to adhere to after discharge (based on [3]) and the amount of time to follow them, based on age of patient and family, effective half-life and residual activity at time of discharge.

We consider the main advantages of the procedure to be:

- Standardization of all computational steps yielding robust dose estimates.
- Elimination of errors, e.g. from transcription or manual input, as all data are gathered from databases.
- Early prediction of a possibly low thyroid dose gives the physician a better chance to react appropriately.
The software has been used on ca. 2,700 patients. It has not only significantly improved the workflow of the radioiodine therapy ward between nurse, physician, and physicist, but has also optimized patient treatment by achieving the desired thyroid dose with the smallest dose to non-target tissues. In more than 95% of patients with Graves’ disease, the therapeutic goal was achieved with a single in-patient treatment.

<table>
<thead>
<tr>
<th>Pat-ID</th>
<th>22772257</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family Name</td>
<td>Sample</td>
</tr>
<tr>
<td>First Name(s)</td>
<td>Diana</td>
</tr>
<tr>
<td>Date of birth</td>
<td>29.02.1935</td>
</tr>
<tr>
<td>Thyroid mass</td>
<td>13 g</td>
</tr>
<tr>
<td>Disorder</td>
<td>Graves</td>
</tr>
<tr>
<td>RIU date</td>
<td>10.03.2004</td>
</tr>
<tr>
<td>Uptake 24h</td>
<td>49.9%</td>
</tr>
<tr>
<td>Uptake late</td>
<td>31.0% at 5 days</td>
</tr>
<tr>
<td>Effective half-life</td>
<td>5.8 days</td>
</tr>
</tbody>
</table>

### Activity to be applied for 250 Gy thyroid dose

<table>
<thead>
<tr>
<th>Activity applied</th>
<th>Marinelli</th>
<th>261 MBq</th>
<th>change dose</th>
<th>Bockisch</th>
<th>261 MBq</th>
<th>discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied after</td>
<td>264 MBq</td>
<td>7.1 mCi</td>
<td>24.03.2004 13:37</td>
<td>Uptake</td>
<td>47.7%</td>
<td>4,2</td>
</tr>
<tr>
<td>Uptake</td>
<td>180 MBq</td>
<td>4.9 mCi</td>
<td>26.03.2004 12:52</td>
<td>Half-life (d)</td>
<td>17.0%</td>
<td>5.1</td>
</tr>
<tr>
<td>Thyroid dose</td>
<td>258 Gy</td>
<td></td>
<td></td>
<td>(based on measured values)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIG. 1. Main calculation page of spreadsheet.**

**REFERENCES**


Quantitative lung SPECT without transmission acquisition: Potential applications in 3D patient-specific dosimetry and in evaluation of treatment response

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Patient specific methods based on 3D quantitative imaging using SPECT/CT and PET/CT are being applied in preclinical and clinical scenarios for the optimization of targeted radionuclide therapy and for the appropriate evaluation of therapeutic response [1,2]. However, CT significantly increases the radiation dose to the patient, especially (but not exclusively) when contrast-enhanced techniques are used for diagnostic purposes in addition to attenuation correction (AC) [3]. Furthermore, CT data are not universally available. Dose estimation in lung is often required as this can be the critical organ that limits the activity administered for therapy. Quantification is particularly problematic due to the variation in attenuation coefficients ($\mu$) in the thorax and direct estimation of $\mu$ values is therefore essential. The density of lung tissue shows relatively wide variability making it unfeasible to assume a universal $\mu$ value. The variation in $\mu$ for different lung slices in six patients was estimated from their CT data (Fig. 1). The $\mu$ values vary from lung apex to base occupying a different range for different patients. This variability could be even larger when pathological changes are present. The aim of this work was a) to estimate quantitative errors in assuming a fixed $\mu$ for lung, and b) to develop a method for estimation of lung attenuation based on emission data.

a) The possible errors in quantification were evaluated using the 3D NCAT phantom for activity levels representative of patient studies. Spherical “lesions” were added to the phantom to simulate abnormal lung SPECT studies. Projections were generated based on the corresponding attenuation maps with $\mu$ value for lungs set to 0.045/cm and a high resolution collimator for “normal” and “abnormal” lungs. High count studies were simulated to minimize noise, and scatter was not included. Data were reconstructed using OSEM (15 subsets, 1 iteration) with and without AC using a range of assigned $\mu$ for lung (0.03–0.06/cm). Counts (cts.) in abnormal (A) and normal (N) lung segments were determined and presented as A/N ratios. The % error in normal lung when assuming a wrong $\mu$ or not performing AC was also measured. Figures in Table 1 demonstrate that an incorrect assumption in the $\mu$ can result in ~10% error. Importantly, the error does not influence normal and abnormal tissue equally, resulting in significant variation in the A/N ratio.

\begin{table}[h]
\centering
\caption{RESULTS OF ASSUMING A FIXED ATTENUATION COEFFICIENT FOR LUNG}
\begin{tabular}{|c|c|c|c|c|}
\hline
Attenuation map & “Normal” cts & % error in & “Lesion” cts & A/N ratio \\
\hline
no AC & 2010 & -72.0 & 301 & 0.150 \\
\hline
$\mu$=0.030/cm & 6502 & -9.5 & 587 & 0.090 \\
\hline
$\mu$=0.045/cm & 7184 & 0.0 & 698 & 0.097 \\
\hline
$\mu$=0.060/cm & 7899 & 10.0 & 838 & 0.106 \\
\hline
\end{tabular}
\end{table}

b) To reduce the error in assuming a fixed attenuation coefficient for the lungs we propose an estimation method based on the emission data only, avoiding the necessity of a separate transmission acquisition. We assume that for pulmonary studies the outline of the body can be obtained from the scattered photon projections and lungs delineated from the emission data.
We assume a constant $\mu$ of tissues outside the lungs: $\mu_T = 0.15$/cm for 140 keV, while for the lungs, $\mu_L$, is constant within each slice $i$. The number of scatter corrected primary cts. in each projection $j$ and slice $i$ can be written as

$$N_{i,j} = A_i \int \rho(r) \exp(-\mu_L d_{L,i,j}(r)) \exp(-\mu_T d_{T,i,j}(r)) dr$$

where $A_i$ is the total activity within the slice, $\rho(r)$ the normalized activity distribution, $d_T(r), d_T(r)$ the primary photon paths from a point $r$ through the lung and non-lung tissues, respectively. Since $\mu_T$ is small so that $\mu_L d_{L,i,j} << 1$ for most ray paths, we can use the Taylor expansion of the second exponential up to the second order to obtain:

$$N_{i,j} = A_i (a_{ij} \mu_L^2 + b_{ij} \mu_L + c_{ij}).$$

Given the outlines of the lungs and the body and the estimated activity distribution $\rho(r)$ based on reconstruction with constant attenuation, analytic projections of the patient can be calculated for different assigned $\mu_L$ values, e.g. 0, 0.03, 0.07. Using (2) the coefficients $a_{ij}, b_{ij}$ and $c_{ij}$ can be derived. The quadratic model (2) can then be fitted to the measured projections for each slice, $A_i$ and $\mu_L$ being the fitting parameters. The new attenuation map $\{\mu_L\}$ can be used to obtain a more accurate activity reconstruction and the process can be repeated iteratively. The method was tested using simulated SPECT emission data based on real patients’ CT scans and assuming uniform activity distribution within the lungs. The results for one patient are shown (Fig. 2) for different levels of noise in emission data. For the six patients, errors in $\mu$ are typically less than 10% compared to the observed variation of more than 50%.

The proposed method provides a simplified approach for quantification in the lung without the need for an additional CT or transmission measurement and should reduce the errors in assuming a constant $\mu$ value.

REFERENCES


Patient characteristics criteria for adjusting $^{18}$F-FDG administered activity for PET: Weight, body mass index and DuBois skin surface area

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Objectives

The EANM procedures guideline for the administered activity of $^{18}$F FDG [1] indicates a value of 6 MBq/Kg for optimal image acquisition with a full ring PET scanner. Since image quality depends not only on the activity/weight ratio but also on other important parameters such as scattering on very large patient’s fat tissues and since a tall and thin patient can weigh as much as a shorter and heavier one, our study intends to quantify the role of other factors such as the body mass index (BMI) and the calculated DuBois skin surface area (SSA) to the acquired PET signal final quality.

Methods

We used data from 63 adult patients’ whole body scans (seven to nine beds; head not included) from which we recorded the height, weight and the total patient activity calculated at the moment of the scan. These parameters were correlated to the total number of true-counts per bed per activity, as an indicator of image quality outcome prediction, acquired by a Siemens LSO full-ring high-resolution Biograph 6 PET/CT scanner.

Results

The total number of true-counts per bed per activity is shown to correlate linearly with the weight of the patient within the measured range (44 to 120 Kg), as expected, as well as with the BMI and SSA, reflecting solely the attenuation coefficient of the body of the patient.

Conclusions

We found that the linear regression coefficient R-squared is higher when we represent the total number of true-counts per bed per activity as a function of the weight ($R^2 = 0.585$) and SSA ($R^2 = 0.596$) of the patient, indicating that the criteria of basing the administered activity on the weight seems to be appropriate ($R^2 = 0.528$ for BMI). However, we observe that patients with higher BMI present higher scattering and attenuation in fat tissues, modifying the underlying relevant clinical FDG distribution both before and after CT based attenuation correction. This suggests that this parameter should also be taken in consideration when establishing the administered activity to those patients, namely for lowering that value for patients with lower BMI. Consequently, the image analysis of PET scans from patients with
the same weight but different BMI values enables the determination of a BMI correction factor for the administered activity of very fat or very thin patients.

**FIG. 1.** Axial images (same scale and graphic representation parameters) at kidneys level from two different patients with approximately the same weight but different BMI. Left image: body weight = 72.0 Kg; height = 186 cm; BMI = 27.87; SSA = 1.95; administered activity = 8.4 mCi; activity at the time of scan = 4.6 mCi; total-trues per bed per activity = 11074. Right image: body weight = 75.0 Kg; height = 163 cm; BMI = 34.51; SSA = 1.85; administered activity = 8.3 mCi; activity at the time of scan = 4.7 mCi; total-trues per bed per activity = 9928.

**REFERENCE**

The effects of acquisition and processing techniques on myocardial SPECT

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The aim of this study was to investigate the effect of some acquisition and reconstruction parameters on cardiac SPECT image quality. An anthropomorphic torso phantom simulating lungs, liver, female breast and cardiac insert filled with $^{99m}$Tc and tomographic acquisition were performed with a dual head Siemens ECAM variable-angle system. Activity ratios of lungs, liver, breast and body sections were 7.5%, 75%, 3% and 7.5% of the myocardium activity, respectively. These ratios were determined from the evaluation of real patient SPECT images. The cardiac insert included one non-filling solid sector and three fillable defects of different volumes, with the angular extensions of 60°, 45°, 90° and 180°.

Eleven different acquisition protocols including different detector angles, orbits, number of projections and matrix sizes were used. Each acquisition was performed with one activity concentration of fillable defects and these ratios were prepared as 0%, 33% and 66% of the myocardium activity. Considering the defect volumes, male-female cases, 22 tomographic acquisitions were made for each defect concentration and a total of 220 studies were carried out. The solid and fillable defects were always fitted to the anterior and inferior parts of the cardiac insert. Detector configurations of 76°, 90° and 180° were used both for circular and noncircular orbits.

The filtered back projection (FBP), and iterative techniques (It-W and OSEM) were used for the reconstruction of one pixel thick transaxial slices, Chang and non-uniform attenuation correction (profile) techniques were also performed. Reconstructed images were transferred to a personal computer with Dicom and further processed with ImageJ processing software. Image sets composed from nine images each with different inferior defect concentration (45°, 90°, 180° defects with 0%, 33% and 66% activity concentrations) were prepared for the comparison of acquisition and processing techniques. The contrast of defects and myocardium cavity was measured numerically through the count contents of ROIs drawn over defects and background areas. The thickness and sharpness of myocardium wall, uniformity of count distribution and image distortion were considered as qualitative analysis for image comparisons. Moreover, Friedman test was used for the evaluation of the defects by ranking the visual score of five observers.

**Detector orbits.** Circular versus non-circular orbits were compared both for 90° and 180° detector configurations using 32 projections, 128×128 matrix and reconstructed with FPP technique. In case of 90° detector angle and female images, better defect contrasts were recorded for non-circular orbits but loss of sharpness, increased wall thickness, and image distortions were noticed for circular orbit images. For 180° detector configuration, slightly better image qualities for females were observed for non-circular orbit images in comparison with circular orbit images.
Detector configurations. Separate acquisitions were made for each of 76°, 90°, 180° detector configurations using non-circular orbits, 32 projections and 128×128 matrix, and FBP technique. Slightly better contrasts were observed for 76° configuration.

Number of projections. 64 and 32 projection images were obtained using non-circular orbit, 128×128 matrix and FBP technique. Better image quality and defect contrasts were obtained for 64 projection images.

Matrix sizes. The images acquired with 128×128 matrix and 646×64 with 1.45 zoom factor were compared for the FBP; It-W and OSEM techniques. Both acquisitions were made for 90° detector configuration, non-circular orbit and 32 projections. 128×128 matrix images were better in quality for all reconstruction algorithms. Up to 20% to 30% contrast improvements were noticed for It-W and FBP but less for OSEM techniques (10%).

Detector numbers. Tomographic images obtained with 90° and 180° dual head configurations were compared with the images of a tomographic acquisition performed with a single detector. Non-circular orbit, 128×128 matrix size and FBP technique and equal number of projections were used for all the studies. Although the accuracy of the alignment of two detectors were confirmed with quality control studies, better image qualities were obtained for the images acquired with a single detector.

Reconstruction and attenuation correction techniques. FBP, It-W and OSEM techniques were compared for 90° detector configuration, non-circular and 32 projections for each detector. Default parameters were used for the iterative techniques and Butterworth filter with a cutoff of 0.5 and order 5 were selected for all the reconstructions. In general, less image distortion and improved contrast was noticed for It-W technique. Better anterior and cavity contrasts were obtained for male images for all the algorithms. Deformation of wall thickness and increased non-uniformity were noticed in female images.

Classical Chang and profile attenuation correction methods were used with the reconstruction techniques. It-W with the profile correction was found to be better than the other combinations.

REFERENCES


Simple and fast camera-based QC of $^{99m}$Tc-HMPAO radiopharmaceutical purity

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Background. Conducting radiochemical purity (RCP) control of simple in-house radiopharmaceutical formulations, before injecting, is regarded a good clinical practice and is therefore generally recommended. The methylene-blue stabilized technetium $^{99m}$Tc exametazime (Ceretec®) is an approved tracer for regional brain perfusion studies usually used to investigate epilepsy, dementia disorders, brain perfusion reserve, acute focal neurological deficits as in transient ischemic attacks (TIA), prolonged reversible ischemic neurological deficit (PRIND) and in stroke. The radiolabeling reaction of Ceretec is dependent on maintaining tin in the divalent (reduced) state. Any oxidant present in the employed sodium pertechnetate solution may adversely affect the quality of the preparation. Therefore, achieving consistently high RCP requires adherence to certain requirements related to the Mo/Tc-generator, specific activity and the age of the $^{99m}$TcO$_4^-$ eluted solution. Herein we present our experience in evaluating and routinely performing radiochemical quality control applying a fast, simple and reliable technique using gamma camera.

Materials and methods. (1) An instant thin layer chromatography (ITLC) QC kit (Cat. #151-660), was from Biodex Medical, USA. It consists of ITLC Whatman and Gelman ITLC/SG stripes. (2) Three small glass vials, methyl ethyl acetone, 0.9% aqueous sodium chloride solution, 50% aqueous acetonitrile diluted with water for injection, The procedure is performed as in: http://www.rxlist.com/cgi/generic4/ceretec_ids.htm Percent lipophilic exametazime complex by this method, is determined by cutting and counting the stripes in a well-type counter. The Camera Protocol is based on an in-house written, semi-automated pixie-macro program with a built-in quality assurance component requesting the operator to enter data on the age of the generator, time of previous elution “milking”, age of the $^{99m}$Tc solution, time of RCP testing after radiolabelling, and identity of the technologist performing the procedure. The imaging protocol applies high-resolution parallel whole collimator, 256×256 matrix size and zoom factor of 1.48 and 3 min acquisition time. A reproducible positioning of the three chromatographs is guaranteed by applying a wooden template (30×30 cm, 5 mm thick) containing three carved lanes (7×0.8×0.2 cm L×W×D, Fig. 1). The program automatically calls seven identical rectangular regions of interest (ROI), six over the ITLC stripes and one for background subtraction. The report includes information entered by the technologist, position of ROIs, scintigraphic image of the chromatograms, count-statistics, percent bioactive complex and impurities (Fig. 2).
Results. The time needed for determining the RCP is about 10–12 minutes. An experienced technologist can determine a good quality formulation by visual inspection of the scintigraphic image (Fig. 2). This method correlated very well with the gamma counter method, \( R +0.99 \) (Fig. 3). Under optimal radiolabelling conditions, most preparations can be used up to 3 hours (Fig. 4), provided the clinician does accept the 80% cut-off recommended by the manufacturer. We were more conservative and chose to use an RCP value of at least 87% which resulted in good quality images. Fig. 4B presents data related to the age of the Tc/Mo-generator and previous recent generator milking event, on the result of the RCP and the time-dependent deterioration of % bioactive \(^{99m}\)Tc-HMPAO complex. Open circles show the concentration of bioactive complex when radiolabeled with a fresh solution that is obtained from an old generator milked earlier on the same day, or radiolabeled with the first eluate from a new generator (up triangles) or with the second eluate from the same new (“Monday”) generator (open squares). Using the first elution from a “Monday” generator resulted in the worst initial RCP values and showed the fastest decomposition over time.

Conclusion. Radiochemical quality control of in-house radiolabeled, more demanding radiopharmaceuticals, can be performed easily, routinely and reliably by using existing camera equipment and software. Our experience indicates that introducing quality assurance component to such programs results in a gradual improvement of the quality of the in-house produced radiopharmaceuticals through a teaching and a positive feedback effect by identifying, discussing and eliminating error sources.
Acceptance and routine tests for a small animal PET scanner


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The main objective of this work was to describe the quality control procedures used to characterize a pre-clinical small animal PET scanner (GE eXplore Vista). These procedures consist of a set of acceptance tests in order to evaluate the physical performance of the scanner and a set of routine tests performed on a daily or weekly basis. The eXplore Vista is a fully 3D PET scanner consisting in 36 detector blocks arranged in two rings. Each detector module of the scanner is a block of 169 phoswich elements arranged in a 13×13 array. Each element is 1.45 mm ×1.45 mm×15 mm in size and composed of two scintillator crystals: a Lutetium Yttrium Orthosilicate (LYSO) and a Gadolinium Orthosilicate (GSO) crystal optically glued together. The GSO element is also optically glued to a position sensitive photomultiplier (PSPMT). The transaxial field of view (FOV) is equal to 6 cm and the axial FOV is equal to 4.6 cm.

In order to evaluate the performance of the eXplore Vista, several parameters such as: spatial resolution (SR), sensitivity, scatter fraction (SF) and noise equivalent counts (NEC) have been measured [1]. The measurement of the spatial resolution was performed by using a point source, a line source and a high resolution phantom (HRP). In order to evaluate the influence of the positron range on spatial resolution, two different radiotracers were used ($^{18}$F or $^{11}$C). A small piece of zeolite (diameter 0.2 mm) was soaked with a $^{18}$F or $^{11}$C solution and used as point source. The zeolite was placed in the centre of the FOV and several images for each energy window (100–700keV, 250–700keV, 400–700keV) were acquired. In order to obtain a line source a stainless steel needle (internal diameter equal to 0.3 mm) was filled with a small amount of activity (about 1MBq). The line source was used to investigate the variation of the spatial resolution with respect to transaxial position to this purpose four images with the needle placed at different y positions (spaced by 5 mm) were acquired. The spatial resolution was also measured with an HRP phantom consisting of a rectangular array of holes with different diameters (2 mm, 1.5 mm, 1 mm and 0.5 mm) and with centres spaced by 4 mm, 3 mm, 2 mm and 1 mm. The phantom was filled with a solution of 15 MBq of $^{18}$F and $^{11}$C and acquired for 1 h. All the images were reconstructed using the filtered back projection (FBP) (ramp filter) after Fourier rebinning. In order to evaluate the absolute sensitivity of the eXplore Vista a small point source (about 1.2 MBq of $^{18}$F) was placed at the centre of FOV. The measurement was performed using all the three energy windows. The measurement of the SF was carried out using a line source with an internal diameter equal to 0.8mm placed respectively in air and inside two water filled cylindrical phantoms (diameter 2.6 cm and 3.0 cm) in order to simulate mouse and rat size objects. Images were acquired using each energy window for 10 minutes. The measurement of the NEC was obtained by placing a mouse sized phantom and a rat sized phantom filled with a solution of about 200 MBq of $^{18}$F at the centre of FOV. Measurements were acquired every 15 minutes during six half-lives. The routine tests performed on a daily basis consist of a blank scan and a measure of the background coincidence counting rate (cps). The last measurement is based on the signal coming from the small amount of $^{176}$Lu inside the LYSO crystal. On a weekly basis a uniformity measurement was also performed. In order to perform all the routine tests a Graphic User Interface (GUI) software was developed using IDL 6.2 (Interactive Data Language). The program allows the user to load interfile files and to save the results as an ASCII file. The blank scan was analysed visually in order to look for diagonal strike artefacts, and a quantitative index was also calculated dividing the standard deviation and the mean value of a central ROI for each slice. The evaluation of the eXplore Vista stability was performed by measuring the coincidences per second without any source in the FOV. The image is acquired with 100–700 energy window for
20 minutes. The measure of uniformity was performed with a uniform cylindrical ⁶⁸Ge phantom and measuring the minimum, maximum and mean intensity of a central ROI for each slice.

The full width at half maximum (FWHM) obtained with the point and the line sources are equal to 1.77 mm and 1.91 mm for ¹⁸F and ¹¹C, respectively. The resulting volumetric resolution is equal to 3.82 mm³ for ¹⁸F and equal to 5.78 mm³ for ¹¹C. The dependence of spatial resolution with respect to radial position is plotted in Fig. 1. Profiles drawn through the HRP hot spots show that ¹⁸F provides a better spatial resolution with respect to ¹¹C.

![Spatial Resolution Graph](image)

**FIG. 1. Values of spatial resolution FWHM (mm) as a function of radial offset obtained using a ¹⁸F line source.**

The absolute sensitivity of the eXplore Vista are 2.2%, 3.9% and 5.9% for 400–700 keV, 250-700 keV and 100–700 keV energy window, respectively. The SF values obtained in air and water for a mouse-sized phantom and a rat-sized phantom are summarized in Table 1.

<table>
<thead>
<tr>
<th>SF% Values in Air and Water for Mouse and Rat-Sized Phantom</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF % in air</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>100–700 keV</td>
</tr>
<tr>
<td>250–700 keV</td>
</tr>
<tr>
<td>400–700 keV</td>
</tr>
</tbody>
</table>

Analysis of the background cps over a period of 12 months showed a maximum variation of about 6% mainly due to software changes in the acquisition system, however the correct value (about 550 cps) can be established after performing a timing calibrations. Visual and quantitative analysis of the blank images showed a good detectors stability over the past 12 months.

Results show that the eXplore Vista provides high spatial resolution and at the same time good sensitivity. The value of the spatial resolution for ¹¹C labelled tracers was worse respect to ¹⁸F, such loss of resolution for ¹¹C was also evident by looking at in vivo mouse images. Simple routine tests such as the analysis of the background cps proved to be very useful in order to detect slight variation from the normal working mode of the scanner.

**REFERENCE**

Comparison of $^{123}$I FP-CIT SPECT acquisition protocols

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The use of $^{123}$I FP-CIT brain SPECT is a valuable tool in the diagnosis of Parkinson’s disease (PD) by accessing the uptake deficits of the striatal dopaminergic system [1]. The final image quality depends on the specific type of camera used, as well as on the acquisition and reconstruction parameters. Typically these studies are characterized by a very low detector count rate, thus optimization of the acquisition parameters is very important [2].

The aim of this study was to compare three different acquisition protocols used in two gamma cameras (two protocols for a Neurocam and one protocol for a Discovery VH).

Material and methods

A phantom study with an RSD striatal phantom was performed. The phantom has five compartments which can be filled separately, left and right compartments of the nucleus caudate (5.4 ml) and putamen (6 ml) were filled with 38 kBq/ml of a $^{123}$I Iodide solution and the brain compartment (~1250 ml) with ~5 kBq/ml of the same solution.

The study consisted of three different acquisitions with the settings listed in Table 1 and all acquisitions were performed with low energy high resolution collimators.

<table>
<thead>
<tr>
<th>TABLE 1. ACQUISITION SETTINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Camera (Protocol)</td>
</tr>
<tr>
<td>Neurocam (P1)</td>
</tr>
<tr>
<td>Neurocam (P2)</td>
</tr>
<tr>
<td>Discovery VH (P3)</td>
</tr>
</tbody>
</table>

All acquisitions were reconstructed with the same reconstruction parameters (Iterative reconstruction, Butterworth post-filter, without attenuation correction). The phantom was also scanned on a CT (matrix size 512×512 and 2.5 mm slice thickness).

All three SPECT datasets were co-registered to the CT scan. Using the CT image and, by segmentation, the five areas were marked and then used to access the statistics for each compartment of the SPECT datasets.
Results

The ratio between activity concentration of the $^{123}$I Iodide solution of the four compartments and the activity concentration of the brain was 7.06.

Using the SPECT statistics for each compartment, the following parameters were calculated:

- (R) the ratio between counts in the nucleus caudate/putamen compartments and the brain compartment
- (C) the contrast between the nucleus caudate/putamen compartments and the brain compartment
- (SNR) the signal to noise ratio between the nucleus caudate/putamen compartments and the brain compartment

The mean values are summarized in Table 2 (the SNR was normalized to the worst case).

**TABLE 2. RESULTS OF CALCULATIONS FOR EACH PROTOCOL**

<table>
<thead>
<tr>
<th>Gamma Camera (Protocol)</th>
<th>R</th>
<th>C</th>
<th>SNR%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurocam (P1)</td>
<td>3.12</td>
<td>0.51</td>
<td>0%</td>
</tr>
<tr>
<td>Neurocam (P2)</td>
<td>2.51</td>
<td>0.43</td>
<td>97%</td>
</tr>
<tr>
<td>Discovery VH (P3)</td>
<td>2.85</td>
<td>0.48</td>
<td>27%</td>
</tr>
</tbody>
</table>

Discussion and conclusion

The results show that both R and C have values of the same magnitude. The SNR was the parameter that changed significantly between the three protocols and as expected gave better results for protocol P2. This fact can be explained by the increased planar pixel statistics resulting from decreasing the acquisition matrix and increasing the frame time. Since the spatial resolution obtained with all protocols is consistent with recommended guidelines for this type of study [2], we conclude that the best protocol to be used is P2, because it presents the best SNR.

REFERENCES


Comparative radioanalytical and biokinetic studies of $^{99m}$Tc-Tin and $^{99m}$Tc-sulphur colloid kits


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Gel chromatography scanning technique (GCS) was used to study the radioanalytical behaviour of $^{99m}$Tc-tin colloid and $^{99m}$Tc-sulphur colloid kits. Sepharose has been found to be more accurate and versatile than the other conventional analytical procedures (Table 1) for radioanalytical evaluation of $^{99m}$Tc-labelled colloids [1]. The obtained radioanalytical results showed that $^{99m}$Tc-sulphur colloid is more susceptible than the $^{99m}$Tc-tin colloids to change due to the analytical environment. This is related to the nature of oxidation state of technetium atom in both colloids. The formation of $^{99m}$Tc-tin colloid is achieved within few minutes after pertechnetate addition, while labeling of sulphur colloid is accomplished through a rather slow process. The organ distribution in mice shows that more than 90% of the injected dose of both colloids are accumulated in the liver, which proved the colloid labeling and optimal size particle [2]. The minor size difference in the blood residual activity is due to the presence of hydrophilic stabilizer in $^{99m}$Tc-sulphur colloid [3].

The blood clearance study in rabbits showed that the biological half-times of activity disappearance of fast phase are longer periods extend to 125 and 65 minutes to $^{99m}$Tc-tin and $^{99m}$Tc-sulphur colloids, respectively.

The in vitro plasma protein binding studies revealed by the GSC method showed that about 85% of $^{99m}$Tc-tin colloid and 16% of $^{99m}$Tc-sulphur colloid were bound to plasma protein, which proved that it does not influence the in vivo kinetics of both colloids.

**TABLE 1. THE RELATIVE PERCENT OF $^{99m}$TC FRACTIONS IN THE LABELLED COLLOIDS, SEPARATED BY THREE RADIOANALYTICAL TECHNIQUES**

<table>
<thead>
<tr>
<th>Labelled preparation</th>
<th>Gel chromatography scanning</th>
<th>Paper chromatography</th>
<th>Electrophoresis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{99m}$Tc colloid</td>
<td>Free pertech.</td>
<td>$^{99m}$Tc colloid</td>
</tr>
<tr>
<td>$^{99m}$Tc-tin colloid</td>
<td>99.6</td>
<td>0.4</td>
<td>99.5</td>
</tr>
<tr>
<td>$^{99m}$Tc-sulphur colloid</td>
<td>14.2</td>
<td>3.1</td>
<td>82.7</td>
</tr>
</tbody>
</table>
REFERENCES


Analysis of Brazilian comparison programme for radionuclides activity measurements used in nuclear medicine - Implementation of a national metrology network

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The Nuclear Medicine Services (NMS) in Brazil routinely use radionuclide calibrators to measure the activity of solutions containing radiopharmaceuticals. These solutions are administered to the patients with the intention to diagnose or treat illnesses. However, for the accomplishment of an optimized examination, the activity of these radiopharmaceuticals must be determined as accurately as possible.

The National Laboratory for Ionizing Radiation Metrology (LNMRI) of the Institute of Radiation Protection and Dosimetry, National Commission on Nuclear Energy (IRD/CNEN), organized, since 1998, a comparison programme for activity measurements of radiopharmaceuticals administered to patients in the NMS with the purpose of promoting quality control [1].

In Rio de Janeiro the programme has been carried out successfully, but there is the need to implement it all around the country. This problem is being resolved through the implementation of a reference laboratories network in various points of the national territory [2].

In establishing this network, the following factors must be observed: the radionuclide calibrators located in the reference laboratories must be traceable to the LNMRI; the operators must be trained by a specialized LNMRI staff; the quality control must be assured through an intercomparison programme.

The performance of the NMS was analysed in relation to two parameters: the ratio $R$, that relates the result to the Brazilian norm requirements [3], and the normalized deviation $E$, associated with the quality of the individual measurements in relation to a reference value [4].

Actively working currently are the second node point, located in Brasília, covering the demand of all the Center-West Region and the third node point, located in Porto Alegre.

This work presents the global results, from 1998 to 2005, with the analysis of discrepancy results made with samples from glass vials and syringes and proposing simple solutions to minimize the problem.

Furthermore, the work presents the comparison results for those node points and proves that the implementation of a radionuclide metrology network is viable, important and feasible, as shown in Table 1.
TABLE 1. EXAMPLE OF COMPARISON RUNS REALIZED FROM 1998 TO 2003. WE OBSERVED THAT NMS' PERFORMANCE BECOMES BETTER IN THE SECOND RUN

<table>
<thead>
<tr>
<th>Year</th>
<th>Radionuclide</th>
<th>Comparison run</th>
<th>Results number</th>
<th>Good performance according CNEN Norm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>$^{99m}$Tc</td>
<td>1</td>
<td>23</td>
<td>78</td>
</tr>
<tr>
<td>2001</td>
<td>$^{99m}$Tc</td>
<td>2</td>
<td>22</td>
<td>86</td>
</tr>
<tr>
<td>2001</td>
<td>$^{67}$Ga</td>
<td>1</td>
<td>32</td>
<td>59</td>
</tr>
<tr>
<td>2003</td>
<td>$^{67}$Ga</td>
<td>2</td>
<td>53</td>
<td>68</td>
</tr>
</tbody>
</table>
Advancement in high speed digital telecommunication system has enabled unique approaches to transfer of knowledge [1]. In remote areas, where on-site professional personnel is not available, nuclear medicine training courses will be held over long distances in an ever increasing extent [2]. Training activities held in countries far away from the IAEA headquarters would entail the necessity for the teachers (trainers) and students (trainees) to convene at distant geographic locations.

The computer network involved is based on a client-server architecture. The server is a Unix system running X windows server with a virtual network computing (VNC) backend to guarantee security and uptime. It is connected to a RAID level 5 storage array of several TBytes. Clients are windows based to assure general accessibility. All communications are based on VNC through SSH (secure shell) tunneling to ensure encryption, e.g. Rivest, Shamir and Adleman encryption (RSA), or digital signature algorithm (DSA) as well as firewall penetration whenever SSH-out is provided. Communication is initiated from within the firewall, using the clients, to enable access to the server. Multiple users that are located at various sites can access the same display session and share their display (see Fig. 1).

The training tool presented here allows sharing of sessions for training or “read with the experts” over the internet, regardless of the distance of the centres. That means that both the expert and the trainee or trainees can access the same data at the same time, as well as follow the processing steps at both sites in exactly the same way. They can also have the possibility to interact with the processing activity performed by the counterpart (e.g. trainee).

The obvious benefit of such a teaching system is that both parties are working in exactly the same environment, assuring:

- All applications are set up and used in the same way. This is essential when processing and reading data.
- All studies are identical. So one can be sure that both parties look at the same images at the same time.
- Data transfer times are minimized: All studies remain on the common image server, no transfer of data needed. This reduces cost and set-up time and improves security.
- All reports are identical for common discussion.
- All archives are password protected and are to be used for specific educational projects only.
- The system manager has full control of who has done what and when.

With the tool presented, it is possible to provide a novel approach for remote training based on a solid platform for individualized training that is independent from available professional software on end-user systems, which only needs a standard PC and communication
environment. The tool does not only facilitate multi-centre communication, but also represents a novel way to provide proven quality control of the interactive training sessions.

**FIG. 1.** Typical setup of long distance training course: trainer and trainee are simultaneously accessing the same server.

**REFERENCES**


QC of nuclear medicine data collected in a worldwide network

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Background

A universal platform that can facilitate the management of medical imaging data and provide access to data sets produced by different imaging modalities or different platforms should significantly simplify the process of conducting multi-centre collaborative investigations, long distance consultation and teaching activity.

For this purpose the desired structure should fulfil various requirements:

1. Data trafficking – ease of accessibility, fast data transfer, secured access, encryption of data during transfer, automatic and on-line anonymization of patients’ information.

2. The software should be capable of reading different formats of various vendors and different dialects of a common accepted standard (DICOM or Interfile). It should allow access to the data in native format, for possible later processing, and in a common format (e.g. DICOM [1]) available for other users.

3. End users should have remote access to images and studies through a non-professional platform, making use of a standard web browser. This implies that no specialized software is required on the end-user side. The software (applets) provided by the master server should permit excellent quality viewing of data, simple image manipulation and for semi-quantitative data analysis. More resource-demanding functions should utilize the power of the host computer and deliver results to the client platform. For facilitating simultaneous multi-user activities, the software should allow simultaneous and synchronized access to identical slices in a given study to enable professionals and trainees to discuss specific findings by making use of a synchronized mouse pointer on both remote screens.

For an international comparison and reading of general nuclear medicine, PET or PET/CT data sets, data are collected from worldwide trial partners on a common server. This, so called HERMES Super Server (Hermes Medical Solutions, Stockholm, Sweden), is used to collect data from various manufacturers, different sites in different countries to an IAEA World Data Base.

Materials

The server used in this project, is a SUN Unix system connected to a RAID level 5 storage system of several TByte. Clients are based on the respective operating systems of the gamma camera/PET computers. All communication is based on SSH tunnelling to ensure encryption (RSA or DSA) as well as firewall penetration whenever SSH-out is provided. Communication is initiated from within the firewall, using the clients, to enable access to the server. Viewing
and processing is done directly on the server, without the need to transfer any image data. All programs used for viewing and processing are FDA and MDD approved.

Different gamma cameras from different vendors have different image formats and different communication protocols [2]. To ensure an optimized conservation of ALL involved image parameters, we

- Collect the studies in any importer communication protocol
- Archive all collected data in their original image format
- Automatically translate to any common image format like Interfile and DICOM when needed.

**Quality control of collected data**

Based on long term experience and feedback from “imaging partners” it was shown that during the conversion process of the native file format to a standard format as Interfile 3.3 or DICOM, loss of image parameters may occasionally occur. These parameters include:

- pixel size
- image orientation
- count rate and total counts
- scan duration, start and end time of a study
- scan speed in whole body acquisition
- radius of rotation essential when using fan-beam collimation
- centre-of-rotation offset
- various collimator properties
- multi-head properties.

We have solved this problem by storing all data on the server in their native formats, as provided from the client gamma camera system. Only this way we can ensure all imaging parameters for later access to the original data that may get lost or discarded on the original system.

The access to image data is project dependent and password protected. Both access and manipulation of data are monitored and carefully managed. All access to the server is HIPPA compliant. Data are stored in a Raid array, to avoid data loss.

Thus we can provide secure and quality controlled means for data storage in international multi-centre trails. Long term access and reproducibility of all image properties are guaranteed for all participating centres.

**REFERENCES**


Some aspects of QA in radiation medicine in the Republic of Moldova

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Quality assurance is based on monitoring, measuring, evaluation, verification and recording of quantities, parameters and facts significant from the point of view of radiation protection. The Republic of Moldova, with the support of the International Atomic Energy Agency, performs the quality assurance and quality control procedures under the framework of the Technical Cooperation Regional Projects RER/6/012 “Quality assurance and quality control in radiation oncology”, and RER/6/011 “Thematic programme on nuclear medicine”. The Ministry of Health and Social Protection carries out the National Project on “Ensuring radiation safety and protection of the patients” the principal goal being quality assurance and quality control in radiotherapy. In 2005, implementation of the National Project “Radiation Protection, Quality Assurance and Quality Control in the Nuclear Medicine” was started.

Quality assurance programmes shall be established to provide, as appropriate, adequate assurance that the specified requirements relating to protection and safety are satisfied and quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of protection and safety. Objectives of quality assurance include: improvement in the quality of the diagnostic information, use of the minimum radionuclide activity that ensures production of the desired diagnostic information, effective use of available resources. The quality of a practice is to fulfill the expectations and demands from the patient, the clinician and yourself. The primary service of quality assessment includes the communication with the client (patient, clinician). The final judge of any nuclear medicine practice is a clinical audit to determine the correctness and impact of the decisions made with respect to any method and process. e.g. internal audit, inspections by the regulatory authority.

The quality assurance programme stipulates: (a) Procedures, i.e. patient history and signs, diagnostic question, appropriateness of investigation, contra-indications; (b) Planning of procedures, i.e. reliable administrative procedures, patient information, patient preparation; (c) Clinical procedures, i.e. approved suppliers and materials, storage, preparation, clinical environment, patient handling and preparation, equipment performance, acquisition protocols, waste disposal; (d) Data analysis, i.e. processing protocol, equipment performance, data accuracy and integrity; (e) Reports, i.e. data, image review, results and further advice; (f) Training and experience of nuclear medicine specialists, physicists and technologists and others involved; (g) General outcomes, i.e. clinical outcome, medical exposure, patient satisfaction, referring physician satisfaction; (h) audits.

Quality assurance requests are the responsibility of the nuclear medicine specialist that the study requested by the referring physician is justified. Special attention must be paid to studies requested for children and pregnant women. There are alternative methods, e.g. ultrasound, MRI etc.

Communication, on a regular basis, between the referring clinician and the nuclear medicine specialist is very important.

A very important problem of quality assurance is the protection of the patients which include: (a) identification of the patient, (b) information about the examination including premeditation, (c) waiting for the examination, (d) an informed and motivated patient is the basis for a successful examination as well as staff who are well educated in care of the patient.
A procedure manual should be available for each type of study. The manual should be reviewed annually. Methods should be in accordance with accepted practices. Efficient use of computers can increase the sensitivity and specificity of an examination.

A diagnostic report includes: patient identification, date and type of study, radiopharmaceutical and activity, study results, e.g. a graph or a series of images, objective description of findings, diagnostic conclusion and recommendations.

Registrants and licensees shall establish a comprehensive quality assurance programme for medical exposures with the participation of appropriate qualified experts in the relevant fields, such as radio physics or radiopharmacy, taking into account the principles established by the WHO and the PAHO.

Quality assurance programmes for medical exposures shall include:

- Measurements of the physical parameters of the radiation generators, imaging devices and irradiation installations at the time of commissioning and periodically thereafter;
- Verification of the appropriate physical and clinical factors used in patient diagnosis or treatment;
- Written records of relevant procedures and results;
- Verification of the appropriate calibration and conditions of operation of dosimetry and monitoring equipment; and
- As far as possible, regular and independent quality audit review of the quality assurance program for radiotherapy procedures.

Factors affecting medical and occupational exposure consist of: receipt and storage, preparation, detection (QC equipment), administration, contamination and radioactive waste.

Quality assurance of the medical exposure includes: choice of examination, determination of technical parameters, optimization of administered activity, methods of reducing the absorbed dose, quality control of equipment and radiopharmaceutical, quality assurance of methods, safe routines to avoid misadministration, quality control of radiopharmaceuticals, radionuclide purity, radiochemical purity, chemical purity, written and practised procedures in preparation and safe handling of radiopharmaceuticals, use of a unique code which guarantees the ability to trace the origin of all components in the preparation, records of radionuclide, kits, etc., labeling of vials and syringes.

Quality assurance of the occupational exposure assumes the design of the facility, safe handling of unsealed sources, management of radioactive waste, safety equipment, personal monitoring, health surveillance, workplace monitoring, emergency procedures, local rules, training and experience of staff.

The main tasks of quality assurance for radiotherapy include:

- Development of methodologies and procedures for acceptance testing and commissioning of radiotherapy equipment.
- Development of QA methods for radiotherapy dose calculations and computerized treatment planning systems.
- Provision of scientific and technical support to Member States for the development of quality control techniques and setting up of national quality audit programmes.
QC studies and biological evaluations of three locally produced renal pharmaceutical preparations: \(^{99m}\text{Tc-DTPA}, {99m}\text{Tc-GH}, \text{and} {99m}\text{Tc-DMSA}\)

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Quality control (QC) studies were done of three locally produced renal preparations of \(^{99m}\text{Tc-DTPA}, \text{^{99m}Tc-GH} [1] \text{and} {99m}\text{Tc-DMSA}, \text{as part of the production activity before the Gulf war [1–2]}. These studies were performed using gel chromatography column scanning (GCS) technique, although there are other alternative techniques [3].

These kits were tested for radiochemical purity, and the labeling yields were found to be excellent. Biological studies included the following parameters: organ distribution (in mice, rats and rabbits), blood clearance in rabbits, and plasma protein binding in rats at different time intervals. Poor renal concentration of three agents in mice was significant at two time intervals. The tissue distribution in mice of DTPA, GH, and DMSA kits, which were stored at 37º C for 30 days, after intravenous injection of the radioactivity at 5, 30, and 60 minutes, respectively, is presented in Table 1.

Blood retention of the renal agents was considerably low compared to those in rats and rabbits at the respective time intervals. The blood clearance of \(^{99m}\text{Tc-DMSA} \text{was relatively slow, and} \text{^{99m}Tc-GH} \text{has rapid blood clearance, identical with that of \(^{99m}\text{Tc-DTPA} \text{for the first} 20 \text{minutes but slower thereafter. The binding of DTPA, GH and DMSA with plasma protein was 5, 65, 95 %} \text{at 1 h, respectively. Various amounts of tin (II) (as SnCl}_2\text{, were used in the kits, with up to 10 times more of the usual dose for respective tin–complex. It was observed that there was no significant variation of the organ distribution in mice.}

**TABLE 1. THE TISSUE DISTRIBUTION OF DTPA, GH, AND DMSA KITS\(^2\)**

<table>
<thead>
<tr>
<th>Organ</th>
<th>(^{99m}\text{Tc-DTPA})</th>
<th>(^{99m}\text{Tc-GH})</th>
<th>(^{99m}\text{Tc-DMSA})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 minutes(^2)</td>
<td>30 minutes(^2)</td>
<td>60 minutes(^2)</td>
</tr>
<tr>
<td>Blood</td>
<td>10.39 (+1.49)</td>
<td>1.86 (+0.23)</td>
<td>5.22 (+0.75)</td>
</tr>
<tr>
<td>Liver</td>
<td>4.42 (+0.73)</td>
<td>4.90 (+0.74)</td>
<td>6.61 (+0.79)</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.58 (+1.49)</td>
<td>1.12 (+0.62)</td>
<td>0.64 (+0.17)</td>
</tr>
<tr>
<td>Intestine</td>
<td>5.56 (+0.60)</td>
<td>8.78 (+1.96)</td>
<td>5.17 (+0.38)</td>
</tr>
<tr>
<td>R-Kidney</td>
<td>3.80 (+0.67)</td>
<td>2.73 (+0.39)</td>
<td>11.39 (+2.47)</td>
</tr>
<tr>
<td>L-Kidney</td>
<td>3.60 (+1.00)</td>
<td>2.69 (+0.45)</td>
<td>11.13 (+2.14)</td>
</tr>
</tbody>
</table>

\(^2\) Stored at 37ºC for 30 days, in mice after intravenous injection of the radioactivity at 5, 30, and 60 minutes, respectively.

\(^2\) Average of ten readings in relative percentage dose.
REFERENCES


Session 9: 

*Plenary IV*

EDUCATION AND QA-RELATED ACTIVITIES
The Pan American Health Organization’s programmes on QA and QC in radiation medicine: Historical perspective

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Since initiating radiation medicine activities in the 1950s, the Pan American Health Organization (PAHO) has developed, promoted and implemented quality assurance/quality control (QA/QC) programmes in the Americas.

In radiation oncology, QA/QC activities started in 1968, after a seminal IAEA/PAHO/WHO meeting on Dosimetric Requirements in Radiotherapy Centers, in Caracas, Venezuela, where the Secondary Standards Dosimetry Laboratory (SSDL) network and the Postal IAEA/PAHO/WHO Dosimetry Programme using TLDs, were created. In 1970, the first regional course for radiation oncologists and radiotherapy physicists, jointly sponsored by PAHO/WHO and the IAEA was held at the Puerto Rico Nuclear Center. Similar courses were organized in Mexico (1973), and Brazil and Chile (1975). In 1980, PAHO contracted a medical physicist to identify and correct errors in those radiotherapy centres where a deviation of greater that 5% had been observed, the first time that such on-site follow-up visits was provided. In 1982, in collaboration with the M.D. Anderson Hospital of the University of Texas and participation of the IAEA and the ICRU, a Working Group on Improvement of Radiation Dosimetry and Quality Assurance was organized in Houston, Texas and attended by SSDL directors. Their recommendations were endorsed by a 1983 Advisory Group Meeting on the Future of the Dose Intercomparison Service for Radiotherapy organized by the IAEA where, with PAHO’s participation, it was decided to expand the programme to include orthovoltage X ray machines and linear accelerators. In 1983, PAHO organized and hosted The First International Symposium on Quality Assurance in Radiation Therapy: Clinical and Physical Aspects, where a consensus on minimal and optimal standards for both clinical and physical QA aspects was reached. In 1988 and 1994, PAHO participated in regional IAEA courses in Peru and Venezuela. QC courses for clinicians and physicists were given in Cuba (1992), Ecuador (1998), Colombia (2002) and Uruguay (2004). From 1980 to 2005, PAHO participated in the congresses of the “Círculo de Radioterapeutas Latino Americanos” and in other international fora. A workshop to review the implementation of the IAEA/WHO Postal Dosimetry Program was held in the Dominican Republic in 1999 with the participation of all the TLD coordinators.

PAHO was most active in the nuclear medicine area in the 1980s. A programme for QA in imaging procedures was initiated in collaboration with the College of American Pathologists and the Latin American Association of Societies of Nuclear Medicine (ALASBIMN). In 1981, PAHO organized an international symposium on quality assurance in collaboration with the USPHS Bureau of Radiological Health (BRH) and the Federated Council of Nuclear Medicine Organizations to review the status of nuclear medicine and to develop minimum standards for QA programmes. In the same year, PAHO also collaborated with ALASBIMN and the IAEA in QA workshops in Bogotá, Colombia and with the IAEA and the Brazilian Association of Physicists in Medicine, in Sao Paulo, Brazil. From 1982 to 1985, PAHO hosted several nuclear medicine symposia with the BRH and the Federated Council of Nuclear Medicine Organizations. With the WHO Collaborating Center in Nuclear Medicine
in Danbury, Connecticut, a postal programme for evaluating the quality of nuclear imaging procedures was initiated in 1983, using phantoms designed by the College of American Pathologists. The programme ran until the late 1980s. In the 1990s and 2000s, nuclear medicine QC programmes continued to be promoted, and one course (Cuba, 1996), was organized.

In diagnostic radiology, following initiatives of the BRH, beginning in the early 1970s PAHO cooperated with national radiation protection services to introduce QA aspects into their radiation control activities such as education, training, and facility inspections. A specialized course on quality assurance in diagnostic radiology was given in Costa Rica in 1989. Since then, 25 national and eight (8) international courses have been organized and/or co-sponsored. Of these, three (3) were in CT; nine (9) in mammography, and the rest, in conventional radiology. Full evaluations of diagnostic radiology equipment and facilities, aimed at establishing national QC programmes, were carried out, mostly in Caribbean countries. From 1999 to 2003, a research project on Quality Assessment of Radiology Services, involving medical physicists and radiologists, was carried out in Argentina, Bolivia, Colombia, Cuba and Mexico, in order to correlate quality indicators for radiology services with the accuracy of the radiological interpretation. The only parameter that correlated was the experience of the interpreting radiologists. In 2001, 61 mammography units in 11 Latin American and Caribbean countries were evaluated in collaboration with the Inter-American College of Radiology, the Institute of Radiation Protection and Dosimetry, Brazil, and the Center for Devices and Radiological Health (CDRH), USA. Eighty-eight percent of the units evaluated complied with image quality requirements and only 8.5% of all the units exceeded the dose limit for average glandular doses.

The publication entitled Organization, Development, Quality Control and Radiation Protection in Radiological Services - Imaging and Radiation Therapy (1997), describes the organizational and technical aspects of radiation medicine services with emphasis on QA/QC programmes.
Transposition of the European Directive (Euratom 97/43) in European countries: A survey and an example from France

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The European Directive Euratom 97/43, dedicated to the radioprotection of patients, must have been transposed in all EU countries. This directive has been based on two main principles, which are Justification and Optimization of medical procedures using ionizing radiation.

Although this transposition in every European country has been a unique opportunity to improve quality of radiological services at a national level, the degree of sophistication in this transposition varies significantly between European countries. The European Association of Radiology conducted recently a survey on the results of this transposition in all European countries. The results of this survey will be presented.

In France, the Directive was transposed by laws, decrees and ministerial orders. In fact, the radiological profession embraced the two principles of the Directive, establishing the basis of a full quality management policy in radiology. A great number of radiologists, nuclear medicine physicians, physicists, and radioprotectionists were involved in the transposition procedure through the professional associations, administrative institutions and scientific societies. The French Society of Radiology and the French Society of Biophysics and Nuclear Medicine in conjunction with the Direction Générale de Sureté Nucléaire et de la Protection (DGSNR) started to work together on the Directive Transposition in 2001.

To apply the principle of optimization, a specific working group was in charge to write the detailed description of all diagnostic procedures utilizing ionizing radiation. This group, made up of experts in all subspecialties of imaging and physicists, provided consensually optimal parameters and recommendations for patient radioprotection. The same group established reference doses on the basis of a national multicentric campaign of dose measurements, done on a few radiological examinations performed on standard patients (chest radiography, plain abdominal film, brain CT and chest CT). According to the transposition, an obligation has been established for all departments of radiology to send annually the results of 20 dose measurements from radiographic and CT examinations on standard patients to the DGSNR. This procedure is requested in order to update the national database permitting to establish yearly the national doses of reference. There is also now an obligation for radiologists to give information of dose delivered during the examination in their radiological report.

To apply the principle of justification, another working group was in charge of establishing the guidelines for good clinical use of medical imaging (Guide du Bon Usage des Examens d’Imagerie Médicale). This document was established on the basis of the methodology defined by the National Agency for Accreditation and Evaluation in Health Care, recently named Haute Autorité en Santé, which labeled the document. The methodology, based on three subsequent steps, was conducted by a steering committee. Firstly, 14 expert groups were created for all subspecialties of radiology. They were in charge of writing 388 items reflecting the different clinical symptoms or suspected pathologic diagnoses, followed by the imaging technique, level of radiation dose, level of indication and level of proof. Secondly, this first
document was submitted to larger groups of experts, including not only radiologists, but also clinicians. These multidisciplinary groups were in charge of amending and improving the first document. The third step involved circulation of this new version of the document to large reading groups composed of radiologists specifically chosen in order to reflect the various aspects of professional activities. These radiologists assessed the document using a scoring scale. In case of important disagreement on specific items, an additional cycle of writing, amending and reading procedures was done. The final document was sent to all national scientific societies representing all medical and surgical disciplines for final approval. Close to 700 professionals were involved in the process. The entire procedure lasted 3 years.

According to the transposition there is an obligation for the referring physician to write the clinical justification of the requested examination. This clinical justification must also be included in the examination report by the radiologist.

There is also an obligation for all professionals using radiodiagnostic, radiotherapy, or nuclear medicine, to be trained by a specific programme in radioprotection of patients submitted to ionizing radiation. This specific training must be repeated every 10 years. Training programmes have been established at a national level.

Regarding the equipment, there is an obligation for quality control and maintenance, with internal and external audits.

The DGSNR have recruited 100 technicians and physicists to establish the national programme of audits in charge of visiting regularly all radiological centres.

In summary, the transposition of the Directive was a remarkable occasion to structure quality management in radiology covering almost all aspects of the profession beyond radioprotection of patients. In this respect the radiologists have improved their professional image for administrative institutions and the general public. The impact of the Directive on the level of radiation delivered in France for medical purposes is under evaluation.
The American Association of Physicists in Medicine (AAPM) was incorporated in 1958. Among the main purposes of the Association as specified in its Articles of Incorporation is to promote the application of physics to medicine and biology, to encourage interest and training in medical physics and related fields, and to prepare and to disseminate technical information in medical physics and related fields. AAPM’s activities in education emanate primarily from its Educational and Science Councils, International Affairs Committee (IAC), Annual Meeting, Annual Summer School, Medical Physics journal, and Website (www.aapm.org). AAPM devotes nearly one third of its total budget to educational activities not only in the United States but also internationally, with many of the international activities being co-sponsored and/or in conjunction and cooperation with the International Organization of Medical Physics, International Atomic Energy Agency, and other international societies. The AAPM’s IAC has subcommittees devoted to all regions of the earth including subcommittees for African Affairs, Asian Oceanic Affairs, European Affairs, Latin American Affairs, Middle East Affairs, and the Exchange Scientist Program.

The AAPM includes under its umbrella of Education the creation of Task Group Reports on various training and standard of practice documents, teaching syllabi, slide sets, PowerPoint presentations, support of continuing educational meetings throughout the world including meetings in developing countries, and free access to most of the educational and professional modules on its website.

The AAPM’s Education Council oversees the activities of several committees and task groups dedicated to national and international educational activities for medical physicists as well as other health professional (such as physicians and medical technologists) via the activities of our committees on Continuing Professional Development, Education and Training of Medical Physicists, International Educational Activities, Public Education, Medical Physics Education of Physicians, Medical Physics Education of Allied Health Professionals, etc. Most of the reports and recommendations of the Education committee are available free of charge on the AAPM website including the Educators Resource Guide (a list of medical physics references and web links), Discoveries and Breakthroughs in Science (a series of commercial TV quality videos on various medical and medical physics topics of interest partially funded by the AAPM), information to assist medical physicists in fulfilling the requirements of the American Board of Radiology (ABR) on Maintenance of Certification (MOC) and Self-Assessment Modules (SAM), and various education slide sets on topics as diverse as the Radiobiology Slide Set, Radiation Effects & Protection Lecture for Medical Students, Fluoroscopy Credentialing Teaching Slides, and many others. Many of these web-based resources are part of the AAPM’s so called ‘Virtual Library’ which also enables AAPM members to fulfill their ABR mandated continuing education credits via this web-based system.
Many of the AAPM’s educational activities are specially targeted to the needs of physicists in developing countries. For example, our Partners in Physics (PIP) program enables scientists from developing nations to join AAPM at no cost under the auspices of a full member from North America. Currently we have 69 PIP members from 32 countries participating in this program. The AAPM’s International Exchange Scientist Program (IESP) and International Scientific Exchange Programs (ISEP) also support travel and international scientific exchange via individual travel as well as sponsorship or co-sponsorship of international and national meetings. Recently for example, the AAPM provided expertise, guest speakers, and financial assistance for a radiation therapy physics course held in Manila, Philippines co-sponsored by the Philippines Organization of Medical Physicists, and also a Workshop in diagnostic, nuclear medicine, and radiation therapy physics held in Yaounde, Cameroon. The AAPM also supports the International Library Program (ILP), which solicits donations and financial support for medical physics libraries in developing countries. We currently have 74 active libraries in 43 countries.

One of AAPM’s most recent activities in international education is being implemented through Task Group 131 on ‘Medical Physics Training in Developing Countries’ which has been charged with developing web-based tools for training Medical Physicists Internationally.

Indeed, AAPM views the shortage of properly trained and credentialed medical physicists as one of our most pressing challenges and is actively working on the development of new academic programs and clinical residencies in medical physics to address the critical worldwide shortage of trained medical physicists. Partly to this end, AAPM maintains a separate endowment fund dedicated to the support of research and training in medical physics. Income from the endowment plus donations from the Radiological Society of North America (RSNA), individuals, and industry support several fellowships and residencies for medical physics trainees as well as seed grants for basic research in medical physics by young investigators.

As the largest and most well endowed organization of medical physics in the world, AAPM will continue to devote its resources to the training and education of medical physicists worldwide, and to promote education and awareness of medical physics to other allied health professionals, governmental agencies, and the general public.
The problems to be solved and a proposed action plan in education and training of medical physicists in Asia Oceania Region

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1. Cooperation between IAEA/RCA and AFOMP/ETC

An Education and Training Committee (ETC) was formed within the Asia Oceania Federation of Organizations of Medical Physics (AFOMP) in 2001.

The first face to face ETC meeting was held in 2002, and a cooperation with IAEA/RCA was confirmed. An AFOMP Workshop on Education and Training of Medical Physicists in the Asia-Pacific Region was held in WC2003 along with a session of Medical Physics Education by the IOMP ETC and AFOMP ETC. Here situations of education and training in AFOMP countries, Europe, North America and activities by IAEA were reported. The definition of qualified medical physicists and role and responsibility of medical physicists were discussed, but concrete results inside the AFOMP countries or RCA members were not found.

The following items were scheduled to be carried out jointly by AFOMP and the IAEA/RCA:

a) Establishment of a common definition of a qualified medical physicist
b) Identifying the current status of medical physics in the region and make recommendation on medical physics staffing
c) Agreement on a regional strategy for the improvement and upgrading of technical standards and safe operating practices including QA/QC in the key areas of medical physics
d) Agreement on a regional programme for education and training to be recognized as a qualified medical physicist
e) Drafting regionally harmonized standards on training in medical physics and circulate the draft for comments and approval by project coordinators (PCs) and medical physics organizations in the Member States
f) Identifying ways of national registration or licensing of medical physicists
g) Assessment of existing professional standards as a component of actions of “Improvement and upgrade of safe operating practices and technical standards.

Task Group Members were selected and a workshop on “AFOMP Standard on medical physics training” was held during the 3rd SEACOMP and 4th AOCMP in Kuala Lumpur.

2. Problems found

AFOMP ETC conducted a survey in 2004 and 2005 with questionnaires to identify the targets and level of standardized education and training of medical physics in Asia and Oceania region. The answers were received from 13 countries out of 18 AFOMP members.

a) For the questions related to the state and demand for medical physics certification and/or licensing, 11 countries answered “yes”. Japan answered “no” in the field of nuclear medicine and Mongolia answered totally “no”.

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b) For the questions on present existence of certification/licensing organizations, 5 countries answered “yes”.

c) Four countries set the highest priority to radiation oncology physics followed by both diagnostic imaging and nuclear medicine generally.

d) Answers to questions concerning a proposed standardized process of education and training of medical physics showed the highest priority for oncology physics.

e) For establishing certification/licensing system, it was reconfirmed that clarification of definition, role and requirement of “qualified medical physicists” were essential. Academic education and training programme of real medical physics in each country was shown to be also a key process for the development of scientific and occupational contribution in this field.

In spite of the efforts since 2001, AFOMP ETC does not have any concrete results of written documents on standardized and integrated materials of qualified medical physicists, responsibilities or roles of medical physicists in the AFOMP region.

3. Proposed plan

Steady activity based on constant financial resource is expected. In WC2006 in Seoul, a workshop on education and training of medical physics was held, and AFOMP activities on education and training were discussed.

In addition to cooperation with IAEA/RCA projects, AFOMP ETC should have its own activity based on steady financial supply from resources such as a fee for corporate membership. Education and training courses or workshops on physics of image quality assurance of CR, DR, MDCT and MRI could be held with the aid of companies of corporate member status. The participation fee from trainees to these courses would be another income to be used for further activities of AFOMP ETC. Six courses and workshops are proposed to be held in the 2006/2007 fiscal year, and increased to 12 courses within five years.

The intention of IAEA/RCA toward RCA countries seems to be aimed at the global level of practice and training. On the other hand, the efforts of AFOMP/ETC must be focused at the local level. For example, training courses in small cities could involve utilizing the diagnostic or therapeutic machines and measurement instruments possessed by a trainee’s hospital. In this way, the activities of the IAEA/RCA and AFOMP ETC would work complementarily to each other.

In conclusion, in spite of the effort since 2001 AFOMP ETC could not have any concrete results of written documents on standardized or integrated materials of qualified medical physicists or responsibilities/role of medical physicists in AFOMP region. As a matter of fact, qualitative and quantitative demands for medical physicists in AFOMP countries are now increasing. But the result our effort is far from the final goal. Steady activity based on continuous financial resource is really expected.

Our effort may be concentrated in the next five years to hold courses on education/training and workshops as mentioned above and to a run constant and good operation of the home page of AFOMP to prepare for e-learning. The target of ETC should be set up very qualitatively such as to double the number of qualified medical physicists in the next five years or so, as its own realistic way.
ESTRO educational activities in radiation oncology

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Enormous progress has been made in the field of radiotherapy over the last years. Clinical science is changing rapidly from a “school-centred” to an evidence based approach. Numerous scientific advances in medical physics and translational research made it possible to implement new technologies for treatment planning into clinical practice. Unprecedented developments in the field of biology and biotechnology are dramatically changing our understanding of malignant disease. This will likely change major aspects of our approach to cancer treatment in the next years. Clinical research and evidence based approaches have increased significantly in radiation oncology. It is one of the most important challenges for the future to integrate these novel developments into optimized comprehensive radiotherapy strategies.

State of the art basic education and training of professionals and continuous professional education are crucial for delivery of optimal quality care to cancer patients as well as for continuous scientific and technological progress in radiation oncology.

Throughout its history during more than 20 years the European Society for Therapeutic Radiology and Oncology (ESTRO) has seen it as a most important task to provide high quality teaching activities to its members. In 1985 ESTRO organized its first course (Physics for Clinical Radiotherapy). Over the years, the society developed more courses and in 2005 the “European School of Radiotherapy” was created, offering a variety of modular basic courses, advanced teaching courses and multidisciplinary courses, including other cancer treatments such as surgery and medical oncology.

In 2007 ESTRO will organize 15 different courses, of which a number will be duplicated in Central Europe and outside Europe. This gradual expansion has been a step by step process driven by the developments in the field and the needs of the members of the society, mainly by activities of individuals and groups within the bodies of ESTRO. Adaptation of courses, contents and methodology was done through the teaching staff, course directors and the ESTRO Education Committee.

More than 1600 participants will have attended ESTRO courses in 2006, more than 500 the ESTRO pre-meeting courses. Besides providing excellent overviews of the state-of-the-art, these teaching activities add a European dimension to training and continuous medical education in the field of radiotherapy.

ESTRO intends to further develop the course curriculum and establish more coherence within its educational activities. A long term strategy for the organization and duplication of courses
is currently being specified in collaboration with the European National Radiotherapy Societies and with Regional Radiotherapy Societies worldwide.

Moreover, the society wants to create a comprehensive ‘School Structure’, with a corporate identity, offering teaching courses, educational publications, examinations and certifications, new ways of teaching such as e-learning and a mobility network for young fellows. The target set is ambitious, but imperative to ensure high quality education and consequently high quality radiotherapy treatment for cancer patients.
The present status of medical physics education and training in Europe. EFOMP recommendations

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European Federation of Organisations for Medical Physics (EFOMP)

1. Introduction

Since its inauguration during the second conference of representatives from European organisations for Medical Physics in London in May 1980, one of the main objectives of the European Federation of Organisations for Medical Physics (EFOMP) has been to harmonize and promote the best practice of Medical Physics in Europe.

To achieve this goal, EFOMP has produced a number of unanimously adopted documents called “Policy Statements”, making recommendations on the appropriate general responsibilities and roles of the Medical Physicist and proposing guidelines for Education, Training and Accreditation Programmes in Medical Physics. The total number of Policy Statements to date is 11.

Policy Statement No. 1 was published at a very early stage, in 1984. It was entitled: “Medical Physics Education and Training: The present European level and recommendations for its future development”, and it represents the starting point of the EFOMP recommendations on Education and Training in Medical Physics. The first EFOMP recommendations on the schemes of Education and Training in Medical Physics and on the education programmes contents were based on these.

New Directives from the Council of the European Union such as the medical exposures directive and the directive on the recognition of professional qualifications and the harmonization of the architecture of the European Higher Education System, arising from the “Bologna declaration” have pointed to the need for an update of this policy.

2. The present status of education and training in Europe

To collect the needed information in an efficient way, a questionnaire has been sent to the Presidents of 34 National Organisation for Medical Physics (NMO) of the countries belonging to EFOMP, during 2005. Twenty-five countries responded to the questionnaire.

The results from this survey forms the basis for the new EFOMP recommendations which are at present being discussed with the national organisations of medical physics.

3. EFOMP recommendations with a view to the new European perspectives

According to the EFOMP recommendations given in the first Policy Statement, education of medical physicists can be divided into three stages. The first is to bring the physicist up to a basic standard during an initial period of training at the university in physics, mathematics and other relevant topics in natural science. The second is to introduce medical physicists in the post-graduate education and the third is in-service training in hospitals. Once completed, the physicist can be recognized as a medical physicist.
At present, 45 European countries are involved in the “Bologna Process”. This offers a great opportunity to harmonize the first two stages of education in the participating countries:

- The first step should correspond to the initial university cycle; the degree in physics or other scientific areas will be more transparent and equivalent throughout Europe as of 2010. (Lasting three years minimum or four years, so 180–240 ECTS)
- The second step should correspond to a second university cycle leading to a master’s degree. (one or two years and up to 300 ECTS). This master should include the theoretical curriculum contents recommended by EFOMP in their Policy Statements and in other documents that EFOMP has produced in collaboration with other relevant societies.
- The third step is in-service training in hospitals. This in-service training period should consist of at least two years, under the supervision of an experienced Medical Physicist.

**Only after completion of these three periods** can the Medical Physicist be considered competent to act independently, and to have reached the minimum qualifications required for enrolment in an EFOMP-approved National Register for Medical Physicists as a Qualified Medical Physicist.

All EFOMP policy statements can be found on the EFOMP website: (http://www.efomp.org).
Education of medical physicists

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In many developing countries, such as those in Latin America, the demands for qualified medical physicists have not yet been met, and the need for these professionals is an acute problem. This presentation addresses the situation in the region and discusses the challenges for the education of medical physicists.

According to international organizations, the 550 million population in Latin American and Caribbean (LAC) countries develop over 800,000 new cancer cases and some 360,000 patients need radiotherapy treatment each year. For these, over 500 radiotherapy units exist. Estimates for the LAC region indicate the existence of some 420 medical physicists, 80% of them working in the radiotherapy services. Most of the clinical imaging services (nuclear medicine, tomography and radiology techniques) have no associated physicist, therefore the radiation protection and image quality assurance aspects are probably not appropriately taken care of. The shortage of medical physicists in the region is estimated at some 300 professionals.

The insufficient quantity of medical physicists is not the only problem in the region. Most of the practising professionals have not followed what is considered as the necessary steps to become a qualified expert. Education and training of a medical physicist demand a graduate level academic education and an appropriate clinical training. Presently, about 15 graduate programmes offer an M.Sc. degree in Medical Physics in the LAC region, and nine hospitals offer supervised in-service clinical training. These educational resources are not uniformly distributed in the region: More than 80% of the educational offer resides in four countries (Brazil, Mexico, Venezuela and Argentina) and one, Brazil, offers 90% of the clinical residences.

Some conditions of the physics and medicine professions in our region probably make more difficult the creation of the needed academic programmes in the LAC region. Medical physics is an area of physics different from the others due to the professional/clinical profile of its practitioners, and this professional track is not easily accepted as of “sufficient” quality by academic physicists doing traditional research or university teaching. On the other hand, medical doctors, who should directly benefit from the close collaboration with an expert in the applications of physics to medicine, tend to see this new member of the hospital staff merely as a technician, reinforcing the idea that this speciality can be performed without a rigorous education. This becomes a vicious circle. Poor salaries and lack of recognition of medical physics as a profession by national authorities help keeping the working conditions at a deplorable level.

One of the successful experiences in medical physics education in Latin America is the M.Sc. (Medical Physics) programme offered since 1997 by the National Autonomous University of Mexico, UNAM, as part of its Graduate Programme in Physics (PCF). In these 10 years, 67 students have been admitted (three from other LAC countries), 32 have obtained their degree, 16 pursue their courses at the moment and other 10 are completing their thesis work. Most of the programme graduates work in public and private health services and their salaries are
quite good. Some have pursued further studies to obtain a Ph.D. degree in Medical Physics (out of Mexico) or in a related field in Mexico. As the organizer of the programme and present coordinator, I can identify many factors that have led to the success of this two year (with thesis) programme. Entrance requirements are strict (a physics exam common with those students applying to the M.Sc. and Ph.D. programmes in Physics). The course load is heavy covering three semesters and combining the standard medical physics curriculum with a medical residency and optional classes in the thesis topic. A wide option of thesis projects is offered in radiotherapy, nuclear medicine, X ray imaging, magnetic resonance imaging and fMR, image processing, optics, lithotripsy, and mathematical models applied to biological problems, among others, which is what makes the programme very attractive to applicants. These characteristics assure the granting of government two year fellowships to all students. Some 40 UNAMI academic members, as well as clinical doctors from health services, participate as tutors, teachers, instructors or thesis directors.

The conditions mentioned in the example above are probably difficult to find in smaller universities, and regional or international cooperation may be required to succeed. An IAEA regional project is elaborating guidelines for the curricular content of medical physics academic and clinical training programmes, as well as recommendations to health and regulatory authorities concerning the professional accreditation of medical physicists.

Support from international agencies should include the availability of textbooks, presentations and other materials, free of charge through the web, as a support to the local teaching and training sessions. The visit of one expert to a developing country programme, to teach a course for many students, is probably much more efficient than the visit of one trainee to a foreign institution, and does not carry the risk of the trainee deciding to remain in the more developed environment. The visiting expert not only brings his/her knowledge but acts as a role model for students, and an example of the expected level of excellence for associated medical physicists and medical doctors. Now that stable educational and training programmes start to exist within the developing regions, scientific visits or fellowships within the region, or even within the same country, offer the possibility to educate under conditions that decrease the “cultural shock” to the returning trainee.

Many challenges exist for the appropriate education and training of medical physicists in developing regions. The accelerated acquisition of sophisticated medical equipment in the more advanced countries within these regions increases the need for qualified professionals. Universities, health services, regulatory authorities, and international assistance, must be coordinated in order to find the best strategy in each particular case.
Recent activities of the International Commission on Radiation Units and Measurements (ICRU) on medical applications of ionizing radiation

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Since its inception in 1925, the International Commission on Radiation Units and Measurements (ICRU) has as its principal objective the development of internationally acceptable recommendations regarding, for example, procedures suitable for the measurement and application of quantities and units of radiation and radioactivity in clinical radiology. Four out of the six most recently published ICRU Reports concern recommendations on medical application of ionizing radiation [1–4]. The subjects dealt with in these reports show a wide variety.

Over the years, the ICRU has published several reports on various aspects of medical imaging. These include Report 41, *Modulation transfer function of screen-film systems* (1986); Report 48, *Phantoms and computational models in therapy, diagnosis and protection* (1992); and Report 54, *Medical imaging – The assessment of image quality* (1995). These reports concentrated on the underlying physics and mathematics of image formation, on the different steps leading from the initial signal to the diagnostic image, or on dosimetric and radiation protection aspects. In image quality in chest radiography [1], the start of a new series of ICRU reports, the emphasis shifts to the physical-medical aspects. Any human imaging procedure is solely for the purpose of providing information to the physician essential for the diagnosis of the disease or condition. Hence, the usual diagnostic sequence includes the prescription of the appropriate type of radiographic examination which is subsequently executed with the appropriate expertise and under optimal conditions. In the context of chest radiography, these issues are thoroughly dealt with in Report 70 [1]. Other reports expected in this series concern assessment of image quality in mammography, relation between image quality and patient exposure in CT, and assessment of image quality in nuclear medicine.

For several decades, the ICRU has been involved in an effort to improve harmonization in reporting radiation treatments. The reports in this series include Report 29, *Dose specification for reporting external beam therapy with photons and electrons* (1978); Report 50, *Prescribing, recording, and reporting photon beam therapy* (1993) and its supplement Report 62 (1999); and recently, Report 71, *Prescribing, recording, and reporting electron beam therapy* (2004) [2]. In Reports 50 and 62 several volumes were defined (or their definitions refined) including the gross tumour volume (GTV), clinical target volume (CTV) and planning target volume (PTV). For the GTV the need to specify the method used for its delineation was stressed. Around the GTV two types of safety margins were identified. A first safety margin was added to take into account subclinical malignant involvement, leading to the concept of CTV. A second type of safety margin was introduced to take into account all types of geometrical uncertainties in patient-beam positioning, leading to the concept of PTV. In addition, the organs at risk (OARs) were identified and as in the case of the PTV a safety margin was applied to compensate for the movements of the OARs and the uncertainties in positioning, leading to the planning organ at risk volume (PRV). For reporting the treatments
the selection of an ICRU reference point was recommended. A separate report on electron beam therapy [2] appeared necessary as the dose distributions of electron beams are so different from those of photon beams that they imply different selection of clinical indications, and require different beam arrangements and often a combination with photon beams. Further reports in this series are foreseen for proton beam therapy, conformal photon beam therapy, and intracavitary therapy in gynecology.

ICRU Report 72 on Dosimetry of beta rays and low energy photons for brachytherapy with sealed sources (2004) [3] followed ICRU Report 56, Dosimetry of external beta rays for radiation protection (1997). Report 72 deals with therapy applications of beta ray emitters, especially dosimetry and related aspects. Low energy photon emitters are also dealt with, e.g. iodine-125 and paladium-103 that are now available for therapy applications (seeds for permanent implants). Specification of beta emitting sources in terms of the reference absorbed-dose rate (in water at a reference distance) is recommended. For photon sources, the reference air kerma rate is recommended.

ICRU Report 74 [4] is the first report published by the ICRU that deals with patient dosimetry for X rays used for medical imaging. The impetus for this report derives from the broad and systematic application of X rays for diagnostic and interventional imaging. The use of different irradiation conditions, in terms of incident radiation quality and beam geometry in relation to the patient’s body, has led to the development of specific dosimetric methods and the definition of appropriate quantities – quantities different from those used for occupational and environmental exposure. Specific dosimetric quantities and measurement methods are defined for patient dosimetry for procedures such as radiography, fluoroscopy, CT, and mammography. Conversion coefficients are often used in practice to relate directly measurable quantities to absorbed doses to different critical organs or at specific reference points. When deterministic effects are considered, a possibility that exists, e.g. in interventional radiology, doses to the most heavily irradiated sites of the body need to be evaluated.

REFERENCES

The use of electron beams in radiotherapy: 1st e-learning course in Latin America


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Radiotherapy in Brazil has now about 80 linear accelerators with electron beams. Due to the continental dimensions of the country, training of medical physicists is still a problem, because many of these physicists are far from the main training centers (Rio de Janeiro and São Paulo) and cannot afford to spend any time there. In other cases, they cannot leave the work since there are not enough physicists at their hospital.

Then, the Quality Assurance Programme of the National Cancer Institute, whose mission is to improve the quality of the radiotherapeutic treatments in Brazil, decided to create its 1st e-learning course to help the medical physicists perform a correct electron beam dosimetry, according to the IAEA TRS-398 and quality control tests based on the IAEA-TECDOC-1151.

The course had the collaboration of the Public Health National School (Fiocruz) and covers the following subjects: 1) therapeutic linear accelerator electron beams: history, production and clinical application, 2) dosimetric equipment and calibration methods, 3) quality control.

It is a 60 hour course, totally at a distance and pedagogically based on the basic principle of constructivism. It is the 1st course on the subject and under this model in Brazil and all Latin America. The students receive a high quality book and CD-ROM (with all the material of the course, including four films with the dosimetric measurements in practice). They also count on full time tutors specially trained in a virtual environment, through which they can communicate with the tutors and among themselves, access a virtual library and participate in special forums. By the end of each subject of the course, the students have to answer questions or perform measurements, which are evaluated by the tutors (receiving specific degrees).

The course has been announced during only two weeks. We received 161 registrations. Five times more than anticipated. We selected 81 candidates that have been divided in four groups (one each three months). The results have been good, with only 25% of giving-up rate (problems with: ionization chamber, phantom, linear accelerator, etc.), below half of the Brazilian average acceptance level (60%) for e-learning courses. Through most of the questions presented, we could see that many “already trained” physicists still have doubts in regard to the IAEA TRS-398.

We intend to conduct a Spanish version of this course, to transfer it to all interested physicists in Latin America.
REFERENCES


System of continuing education and professional development of medical radiation physicists in Russia

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The active process of technical equipment of radiation therapy, nuclear medicine and diagnostic radiology departments requires increased staffing of qualified medical physicists in Russia. To work with the radiotherapy equipment, treatment and diagnostic procedures available in Russian clinics today, it is necessary to have 1,000 medical radiation physics, 30% of which should have a high degree of professional excellence. To achieve the required high technology equipment and procedure level it is essential to have 5,000 specialists. Today Russia has only 280 medical radiation physicists, 25 of which have high qualification – less than 10%. The efficient exploitation of modern radiation therapeutic diagnostic technologies and equipment demands highly qualified medical radiation physicists.

However, in Russia the medical physicist responsibilities in the clinic are carried out by the specialists who do not have the basic radiation physics education and the necessary basis of physical and technical knowledge. Medical and clinical physics knowledge is acquired at random through various courses, by self education or empirically without quality and thoroughness control.

It is natural that it adversely affects the physical and technical maintenance of radiation therapy and, in the end, the cancer patient treatment quality.

Medical physicists are required in different areas, such as:

1. clinics together with the physician to deliver procedures in radiotherapy, nuclear medicine and diagnostic radiology
2. scientific and engineering organizations involved in the new radiological equipment and technology development
3. universities and other educational institutions engaged in the system of continuing education and professional development of medical physicists and research activities
4. companies supplying medical radiological equipment
5. companies busy with the equipment maintenance, adjustment and certification
6. project organizations involved in scientific planning, design and development of the system equipment of radiation therapeutic and diagnostic centres.

It is understood that the areas mentioned above demand specific knowledge and skills from the medical physicists and this should be taken into consideration when elaborating the educational programmes.

There are several departments of “medical physics” speciality in Russian universities. However, the approved student education programme does not meet the modern requirements. Practically, there are no qualified medical physics professors in universities. Therefore, as
before, the majority of graduates and medical physicists in clinics do not fit the necessary qualification.

The Association of Medical Physicists in Russia (AMPR) has developed and realized the programme on the system of continuing education and professional development of medical radiation physicists based on the cycle of special courses on different sections of radiation therapeutic and diagnostic physics. AMPR and the leading oncology centres in Russia regularly organize courses. The ESTRO teaching courses, supported by the IAEA, also contribute a lot to the professional education of Russian medical physicists.

For the efficient organization of scientific and education activities, mainly in the field of the continuing education and professional development of medical physicists, AMPR has established a non-profit Institute of Medical Physics and Engineering (IMPE) which has united practically all leading scientists and professors in medical radiation physics.

The group of highly skilled professors is chosen from the best Russian specialists and specially prepared for the training courses. Guidelines and recommendations are developed. Practical studies are conducted in the leading oncology centres.

A viable education and training system allows to provide the necessary professional knowledge level, individual qualification control and certification of medical physicists.

However, AMPR and IMPE are doing on their own without support from the government, sponsors and investors.

AMPR and IMPE are interested in the cooperation and support of their activities from the IAEA, ESTRO, IOMP, other international organizations and institutions.
Session 10a:
Radiation Treatment
DOSIMETRY AUDITS IN RADIOTHERAPY
Experience gained from the RPC's credentialing programmes for advanced technology clinical trials

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A. The RPC’s credentialing programmes

The Radiological Physics Center (RPC) was established to assure the US National Cancer Institute (NCI) that institutions participating in clinical trials have adequate quality assurance procedures. To accomplish this, the RPC has developed a variety of remote audit tools. One of these tools consists of a family of anthropomorphic phantoms that can be used to evaluate the delivery of advanced technology external beam therapy techniques including stereotactic radiosurgery (SRS) and intensity-modulated radiation therapy (IMRT) [1]. These phantoms include a stereotactic brain phantom, a stereotactic thorax/lung phantom, a stereotactic abdomen/liver phantom, an IMRT head and neck phantom, and an IMRT pelvis phantom. Recently, several NCI-funded cancer study groups have begun clinical trials that require the use of such advanced technologies. To assure that participating institutions can deliver these advanced treatment methods accurately and consistently, the study groups have requested that the RPC conduct credentialing programmes using the anthropomorphic phantoms. Over the last five years, the RPC has gained considerable experience with these phantoms, allowing some conclusions to be drawn about the ability of institutions to deliver SRS and IMRT dose distributions that are in agreement with their own treatment plans, under representative clinical conditions.

B. Anthropomorphic phantom design

The RPC phantoms all have an anthropomorphic outer plastic shell to simulate realistic patient anatomy. The phantoms are lightweight to reduce mailing costs, and are built from materials that can be imaged with CT. The inserts for imaging are constructed of water equivalent plastic materials that can be distinguished on CT. The phantoms also contain dosimeters for recording the radiation dose delivered by the institution. TLDs determine absolute doses at key point locations, while radiochromic films provide dose distribution information in two or three planes through the targets and organs at risk.

C. Anthropomorphic phantom irradiation procedures

Upon receipt at an institution, the phantom shell is filled with water, and CT imaging is performed. The images are transferred and a treatment plan is prepared. Once the plan is completed, the phantom is moved to the treatment unit, and the treatment is delivered. With some phantoms, the institution is required to place the phantom on a reciprocating table to simulate respiratory motion, during both imaging and treatment.

D. Results from phantom irradiations

The RPC head and neck phantoms have been irradiated by 154 institutions, some multiple times, for a total of 177 irradiations. The RPC pelvis IMRT phantoms have been irradiated 49
times. The brain SRS phantoms have been irradiated 75 times, while the thorax SRS phantoms have been irradiated 25 times by 21 institutions. The abdomen SRS phantoms are the newest of the phantoms and to date have been irradiated by 4 institutions.

The following criteria were used to evaluate the measurements: the ratio of measured dose to institutions’ stated dose was expected to agree within 7%. The distance to agreement in the high-dose gradient region near the organ at risk (OAR) was expected to be no greater than 4 mm. These criteria were established in collaboration with the study groups for which the phantom is being used. They incorporate the uncertainty of the TLD system (standard deviation ≈1.0%) and radiochromic film (random error <1 mm) but also the experience obtained with an initial series of participating institutions. Roughly one third (51/177) of all of the irradiations of the head and neck phantom failed to meet these criteria. In fact, only 66% of first-time irradiations passed the criteria. Twenty-eight of the failures were dose discrepancies as measured with TLD, seven were dose distribution discrepancies measured with radiochromic film, and thirteen reflected disagreements in both TLD and film measurements. The failure rate is lower with the other phantoms but is still significant.

E. Interpretation of results

Examination of the results from the phantoms revealed a number of errors made by institutions. These included incorrect data input into the treatment planning system, inaccurate modeling by the treatment planning algorithm of small field sizes formed by MLC leaves with rounded leaf ends [2], indexing errors in the table movement system for serial tomographic IMRT, inaccurate phantom positioning, and inadequate heterogeneity corrections.

F. Conclusions

The data available for analysis of the irradiated phantoms yielded an insight into the accuracy of delivery of IMRT at a cross section of North American institutions. Further, the analysis permits an improved understanding of the types of errors being made. These data show that quality assurance continues to play a critical role in IMRT treatment delivery.

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Inter-centre radiotherapy dosimetry audits in Scotland: Feasibility of in vivo audits using diodes

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The Scottish group of the UK radiotherapy dosimetry audit network has operated since 1992. It developed from the first systematic UK-wide national dosimetry intercomparison, carried out for megavoltage photon beams (1988–1991) [1] and was strengthened by the subsequent follow-up for megavoltage photons and audit of electron beams (1994–1996) [2]. It now routinely audits centres in Scotland, northern England and Northern Ireland and has cooperated with Irish centres to provide audits there [3]. It has continually developed audit methods to expand the range of modalities and facilities included and to provide a cost effective, but comprehensive system. It has piloted a number of audits which have the potential to be used on a wider basis. It has also acted on request as an independent verification of new TPSs, linacs, etc. before clinical implementation.

All audits are based on site visits by an external auditor, using mainly ion chamber dosimetry, and comparison of audit-measured doses in epoxy-resin phantoms to locally stated values. They also include procedural audit of the local centre’s dosimetry and planning methods, QC programme records and results, etc. Audits have been at variable intervals, but have averaged at approximately one every 2.5 years [4]. One auditor has been responsible for a complete round of audit visits, measurements and reports. The most recent full rounds have included planned dose distributions in ‘head and neck’ sites in a semi anatomic phantom, a brachytherapy source specification audit and a repeat audit of electron and kV X ray beams (last carried out 8–9 years before).

A pilot audit has been carried out to test the methodology for MLC dosimetry, utilizing similar fields to those included in the EQUAL-ESTRO MLC TLD audits (reference, small square, circular, inverted Y, irregular fields with and without wedge). The local centre was requested to clinically plan and deliver specific doses at 10 cm deep and these were measured (ion chamber) in a phantom. A second pilot audit has been carried out at the same time (same visits) for in vivo patient dosimetry during treatment using 6MV X ray beams for head-and-neck and breast patients. One common set of diodes was used, taken from one department (Edinburgh Cancer Centre, ECC) to another. The audit diodes are calibrated against the audit ionization chamber in the centre’s beam, but the exit-to-entrance calibration ratio and the irradiation parameter correction factors are those determined on ECC machines, selecting the most appropriate values to suit the machines in the visited departments, even though not necessarily of the same manufacturer. All possible patients were measured with the diodes during the visit and the measured entrance doses (head and neck) and entrance and exit doses (breast) were compared to the expected planned and delivered doses.
The most recent ‘head and neck’ audits around the whole group have shown a mean ratio (audit/locally stated) of all measurement points within the ‘target volumes’ of 0.994 with a standard deviation (s.d.) of 2%. 98% of all measured points were within the audit tolerance of 5%. The electron beam calibration audit has shown a mean ratio of 0.992 (s.d. 0.7%), which can be compared to the previous results of 0.997 (1.8%). The kV X ray calibration audit has shown a mean ratio of 1.006 (1.5%). At the same visits some MV X ray beams have also been measured and show a mean ratio of 1.003, with no beams differing by more than 1% between audit value and locally stated value.

The MLC pilot included 40 fields (8 beams) and showed a mean of 1.000, s.d. 1.1%, range 0.981–1.024 for all fields (0.998, 0.9%, 0.981–1.009 for unwedged fields). The in vivo audit pilot in two centres has included 63 patients and has shown mean audit/locally stated ratios of 0.994 for head and neck (s.d. 2%, range -8.6% to +3.6%) and 0.977 for breast (s.d. 2%, range -6.2% to +1%). Tolerances were set at ±5% for head and neck from an expected ratio of unity; 3/51 were outside, all were either on steeply angled surfaces or under steep wedges and are thought to be influenced by diode positioning precision. For breast, a tolerance of ±5% from the expected value of 0.980 was set; no patient doses lay outside this. The pilot studies give confidence in the methodologies and provide the basis for extending these audits to the full group. The in vivo audit results can be viewed and interpreted within the context of the Edinburgh department experience and results from 14 years of systematic diode based patient dose verification [5].

The Scottish+ audit group continues to expand the scope of audits and demonstrate generally good performance in the centres within the group and provide clinical confidence in performance. Repeat audits show improved results with time. Pilot audit studies for MLC and in vivo patient dosimetry have been developed for use in the wider group.

REFERENCES


QA of conformal radiotherapy for multi-centre radiotherapy trials in Australasia

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The precision available in dose delivery in radiotherapy allows patient doses to be prescribed and delivered very accurately. Increasingly, the dose prescription is based on data extracted from multi-centre clinical trials. The optimal prescription extracted from trial data will be blurred by any inconsistencies in treatment delivery across all patients across all treating centres participating in the trial. These inconsistencies, together with treatment errors, will reduce the dose effect being observed in the clinical trial.

Inconsistencies in treatment delivery in a multi-centre trial can arise from a variety of sources including errors in protocol interpretation, protocol violations, variation in radiographic, treatment planning and irradiation techniques, treatment delivery errors and variations in the reporting of dose delivery.

One way to overcome and/or quantify inconsistencies in a radiotherapy clinical trial is to undertake quality assurance (QA) procedures aimed at identifying errors. Programmes for undertaking such QA have been developed by international collaborative trials dosimetry groups, e.g. EQUAL (Europe) and RPC (USA).

A method of quantifying treatment inconsistencies in Australasia using an anthropomorphic phantom was trialed for specific rectal and prostate radiotherapy trials, with design of the phantom and study protocol based on a set of recommendations from a previous study [1]. Treatment of this phantom at multiple Australasian sites was undertaken, involving collection of digital and physical dosimetric information for evaluation of multiple steps of the treatment process. Specifically, the study involved determining the variation across participating centres of:

- Absolute linear accelerator output
- Quality of radiography for treatment planning
- Treatment planning techniques including outlining of structures
- Treatment delivery strategies
- Calculation of dose-volume parameters
- Assessment of patient setup at treatment
- Final treatment delivery
- Treatment reporting.

The pelvic phantom was designed from a patient’s CT data set and includes radiographically equivalent prostate and seminal vesicles, bladder, rectum, muscle and bony anatomy. Positions for 25 TLDs were established as well as for a small ionization chamber to be placed at the centre of the prostate volume. The phantom was taken to each participating centre by two team members who supervised its CT, planning and treatment delivery and who independently performed an absolute measurement of accelerator output. Digital planning
data was extracted for subsequent analysis on an independent DICOM/RTOG data viewer.

Twenty-four separate radiotherapy departments have been visited and have treated the phantom. In-phantom measurements have revealed substantial consistency in dose delivery, with several discrepancies occurring as a result of protocol mis-interpretation, phantom design issues and treatment setup errors. Results for absolute output of the 30 beams surveyed in this study are presented in Table 1.

![Histogram](image)

**FIG. 1. Histogram of differences in absolute beam output, study measurement relative to local measurement.**

The logistics of undertaking the study shall be discussed in the context of other international QA studies of this nature. This project will potentially lead into an ongoing service to radiotherapy centres and trial groups for ensuring treatment quality for current and emerging treatment techniques.

**REFERENCE**

Intra operative electron radiation therapy (IOERT) dosimetry intercomparison in Italy

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The Italian National Institute of Health (ISS) has long been active in performing mailed dosimetry intercomparisons among the Italian radiotherapy centres in various treatment modalities. The ISS, in the framework of national continuous quality improvement programmes in radiotherapy, operates in cooperation with experts committees, with the participation of radiation oncologists, medical physicists and technicians, all of them belonging to the same radiotherapy centres to be audited. Participation of a centre is on a voluntary basis.

A relevant intercomparison refers to high energy electron beams collimated for intra-operative radiation therapy treatments. It was considered interesting and important to perform a dosimetry intercomparison for IOERT owing to different reasons. First of all, the use of IORT electron beams poses problems for dosimetry that deserve proper solution. The matter has been discussed in the Italian Guidelines for Quality Assurance in IORT [1] issued recently. In fact, the presence of specific applicators modifies the physical-geometrical characteristics of the electron beams (quality, output, homogeneity, etc.) and does not allow total conformity with the reference conditions specified in the dosimetric protocols, giving rise to an increased uncertainty in the determination of the absorbed dose to water [2,3]. Also, the use of dedicated mobile accelerators, characterized by very high dose per pulse (3–12 cGy/pulse, compared to 0.1–0.6 cGy/pulse of conventional linacs) makes application of the internationally accepted dosimetry protocols difficult or even unfeasible. For mobile dedicated accelerators, the recently published Italian Guidelines [1] recommend the use of Fricke dosimetry for beam output (Gy/Monitor Unit) determination. The second reason for performing a dosimetry intercomparison in IOERT is the large diffusion of this treatment modality in Italy. Twenty (20) radiotherapy centres are presently performing IOERT treatments or are equipped with an already installed IOERT treatment unit: five out of 20 are using conventional linacs and the others dedicated mobile accelerators. A third reason is the interest in comparing the accuracy level in dose delivery among the radiotherapy centres when using either the conventional linacs (ionization chamber based dosimetry) or the high dose rate dedicated mobile accelerators (Fricke based dosimetry). Seventeen Italian centres applying IORT modality participated in the intercomparison, four equipped with conventional accelerator and 13 using a dedicated machine.

The goal of the IOERT intercomparison was to verify the compliance of the dose stated by each radiotherapy centre with the dose measured by ISS, acting as the reference dosimetry center. The intercomparison started in 2004 and was terminated in April 2006.

The alanine/EPR dosimetry system installed at ISS was used for reference dose measurements. Encapsulated alanine dosimeters were irradiated in water with beams collimated by specific IOERT applicators of different size and geometry. The centres were asked to irradiate the alanine dosimeters with a dose of 10 Gy under reference conditions (water phantom, depth of maximum dose, 100 cm source to surface distance and plane-base
circular applicator of 10 cm in diameter) and under non-reference conditions (as in the previous case but with the use of circular beveled-base applicator with diameter of 10 cm). Irradiations had to be performed at two different energies, the lower in the 6–8 MeV range and the higher in the 9–12 MeV range. Irradiation had to be repeated three times for both conditions and for both energy selected. The mean value of the alanine measured dose in the thrice repeated irradiations, $D_{\text{ala}}$, is compared with the dose value stated by the Center, $D_{\text{Center}}$. The parameter under study was the ratio $D_{\text{ala}}/D_{\text{Center}}$. In reference conditions the mean value of the ratio was $1.000\pm2.4\%$ (1σ) for the lower energy and $1.000\pm2.0\%$ (1σ) for the higher energy. As for the non-reference conditions, the mean value of the ratio was $1.000\pm2.9\%$ (1σ) and $1.000\pm3.6\%$ (1σ) for the two energies, respectively. The results are quite satisfactory and demonstrate the correctness of the Italian guidelines recommendation to calibrate IOERT beams produced by dedicated accelerators against Fricke dosimetry. Also, the level of accuracy in dose delivery was comparable with that where conventional linacs or high dose rate dedicated mobile accelerators are used.

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Development of a methodology for TLD postal dosimetry audit of high-energy radiotherapy photon beams in non-reference conditions: An IAEA coordinated research project


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In 2001 the IAEA initiated a coordinated research project (CRP E2.40.12) that extends the scope of activities of the TLD-based national dosimetry audit programmes in radiotherapy [1] from reference conditions to more complex audit measurements in non-reference conditions in a variety of clinically relevant irradiation geometries involving regular fields.

The strategy for national TLD programmes has been developed involving three sequential audit steps: (i) beam output in reference conditions for high energy photon beams, (ii) dose in reference and non-reference conditions on the beam axis for photons and electron beams, (iii) reference and non-reference conditions off-axis for open and wedged symmetric and asymmetric fields for photon beams.

Based on the IAEA standard TLD holder for high energy photon beams, a modified TLD holder with horizontal arm was developed that enables off-axis measurements. Three TLDs can be irradiated at a time, two off-axis TLDs placed at ±5 cm from the central TLD. New procedures were developed for the TLD irradiation at hospitals. The off-axis measurement
methodology for photon beams was tested in a few irradiation runs in the participating countries.

The results are shown in Figs 1(a) and 1(b). Ratios of the IAEA TLD measured dose to the participant stated dose shown in Fig. 1a pertain to the reference conditions, non-reference conditions on- and off-axis for open fields, and on- and off-axis for wedged fields. In total 203 measurement points were taken for Co-60 and high energy X ray beams of 6 MV–23 MV with the mean ratio of measured dose to the participant stated dose of 0.999 and the standard deviation of 0.013.

The statistical distribution of all ratios representing 146 measurements of the different beam parameters for all beams has a mean of 0.999 and a standard deviation of 0.012.

The next step of the CRP continues with a new multicentre study involving the tests of the TLD methodology for asymmetric photon beams.

The expertise built-up in this project for the audit of dose in non-reference conditions is being adapted by the national TLD networks to the specific conditions in each participating country. This involves scientific investigations leading to new developments at national levels.

**REFERENCE**

TLD audits in radiotherapy centres in Poland
(non-reference conditions)

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The Secondary Standard Dosimetry Laboratory (SSDL) of the Medical Physics Department, Centre of Oncology in Warsaw became a member of the IAEA/WHO international network of SSDLs in 1988 and is periodically audited by the IAEA.

The SSDL has been carrying out external postal TLD audits in teletherapy centres since 1991. In Poland, there are 22 radiotherapy centres performing external beam radiotherapy, and a total number of 73 megavoltage units. Regular yearly audit runs have been carried out, covering Co-60, photon and electron beam output measurements in standard conditions. A significant number of deviations in non-reference situations, as used clinically on patients, had been observed in international audit networks operating worldwide. The objective of the study is to develop a general strategy for the TLD based quality audit programme for radiation dosimetry in non-reference conditions at a national level [1,2]. Regular yearly audit runs have been extended to non-standard conditions since 2003. The results of subsequent runs are presented.

Pilot studies were performed in order to test the methodology for the dosimetry measurements, and the documentation for the practical operation of the audit system was prepared. The first TLD run in non-reference conditions for on axis measurements was performed for nine Co-60 units in different radiotherapy centres. The second run for linac photon beams was done in all 22 Polish teleradiotherapy centres. The participants determined the doses with various types of treatment planning systems. The TLD capsules were irradiated on axis at 10 and 5 cm depth for three open fields (8×8 cm, 10×10 cm, 10×20 cm) and one wedge field (10×10 cm).

![FIG. 1. Results of TLD audit in non-reference condition for on axis measurements.](image)

The results of the audit in non-reference conditions for on-axis measurements are all within the 3.5% tolerance limit (Fig. 1.) which is usually used for reference conditions.

A feasibility study has been done of a new holder for off axis measurements (5 cm at both
sides from the axis). The feasibility tests of the holders and phantoms and methodology for external audit in a variety of non-reference conditions were done. The first pilot studies were done at the Centre of Oncology in Warsaw for three Co-60 units and for three linac photon beams: 4, 6 and 15 MV [3].

The results of the pilot study of a new holder for off axis measurements show that it is possible to keep the dose determination within tolerance limits by implementing the correct methodology and carefully carried out measurements and calculations of doses. A feasibility study of the audit in non-reference conditions off-axis has been performed for four mega voltage units. Measurement conditions were, as follows: depth 10 cm, field size 20×20 cm, measurements performed for X and Y profiles on axis and ±5 cm off axis for the open field, and along Y profile for the wedged field. The results are presented in Table 1.

TABLE 1. RESULTS OF THE PILOT STUDY OF A NEW HOLDER FOR OFF AXIS MEASUREMENTS

<table>
<thead>
<tr>
<th>Beam</th>
<th>Profile X</th>
<th>Profile Y</th>
<th>Profile Y (wedge)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.8</td>
<td>-0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>4 MV</td>
<td>1.8</td>
<td>-4.2</td>
<td>0.3</td>
</tr>
<tr>
<td>6 MV</td>
<td>-2.5</td>
<td>-0.4</td>
<td>-0.1</td>
</tr>
<tr>
<td>15 MV</td>
<td>-1.5</td>
<td>-1.9</td>
<td>-2.4</td>
</tr>
</tbody>
</table>

delta (%)

The overall quality of radiotherapy seems to be kept at an acceptable level despite the extremely high patient load in most centres. The results of the TLD postal audits indicate high levels of accuracy of dose determination in audited radiotherapy centres in subsequent audit runs.

ACKNOWLEDGEMENT

The project is supported under an IAEA coordinated research project.

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Audit of radiotherapy beams in non-reference conditions:  
Results of the pilot studies

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Since 1995, the Algerian External Audit Group which is part of the Secondary Standard Dosimetry Laboratory, has set up a quality assurance programme for radiation therapy dosimetry. A methodology for the audit of radiotherapy beams using thermoluminescent dosimeters has been established. The work carried out under the framework of an IAEA CRP\(^{1}\) allowed us to check the accuracy of delivered absorbed doses for high energy photon beams in reference conditions.

A further CRP was established in 2001\(^{2}\) \([1]\) to take into account complex audit measurements in real treatment geometries, i.e. different depths and field sizes, use of wedge filters, etc. In addition to reference beam output, the audit in non-reference conditions could detect any errors in beam data delivered by the treatment planning system (TPS) – geometries, such as depth dose data, beam output variations with field size, wedge and tray transmission factors, field flatness and symmetry.

Under the framework of this CRP, the Algerian EAG has launched pilot studies including five radiotherapy centres (nine \(^{60}\)Co beams and four high energy X rays). In these studies, absorbed doses were checked versus depth and field sizes using either TLD and ionization chamber.

The second study was undertaken using the new TLD holder, with horizontal arm. This holder allowed us to check also the beam profiles and symmetry. Prior to the pilot study, the influence of the horizontal arm was evaluated with TLD capsules to be 1.007, 1.005 and 1.008 at the depths of 5, 10 and 15 cm, respectively. Furthermore, three capsules can be irradiated together with this holder; the cross effect of the capsules has been found to be negligible.

Finally, a third pilot study, which is still under process, concerns the audit of radiotherapy beams in non-reference conditions of axis.

The methodologies followed by the EAG are explained in this paper and the results obtained during the pilot studies are interpreted.

REFERENCE


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\(^{1}\) IAEA CRP E2.40.07, “Development of a QA programme for radiation therapy dosimetry in developing countries”.

\(^{2}\) IAEA CRP E2.40.12 “Development of TLD-based quality audits for radiotherapy dosimetry in non-reference conditions”.

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FIG. 1. Study of the ability for the TLDs to measure depth dose data (a), beam output (b) and beam profile (c). The results are compared to those obtained with ionization chambers. For depth dose data, only results corresponding to 10 cm × 10 cm are given in (a) where data published by British journal of radiology, supplement 25, are also included.

FIG. 2. Results of the first pilot study “audit of radiotherapy beams in non-reference condition, on axis measurements”. The fact that the majority of the values are positive values could be explained by the fact that all the radiotherapy ionization chambers were calibrated at the same period at the SSDL, while the TLD was calibrated with a newly calibrated secondary standard chamber with slightly lower calibration coefficient.
Beam calibration check with TLD: Experimental determination of the holder effect

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A simple and worldwide method for checking the radiotherapy beam calibrations is by using thermoluminescent dosimeters [1,2]. Teflon capsules (3 mm inner diameter, 20 mm inner length and 1.0 mm wall thickness) filled with about 160 mg of lithium-fluoride powder are used as dosemeters. LiF, as thermoluminescent material, is usually chosen considering its effective atomic number ($Z_{\text{eff, LiF}} = 8.14$) which makes it close to tissue equivalent ($Z_{\text{eff, tissue}} = 7.42$) for the high energy beams used in radiotherapy. The choice of powdered TL material instead of solid chips or roads is justified by the great precision that must be reached (a precision of better than $\pm 2\%$ (1 sd.) on the measured dose; it requires a standard deviation of the TL reading of $\pm 1.5\%$ or less [3]).

Most of the international TLD networks operating in Europe and the USA, EQUAL (ESTRO Quality Assurance network), EC QA network (European Community Quality Assurance network within the programme 'Europe against Cancer'), and the Radiation Physics Centre (RPC) in Houston, USA, use the methodology developed by the IAEA. A set of capsules is sent to participants who are requested to irradiate them at an absorbed dose as close as possible to 2 Gy. The capsules are irradiated in a water phantom using an IAEA holder stand.

For beam calibration check purpose; the capsules are inserted into the upper hole of the IAEA holder (4) at a depth of 5 cm. If the capsules have to be irradiated at a depth of 10 cm, then a 5 cm length supplement piece of PMMA is added to the upper part of the holder. Adjusting the water level to its top brings the hole at 10 cm depth. For beam quality check, capsules are inserted into both holes of the lengthened holder. After adjusting the water level, the upper capsule is set at a depth of 10 cm and the lower one at a depth of 20 cm.

Most recently, the IAEA provided the participants of an IAEA CRP\textsuperscript{1}, new holders with a hole situated at 10 cm, intended to be used for checking the beam calibration performed according to TRS-398, which recommends to use a single reference depth of 10 cm.

Due to absorption and scattering, the absorbed dose determined by the capsule is slightly different from the dose determined in the absence of the holder. Hence the application of a correction factor taking this effect into account. Since the magnitude of this correction factor depends on the length of the holder in front of the TLD, it should be determined for each situation such as the determination of the beam quality where the lower capsule is at 20 cm and is also shielded by the upper capsule.

\begin{footnotesize}
\begin{enumerate}
\item IAEA CRP E2.40.07 “Development of a quality assurance programme for radiation therapy dosimetry in developing countries”.
\end{enumerate}
\end{footnotesize}
In the present work, we have investigated the effect of beam shielding over the response of the capsules using a modified standard holder. This holder is machined in order to vary the length of the plastic tube in front of the TLD by 1 cm steps (Fig. 1). The effect is investigated using three waterproof ionization chambers of different sizes: a 0.125 cm$^3$ PTW 31002, a 0.3 cm$^3$ PTW 31003 and a 0.6 cm$^3$ Wellhöfer IC 70 Farmer. A PTW UNIDOS 10001 electrometer is used and the ionization charges are collected using the RS 232 interface and a labview software. The measurements were performed using a MEDTEC cubic water phantom equipped with a precise positionning device. The response of the three chambers positionned at 10 cm depth in water are presented in Fig. 2, versus the length of the holder in front of the cavities. Similar results were obtained for other depths. In Fig. 3, we can see the variation of the shielding effect over a TLD capsule, determined by interpolating the measurements of the ionization chamber.

**REFERENCES**


The results from external TLD audit in reference and non-reference conditions in Bulgarian radiotherapy centres

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The necessity of national and international dose intercomparisons is brought about by the high degree of precision and accuracy required in radiotherapy. The aim of the intercomparisons is to check and improve the dosimetry uniformity and accuracy in order to achieve consistency and comparability of radiation dose delivery to the patients. According to the International Commission on Radiation Units and Measurements (ICRU) the dose delivered to the target volume should be known at least to within ±5\% [1]. Some investigations indicate that even better accuracy is preferable [2].

Since 1975 the Laboratory of Clinical Dosimetry and Ionizing Radiation Metrology (SSDL-Sofia) has been conducting a postal dose intercomparison programme for all Co\textsuperscript{60} teletherapy units in the country. The method used is similar to the IAEA method. The first run was carried out in 1975 and 11 runs have been accomplished so far. Of 285 results, 251 (88\%) deviation between dose stated by the participants and the dose measured by our laboratory were within ±5\% and three (3) deviations were outside ±10\%.

Since 2004 SSDL-Sofia has been developing an operating procedure for the photon beam audits on-axis in non-reference conditions including three radiotherapy centres. Instruction sheets, data sheets and result reporting forms are prepared under the IAEA methodology. Deviation between dose stated by the participants and the dose measured by our laboratory were within ±5\%, excluding one result regarding wedge transmission factor, where the deviation was greater then 5\%.

When the absolute value of the deviation is grater then 5\%, the participant is asked to take urgently the necessary steps in order to find the source of the error. If the errors fail, we make a site inspection and the unit is thoroughly checked and if necessary recalibrated or explained through the audit methodology.

This year SSDL-Sofia will organize a national run of external TLD audits for all radiotherapy units in non-reference conditions on-axis and a pilot run for selected groups of radiotherapy centres in non-reference conditions off-axis using a new IAEA TLD holder with horizontal arm for dose measurements under IAEA methodology. The results will be reported in November 2006.

The required high accuracy in therapy level dose measurements and determinations can be achieved only each step in the sequence of dosimetric procedures – from the PSDL to the irradiation of the patient is performed very carefully with the highest possible precision.
ACKNOWLEDGEMENT

This investigation is supported by the IAEA through Research Contract No. BUL-11915 on “Development of methods for extending TLD quality audit in Bulgaria of high energy photon and Co$^{60}$ gamma ray beams in external radiotherapy to measurements in non-reference conditions”.

REFERENCES


TLD audit in radiotherapy in the Czech Republic

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Since 1997, the measuring centre of the National Radiation Protection Institute in Prague has been performing TLD audit in external beam radiotherapy via mailed TL dosimeters, with the objective to check dose delivery accuracy and inform the authority, the State Office for Nuclear Safety (SONS), on the situation.

The present number of radiotherapy centres in the Czech Republic is 30; they are running 60 high energy external beam units. There are 14 $^{137}$Cs, 21 $^{60}$Co irradiators and 25 linear accelerators currently in use. Fourteen linacs are equipped with multileaf collimators (9 Varian, 1 Siemens and 4 Elekta machines).

Lithium fluoride powder (type MT-N produced by TLD Poland) distributed in opaque polyethylene capsules (type used by the IAEA/WHO TLD postal programme) is mailed to the centre together with a sheet to enter details on the TLD irradiation. Instructions and photon and electron standard IAEA holders have been distributed to all Czech radiotherapy centres. Dosimeters need to be irradiated within a defined time window; in the middle of it, the system is calibrated (2 Gy in the SSDL-$^{60}$Co beam under reference conditions). Irradiated powder is dispensed into metallic containers and put onto the reader’s planchette – each capsule provides 9 or 10 samples. Harshaw manual reader models either 4000 or 4500 are used. To determine the absorbed dose to water from the TLD reading, correction factors for the beam quality, dose response linearity and fading need to be applied. They are stated separately for each batch of powder, in accordance with published methodologies.

The basic mode of TLD audit is done for both photon and electron beams used clinically at least once every two years. Absorbed dose on radiation beam axis in the reference field of $10\times10\,\text{cm}^2$ in an appropriate water phantom with common SSD or SAD set-up is checked. The depth depends on the beam quality. Dose to water at the position of TLD must be 2 Gy.

The advanced mode – Multi-Purpose Phantom (MPP) tests for photon beams – have been performed as a research project with the EC-MPP, checking dose delivery accuracy both on and off radiation beam axis for seven MPP set-ups. It simulates the process done with patients, from CT scans to the irradiation in accordance with calculated treatment plans. MPP audit is relatively time consuming, and it is done on SONS’ or the center’s request.

MultiLeaf Collimator (MLC) TLD audit for high energy X ray beams has been introduced. MLC audit has been performed for all MLC-equipped linacs within a pilot study. Since 2005, it has been applied together with the basic audit. Further, it is supposed to be done upon request by SONS or the center. As a result of the pilot study, the number of checked MLC set-ups was reduced from eight to four – the rest was found redundant.

The deviations between dose stated by the radiation therapy centre and dose measured via TLDs is determined. For the basic mode of TLD audit, MLC audit and most of MPP audit (on-axis measurements without wedges), the tolerance level is set to $\pm 3\%$. For more complicated MPP set-ups, the tolerance level is $\pm 5\%$. As for basic TLD audit, deviations
between ±3% and ±6% are considered as minor and the audit is repeated. If deviation exceeds ±6% (major deviation), the centre is required to investigate the situation and to explain possible causes. The emergency level is 10%. For the advanced modes of TLD audit, the deviations are treated individually.

The acceptance level of 3% is relatively strict, which is affordable because of the small size of the country and better ability to confirm the results promptly if tolerance levels are exceeded. Still, 85% of the results meet the criteria. Both basic and advanced modes of TLD audit may discover deviations in clinical dosimetry or in treatment planning, although they do not provide enough information for proper interpretation of errors. The results show the importance of independent TLD audit as a flexible and operational part of the comprehensive quality assurance programme.

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Postal audit in reference and non-reference conditions in Brazil

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Since 2003, the Quality Control Programme in Radiotherapy (PQRT) of the National Cancer Institute - Rio de Janeiro, has implemented a new postal audit system in Brazil and five other countries in Latin America.

This new system evaluates the therapeutic photon beams ($^{60}$Co and linear accelerators) in \textbf{reference and non-reference conditions}. It evaluates:
- dose in the central axis in reference conditions
- dose in the central axis at different depths
- dose for rectangular fields
- tray transmission factor
- wedge filter transmission factor
- beam symmetry
- beam flatness
- beam quality (for linear accelerators).

The system (Fig. 1) consists of a lucite support and powder thermoluminescent dosimeters (TLD-100: LiF doped with Mg and Ti). TLD annealing follows the IAEA protocol [1]. Their linearity, energetic dependence and fading are analysed in the beginning of the process.

To evaluate the absorbed dose in the TLDs we use the following equation:

$$D_{TL} = \left( \overline{TL} - \overline{TL}_n \right) \cdot \frac{D_{Ref}}{T_{TL,Ref}} \cdot f_{Dev} \cdot f_{Lin} \cdot f_E$$

(1)

The readings uncertainty for each TLD is ±0,5\% (1 sd).
Total system uncertainty is ±1,8\% (1 sd).

Classification of results in regard to the dose follows the IAEA model:
- optimum level: ≤ ±3\%
- tolerance level: ≤ ±5\%
- emergency level: > ±10\%.

For the other analysed parameters, we use:
- optimum level: ≤ ±1 sd
- tolerance level: ≤ ±2 sd
- emergency level: ≤ ±3 sd.
This system has already been used to evaluate 126 radiotherapeutic equipment in Brazil (44 $^{60}$Co and 82 linear accelerators), corresponding to 140 photon beams and 936 parameters analysed. These results are shown in Fig. 2.

In 2005, this system has been applied also in five other countries in Latin America, in 20 radiotherapeutic equipments (eight (8) $^{60}$Co and 12 linear accelerators), evaluating 132 parameters in 22 photon beams. Fig. 3 shows the results.

![FIG. 2. Brazilian results.](image1)

![FIG. 3. Latin American results.](image2)

The main problem found in the Brazilian radiotherapy services is related to the beam flatness of the $^{60}$Co equipment, with 12% of them out of the acceptable limit. Among the linear accelerators, the main problems were related to depth dose (8.5% out) and the beam flatness (7% out). On the other hand, among the 22 photon beams analysed in the other five countries in Latin America, the main problems were related only to linear accelerators. They were: dose in rectangular fields, beam symmetry and flatness, with 8% of the beams out of the acceptable limits.

When any parameter is out of acceptable limits, we immediately contact the local physicist to try to solve the problem, and another postal system is sent.

Our experience with this new postal system has already shown how useful, cheap and practical it is to control these eight basic and important parameters of any photon beam clinically applied. Due to this work, we could routinely get 90.7% of the audited beams within the levels recommended by the IAEA-TECDOC-1151 [2].

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A programme for dose quality audits for high-energy radiotherapy beams in non-reference conditions in Argentina

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Under the framework of the IAEA Coordinated Research Project on “Dose quality audits for high energy radiotherapy beams in non-reference conditions”, the External Audit Group (EAG) of Argentina is running a programme in order to offer a service of TLD audits.

This programme involves several steps, some of which are currently being performed: acquisition and characterization of a new PTW PCL3 reader; processing of TLD powder and determination of calibration, fading, linearity, energy and holder correction factors; dose audit in non-reference conditions, on axis and off axis, for high energy photon beams; dose audit in reference and non-reference on axis for high energy electron beams.

A new reader PTW PCL3 was acquired, including a manual dispenser for TLD powder, an oven FIMEL ETT for TLD annealing, and a number of cupels to dispense the powder. The powder in use is TLD100 LiF(Mg,Ti), Rexon TLD Systems, 80–200 mesh. The characterization included the intensive operator training in loading powder in polyethylene capsules and dispensing aliquots of powder in the cupels. The cupels were weighed and a selection was made under the criteria of 2 SD in order to reduce the final uncertainty. The mass of aliquots is dependent on total mass of powder loaded in the dispenser, i.e. the mass of powder loaded in each capsule. In order to reduce the standard deviation of readings in each capsules the environmental conditions of room, the stabilization time and other requirements were established prior to starting the reading sessions. Following careful procedures, the readings showed a standard deviation of 0.6% for four readings per capsule. The annealing procedure is as recommended in the literature: 1 h at 400°C and 24 h at 80°C. The powder annealed is sieved using 80 and 200 mesh sieve.

Fading shows a variation of 4.5% in the first 20 days with stable behaviour after this time. The linearity correction factor (Fig. 1) varies from 1.016 at 1.5Gy to 0.982 at 2.5Gy. Figs 2 and 3 show the energy correction factors for photons and electrons, respectively. To obtain reliable values, more determinations of this factors are being performed.

![FIG. 1. Linearity correction factor.](image1)
![FIG. 2. Energy correction factor for photons.](image2)
![FIG. 3. Energy correction factor for electrons.](image3)
The complete programme for audits in Co-60 beams and high energy X ray beams consists of the following steps:

- TLD audits for photon beams in reference condition Photon beams in reference and non-reference conditions on-axis (two depths, three different open field sizes and two wedged field size)
- Photon beams in reference and non-reference conditions off-axis (open and wedged fields with TLDs located on main transversal axis at reference depth).

The audits for electron beams included similar steps: irradiation at a reference depth, \( z_{\text{ref}} \) on-axis (6–9 MeV, 10 MeV; 12–18 MeV) at two field sizes; electron beams at two depths, \( z_{\text{ref}} \) and \( R_{50} \) on-axis) at two field sizes.

A postal audit for Co-60 beams in reference condition was performed on 23 machines as the first step of a complete audit. For this step the participating centre is requested to irradiate each of the three capsules separately to a dose of 2 Gy to water, in a water phantom, at the central axis of a vertical irradiation beam, at 5 cm depth. The field size used is 10 cm \( \times \) 10 cm at either source-to-surface distance (SSD) or source-to-capsule distance. All participants have to complete a data sheet giving the method used for the absorbed dose determination. Once the TL-dosimeters return, the measurements corresponding to a batch are made on the same day. From each capsule 4 TL-reading are obtained. The mean value is determined for each capsule. The reading is referred to reference readings in order to compensate reader fluctuations and using the linearity factor and the holder factor (constant equal to 1.01) the dose is obtained. The overall uncertainty of the dose determination is 2.4% (3% including the dosimetry protocol).

Six of the 23 participating machines obtained the dose deviation outside the interval ±5%. Corresponding follow-up is being made. The others (17 machines) will participate in the next step (in reference and non-reference conditions on-axis).

This paper will include the results of audits in non-references conditions, on-axis and off-axis, for Co-60 machines and at least 10 Linear Accelerators (X ray and electron beams) operating in the country.

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Implementation of an absorbed dose postal QA programme for radiosurgery

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Radiosurgery is becoming a well accepted method for the treatment of small intra cranial benign lesions and neoplastic tumours. It can be delivered using multiple sources of \textsuperscript{60}Co gamma rays (i.e. Gamma knife) or using high energy photons, typically 6 MV, produced by clinical linear accelerators.

The main objective of this work was to develop, test, and implement a Postal System of Quality Assurance of the absorbed dose applicable specifically to radiosurgery. Due to the specificity of the radiation field including the steep dose gradients, several measuring systems were necessary in order to guarantee the required dose accuracy. The ionization chamber (0,125 cm\textsuperscript{3} / PTW-Model 31010), thermoluminescent mini dosimeters (TLD), film, and mini Alanina dosimeters were selected.

The dosimeters were calibrated against a PTW ionization dosimeter previously calibrated at the PTW secondary standards.

The postal evaluation system consist of a main cylindrical acrylic phantom as described in Fig. 1, with 16 cm of length and 21 cm of diameter, and four smaller cylindrical (C\textsubscript{1}–C\textsubscript{4}) inserts with 10 cm of length and 7 cm of diameter with the following specific characteristics:

- C\textsubscript{1} contains a small air volume with 2 cm of diameter that simulates the target with 3 air micro spheres with a diameter of 3 mm.
- C\textsubscript{2} contains five cylindrical rods where the mini TLDs with 2 mm of diameter and 0,5 mm of length were inserted and placed 5, 15, and 35 mm from the centre.
- C\textsubscript{3} contains five cylindrical rods where the alanine dosimeters with 1 mm of diameter and 2 mm of length were inserted at distances similar to those of the TLDs.
- C\textsubscript{4} contains an oncology film (X Omat-V) placed inside.

In addition, a set of forms for data register and written procedures were sent to the participating institutions. A total dose of 25 Gy is requested to be delivered at the target. The overall management procedure is described in Fig. 2, and the three main phases of the procedure are as follows: 1) An evaluation was made of the coordinate system of CT images as defined in the center of the target as well as at the micro spheres in the treatment planning system for later comparison with the reference coordinates. For this evaluation the four participating institutions agreed within 0,3%; 2) The positioning accuracy of a 2 cm diameter.
beam was studied by placing small steel balls in the C1 insert in order to produce a set of images for the phantom position at 0 and 90 degrees. The agreement was within 0.7mm; 3) Accuracy of the treatment planning system was evaluated by comparing the calculated values and the measured values with TLDs, Alanine and Film all placed at the centre of the cylinders C2, C3 and C4. The required doses were 10 Gy for the TLDs, 25 Gy for alanine, and 1.2 Gy for film.

The results obtained showed an agreement better than 1.26% for the dose at the mid-target position, 1.51% at 5mm away from the mid target, 2.9% at 15mm away from the central point at the target, 2.9% at 35mm away from central point, and finally 0.48% for the total absorbed dose. The overall results of the participating institutions are within the recommended tolerance levels [1] and the metrological coherence of this project encourages its recommendation to be used as part of a QA of the radiosurgery procedures.

**FIG. 2.** Overall organization of the postal QA dosimetry programme for radiosurgery.

**REFERENCES**


QA status of radiotherapy in Vietnam

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In Vietnam, there are 11 radiotherapy centres with four Linacs, 13 radiotherapy cobalt-60 sources and several therapeutic X ray machines and afterloading machines being used. The staff of the National Dosimetry Calibration Laboratory (NDCL) performed the measurement of radiation output of radiotherapy equipment in air and a water phantom under standard conditions at the treatment distance. Generally, measurements are done every two years with standard dosimetry system traceable to SSDL of the IAEA. After setting up, commissioning, repair of the radiotherapy units and changing the new source, the Ministry of Health asked NDCL to do acceptance tests for radiotherapy equipment. During on-site visit, apart from measuring the radiation output, various parameters of equipment were controlled, as follows :

- Verification of mechanical parameters including correspondence between the mechanical axis of the collimator and the light beam axis, isocenter position, optical distance meter, symmetry of the collimator jaws, geometrical field size indication;
- Verification of photon beam characteristics including correspondence between the light field and the radiation field at reference depth, flatness and symmetry of radiation field [1,2];
- Verification of treatment planning for medical linear accelerators [3,4].

At several times IAEA experts visited the radiotherapy departments to measure beam output of equipment by both the experts’ and local secondary standard dosimetry systems. The Vietnam Directorate of Standard and Quality recently issued the protocol named “Cobalt-60 teletherapy equipment: Methods and means of verification” to enhance the quality of radiotherapy equipment [5].

With 15 years of experience in performing quality control for X ray machines/Cobalt-60 units, ISNT is likely able to satisfy the requirement of solving physics problems for radiotherapy. However, it is very difficult for us to solve the mechanical problems of radiotherapy units found during quality control of the equipment.

Establishment of the External Audit Group and TLD postal programme for radiotherapy departments. The External Audit Group (EAG) was established with the staff and facilities of SSDL, Medical Physics Group of the radiotherapy departments and officers of the Vietnam Radiation Protection & Nuclear Safety Agency (VARANSAC) and Ministry of Health. The flowchart of EAG is shown in Fig. 1. Since 2001, EAG has organized the TLD based quality audit in dosimetry for radiotherapy departments annually.

The EAG has prepared some forms and documents for the audits following IAEA guidelines [6,7], such as:

- instruction sheets describing the geometrical set-up for TLD irradiation and the irradiation procedures;
data sheets for the clinical beams, where details concerning beam calibration and TLD irradiation are reported by the participating departments, including the date of irradiation of TL dosimeters, dose delivered to the dosimeters, quality index for photon beams, ion chamber calibration factor and its traceability, information on the dosimetry protocol used and date of the last external audit in which the centre has been involved.

TL dosimeters have been prepared in SSDL-Vietnam which belongs to Centre of Radiation Protection & Environment Monitoring. Usually we try to run this programme simultaneously with IAEA TLD audits for the radiotherapy departments in Vietnam. Thus, at the same time every radiation beam to be included in the TLD audits is provided with the above-mentioned instruction sheets and data sheets, a holder for irradiation of the TLD samples and two sets of TLDs for the irradiation, together with control capsules to monitor the background, undesirable accidental irradiation (one from SSDL-Vietnam, another from the IAEA). After the TLDs are irradiated they are returned to SSDL-Vietnam together with calculated, reported sheets and data sheets. One set of TLDs would be sent to the IAEA for reading and another will be read out in SSDL-Vietnam by Harshaw reader 4000. EAG and the IAEA would then inform every participating radiotherapy department the results of doses related to their radiation beam including the ratio of the dose \( D_{TLD} \) measured with the TLD method to the dose \( D_{stat} \) stated by the participating centre (\( CF = D_{TLD} / D_{stat} \)). The percentage relative deviation between the stated and the measured dose (defined as \( Dev = 100\% x (D_{stat} - D_{TLD}) / D_{TLD} \)) should also be informed by the EAG and IAEA. A relative deviation with negative (positive) sign will indicate that the user estimates lower (higher) dose than what is measured, a patient would therefore receive higher (lower) dose than what is intended, as expressed by the factor given in the last column.

The measurement set-up and related procedures are described. The detailed results and comparisons are presented.

REFERENCES

Credentialing for advanced technology clinical trials using anthropomorphic phantoms

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The Radiological Physics Center (RPC) was established as a resource in radiation dosimetry and physics for cooperative clinical trial groups and radiotherapy facilities that deliver radiation treatments to patients entered onto cooperative group protocols. The RPC’s primary responsibility is to assure NCI and the cooperative groups that the participating institutions have adequate quality assurance procedures and no major systematic dosimetry discrepancies, so that radiation treatments that are delivered are clinically comparable to those delivered by other institutions in the cooperative groups. To accomplish this, the RPC monitors the basic machine output and brachytherapy source strengths, the dosimetry data utilized by the institutions, calculational algorithms used for treatment planning, and the institutions’ quality control procedures. The methods of monitoring include on-site dosimetry review by an RPC physicist, and several remote audit tools. The remote audit tools include 1) mailed dosimeters (TLD) evaluated on a periodic basis to verify output calibration and questionnaires regarding changes in personnel, equipment, and dosimetry practices; 2) comparison of dosimetry data with RPC “standard data” to verify the compatibility of dosimetry data; 3) evaluation of reference and actual patient calculations to verify the validity of treatment planning algorithms; 4) review of the institutions’ quality assurance procedures and records; and 5) mailable anthropomorphic phantoms to verify tumour dose delivery for special treatment techniques.

The RPC has developed an extensive credentialing programme for institutions wishing to participate in clinical trials that use advanced technologies such as stereotactic radiosurgery (SRS) and intensity-modulated radiation therapy (IMRT). This programme requires institutions to submit questionnaires designed to test the participants’ knowledge of the specific clinical trial, and to describe the institution’s equipment and QA procedures. The credentialing programme also requires the institution to prepare a treatment plan that is compliant with the requirements of the protocol, and submit the plan, most often through an electronic digital data exchange process. The programme also requires the institution to irradiate a standardized anthropomorphic QA phantom.

To meet the anthropomorphic QA phantom irradiation requirement, the RPC has designed and constructed a family of anthropomorphic phantoms that have now been used to credential more than 304 institutions for advanced technology clinical trials. These QA phantoms are water-filled plastic shells with imageable targets, avoidance structures, and heterogeneities. The phantoms contain TLD and radiochromic film dosimeters, to record the dose delivered by the institution. Phantoms have been constructed that represent 1) the head, for SRS brain trials; 2) the head and neck, for IMRT trials; 3) the thorax, for SRS treatment of lung tumours; (4) the abdomen, for SRS treatment of small tumours in organs such as the liver; and (5) the pelvis, for IMRT treatments of the prostate and cervix. The abdomen phantom is unique in that it contains two targets within the liver structure and three organs at risk (OAR); the stomach, kidney and spine. This phantom is placed on a 2D reciprocating table to simulate respiratory motion in the AP and SI directions.
When an institution requests to participate in a clinical trial that requires a phantom irradiation, a phantom is shipped by overnight express to the institution. Upon receipt of the phantom, the institution must first fill the phantom with water and install the imaging and dosimetry inserts, if appropriate. The institution is instructed to perform their routine CT imaging/simulation procedures, and prepare a treatment plan according to instructions given them, which are consistent with the requirements of the clinical trial. Next, the institution is to transfer the phantom to the treatment unit and deliver the planned treatment. Finally, the institution returns the phantom, with the dosimetry and imaging inserts, to the RPC.

At the RPC, the dosimetry systems are disassembled and the dosimeters are analysed to determine the absolute dose (TLD) and the dose distribution (radiochromic film). The measured dose distribution is then compared with the institution’s treatment plan, and a report of the analysis is submitted to the institution and to the study group sponsoring the clinical trial. A determination is made, based on criteria negotiated with the study group, of whether the institution’s dose delivery was in sufficient agreement with the treatment plan, and whether or not the institution will be credentialed for the trial.

ACKNOWLEDGEMENT

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REFERENCES


The IAEA/WHO TLD postal dose audits as a tool for evaluating the status of dosimetry practices in radiotherapy hospitals in developing countries

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This paper presents the analysis of results of the IAEA/WHO TLD audits performed in hospitals in developing countries in 2000–2005. The analysis is based on the information obtained from TLD data sheets filled in by the participants in the audit programme.

Over the period from 2000 to 2005, the IAEA/WHO TLD programme [1,2] has checked the calibration of approximately 2,400 photon beams in 1,100 radiotherapy hospitals. These checks were made in 110 countries in Africa (AF), Latin America and the Caribbean (AM), the Eastern Mediterranean (EM), Eastern Europe (EU), Southeast Asia (SE) and the Western Pacific (WP).

The distribution of TLD results for X ray beams from linacs and Co-60 machines shows that the calibration of X ray beams is more accurate than for Co-60 beams with higher percentage of acceptable results for linacs (88%–98% in different regions) than for Co-60 beams (73%–93%). The largest proportion of Co-60 machines to linear accelerators is in SE (82% and 18%, respectively) and EU (60% and 40%, respectively) whereas in other regions this proportion is reversed, with more linac installations than Co-60 units. The best TLD results are noted for Eastern Mediterranean and Africa, and the poorest for Eastern Europe and Western Pacific countries. TLD data sheets also indicate that hospitals with linacs are typically staffed with medical physicists, whereas this is not the case for some Co-60 installations, where TLD irradiations are performed by physicians or radiotherapy technicians. It was found that almost half of the large deviations (beyond 10%) occur for Co-60 machines, indicating inadequate qualification of staff working with these machines. In AM and WP regions, where many linacs are not covered with regular medical physics service, the percentage of large deviations for high-energy X ray beams is exceptionally high.

Part of TLD data sheets are returned to the IAEA with an incompletely filled-in or an empty section related to the ionization chamber measurements. In many cases this means that neither a dosimetry equipment nor a medical physicist is available at the hospital. The data sheet analysis also indicates that the results for these hospitals that returned incomplete data sheets are significantly worse than the global results for the particular region. The largest number of incomplete data sheets come from AM, EU and SE regions: 32%, 25% and 23% of the total, respectively. Further analysis of the data sheets shows that non-reporting of the ionization chamber measurements in the EU region is mostly because the dosimetry equipment is not available in many hospitals, but majority of the hospitals have a medical physicist on duty. The situation is different in the AM region, where the non-reporting is explained in many cases by the fact that the medical physicist is not available at the hospital. In this region, and also in WP region, many machines do not undergo regular calibrations, as often hospitals rely on services of visiting physicists which is by far insufficient for the adequate QC programme required in radiotherapy.
Large deviations (more than 10%) in the results of TLD audits are typically due to errors in dose calculation or in the geometry setup of the TLDs during the irradiation (for example, use monitor units/time for SSD setup and irradiation of TLDs at SAD set up, and vice versa). The physicists making these mistakes are either not sufficiently trained in radiotherapy dosimetry or have insufficient experience in clinical work.

If the determination of the absorbed dose to water using an ionization chamber was made following the TLD irradiation, the physicists are requested to report the Code of Practice (CoP) they used. The distribution of the CoPs used for dose determination in different regions is given in Fig. 1. The majority of hospitals in AM, EM and AF regions use modern CoPs based on air kerma (Nk) and absorbed dose to water (ND,w) standards [3,4], while many centres in EU, SE and WP regions are still using old exposure based (Nx) dosimetry protocols.

![FIG. 1. Percentage distribution of Codes of Practice used in different regions for beam calibration.](image)

Information obtained from the analysis of the TLD data sheets is useful in the evaluation of results of the IAEA/WHO TLD audits and the status of the dosimetry in radiotherapy hospitals in developing countries.

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Session 10b: 
*Radiation Imaging*
QUALITY ASSURANCE FOR DIAGNOSTIC RADIOLOGY
Clinical teleradiology and PACS QA

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The conversion of medical imaging to exclusively electronic formats is accelerating. The traditional role of medical physics in ensuring optimal image quality at the lowest achievable dose continues. However we no longer can satisfy ourselves with examining image quality on film alone. Rather, physicists must become familiar with teleradiology and picture archive and communications system (PACS) operation, their constituent equipment and related standards.

Medical physicists must become involved in teleradiology and PACS quality assurance. Medical physicists should understand all aspects of the acquisition, transmission, display and storage of medical images. It is essential that one knows the fidelity of the images stored and displayed on a PACS or teleradiology system. Responsibilities can include assessment of system design and workflow, evaluation of operational parameters, and evaluation of physical performance. The latter, which includes display and laser printer QC, will most commonly occupy the majority of a physicist’s time.

Medical display workstations are a major part of PACS. Display quality has a fundamental importance in the overall effectiveness of a diagnostic imaging practice. Unfortunately, display quality degrades over time. Degradation occurs both in luminance and in resolution characteristics of the display, two major performance indicators. Thus, it is vitally important to ensure that utilization of these devices does not compromise image quality, as suggested by a number of studies. Display testing in the form of acceptance testing or routine quality control provides a means by which any user can be assured that the display quality is adequate and is maintained throughout the useful life of the device. It will also determine when a display device should be decommissioned. A comprehensive PACS display QC programme will insure the consistency and integrity of image presentations in the broad electronic imaging practice.

Display quality assessment is relatively new. A number of investigations have begun to address the quality control aspects of electronic displays, and the DICOM Grayscale Standard Display Function working group has recently provided recommendations for the grayscale of soft copy displays.[1] However, the assessment of many critical medical display characteristics has not been standardized, the recommended methods have been either too complicated or too subjective, and the methods have not been endorsed by the medical community.

The professional guidelines of the American Association for Physicists in Medicine (AAPM) assert that the assessment of performance for electronic display devices in health care institutions falls within the professional responsibilities of medical physicists. The monthly or quarterly routine QC procedures may be performed by a trained QC technician under the direct supervision of a medical physicist, while the more extensive inspections involved in acceptance testing and annual tests can be performed by the physicist. An AAPM Task Group (TG18) recently completed work to address acceptance testing and quality control of medical electronic display devices [2]. The TG18 report provides standard guidelines for performing...
display evaluations by practising medical physicists, engineers, and display investigators, in order to assure adequate display performance for clinical tasks, and to facilitate inter- and intra-institutional comparisons. The scope of the effort is limited to devices for displaying monochrome radiological images. The performance characteristics considered include luminance response, luminance uniformity, resolution, noise, veiling glare, ambient light response, color uniformity, and geometrical distortions. Based on the current standard of practice, suggestions have been made for the acceptable ranges of display performance with limited impact on diagnostic efficacy.

Under the AAPM TG18 protocol, display testing can be undertaken at several levels depending upon whether they are for acceptance testing or quality control. New display devices should be evaluated via acceptance testing procedures, which are generally more extensive and more quantitative than routine QC evaluations and might take 1–2 hours. Annual display inspections consist of a large subset of the acceptance testing procedures taking about an hour, while the monthly/quarterly inspection relies more heavily on testing procedures that are less time consuming (~20 minutes). Daily QC recommended to be performed by the actual user of the display device is visual and should take less than one minute to complete.

For testing any given display quality characteristic, three types of testing may be used: visual, quantitative, and advanced. The latter is more appropriate for laboratory and research related evaluations. The visual and quantitative tests are used in the acceptance testing and quality control procedures.

In evaluating the performance of a display device, it is also important to take into account the intended purpose of the device. In clinical practice today, display devices are often used in two capacities: as primary, so-called diagnostic, displays and as secondary, so-called clinical, displays. The former devices are used for diagnostic interpretation of medical images leading to the generation of an interpretation report, while the latter are used for clinical review of images for which the official interpretations are already rendered. The performance criteria are usually less stringent for secondary class display devices.

A summary, a comprehensive PACS QA programme, including display QC, is an integral part of a medical physicist’s duties in this electronic age. An appropriate programme includes acceptance testing and ongoing QC evaluations. When combined with proper QC methods for the acquisition devices in a PACS, display QC will ensure that image quality is optimized.

REFERENCES


A summary of the latest UK guidance on routine performance testing of diagnostic X ray imaging systems, including simple but effective regular operator performance tests

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The subject of quality assurance in radiology has been an issue in the UK since the publication in 1990 of a joint report by the Royal College of Radiologists and the National Radiological Protection Board (NRPB) [1]. This included sixteen recommendations, one of which began: All X ray imaging equipment should be subject to regular performance checks which, if necessary, should lead to appropriate corrective action or replacement. The report concluded that there was a clear need for further guidance on quality assurance (QA), particularly on the ‘minimum standard to be achieved in the regular performance checking of X ray equipment’. Despite the wealth of publications devoted to QA in radiology departments, there was a need for concise, up-to-date guidance which addresses the ‘what, who, when and how’ of routine performance testing of diagnostic X ray imaging systems.

Subsequently a working party was set up, consisting of representatives from the College of Radiographers, the Institute of Physics and Engineering in Medicine (IPEM) and the National Radiological Protection Board (NRPB). The aim of the group was to provide recommendations on quality assurance that culminated in the publication in 1997 of IPEM Report 77 [2], which has been referenced on a wide scale in Europe [3]. These recommended standards aim to clarify and define the phrase ‘regular performance checks of X ray equipment’ for the guidance of all professionals with an interest and responsibility in diagnostic X ray imaging systems, including employers, managers, users, inspectors, purchasers and suppliers. One important aspect of the report is the attempt to provide guidance on what action to take when considering the results of routine performance tests. This led to defining action levels which, if exceeded, require remedial action or suspension from use of the equipment.

This report has recently been revised [4] to take account of new documentation and developments in equipment and practice since the original publication almost ten years ago. This has led to a restructuring of the report and the introduction of additional chapters.

In terms of documentation, published legislation and guidance has underlined the importance of monitoring X ray equipment performance and recently referenced reports provide up to date information and advice on how the tests should be carried out.

Advances in X ray imaging equipment, such as the introduction of multi slice CT scanners and digital detectors for fluoroscopy and dental radiography have necessitated revision and expansion of existing chapters. Additional chapters have also been required to cover routine testing of computed radiography and direct digital radiography systems.

With the proliferation of picture archive and communication systems (PACS), teleradiology and e-health, diagnostic images can now be widely distributed and viewed on a number of display devices. This has led to the introduction of a new chapter addressing image display devices.
The data from regular reviews of patient doses in the UK [5] are being used to determine national diagnostic reference levels (DRL) [6]. These have been incorporated into the revised patient dose chapter in an attempt to assess the overall impact of equipment performance and operator technique.

IPEM Report 91 also includes a glossary to clarify terms used in the original document such as reproducibility and repeatability.

REFERENCES


Investigation of the fluoroscopy units used in radiology and cardiology

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\textbf{Aim}

A nationwide survey was launched in 2002 in Switzerland in order to investigate the use of fluoroscopy and to establish national reference levels (RL) for dose intensive procedures particularly in interventional radiology. The two year investigation covered five radiology and nine cardiology departments in public hospitals and private clinics, and focused on twelve types of examinations: six diagnostic and six interventional [1]. The performance of the fluoroscopy units used in these healthcare centres (image quality and dose) was assessed extensively. This characterization was useful since, unlike the American RAD-IR study [2] where the fluoroscopy units where similar (Siemens, with Cu filtration), a large variability in the brands and the technical specifications of the fluoroscopy units used in the participating centres are registered in our case. The units are often programmed according to the anatomical region under investigation. Knowledge of the parameters used for the various categories of examinations is crucial for analysis of the results of the survey.

\textbf{Methods}

First, the DAP meters of the fluoroscopy units were checked using an external reference DAP meter put on top of the measuring device of the fluoroscopy unit. The units were then characterized in terms of the image quality and the patient dose associated to the various modes used. Assessment of the image quality consisted of establishing the spatial resolution limit at the middle of a Leeds TOR(CDR) Test Object [3]. The dose measurements were performed using an 11 cm\textsuperscript{3} ionization chamber connected to a Radcal 3036 dosemeter and a 20 cm thick PMMA phantom. The characteristics of the fluoroscopy units (dose rate, dose per frame, image quality index and spatial resolution) were established for three imaging modes (radiography, fluoroscopy and cine), various diameters (or magnifications) of the image intensifier and various imaging frequencies and for six categories of examinations: 1) barium based examinations, 2) bile tractus examinations, 3) abdominal and peripheral angiographies, 4) cerebral angiographies, 5) coronography and PTCA, and 6) electro physiology and thermo ablation.

\textbf{Results}

Apart from two cases where the indication of the local DAP meter was a factor two higher than the reference instrument, all the DAP meters gave doses within the limits set by the Swiss Ordinance on X ray Units (±30%). Fig. 1 shows the variation of the image quality index with the dose rate (fluoroscopy mode) and the dose per image (radiography mode) for biliary tract examinations. Table 1 shows the average parameters for various radiological modalities involving fluoroscopy. The variation of the dose rate for the same irradiation geometry was found to be of the order of a factor 3 for the best detection at low contrast. A
significant decrease of the dose rate was registered (a factor 2.5-3 for a 20 cm PMMA slab) when adding a Cu filtration.

\[ \text{FIG. 1. Variation of the image quality index with the dose rate (fluoroscopy mode) and the dose per image (radiography mode) for bilary tract examinations.} \]

\[ \text{TABLE 1. AVERAGE PARAMETERS FOR VARIOUS RADIOLOGICAL MODALITIES INVOLVING FLUOROSCOPY} \]

<table>
<thead>
<tr>
<th>Modality</th>
<th>Barium examinations</th>
<th>Biliary examinations</th>
<th>Abdominal angiographies</th>
<th>Cerebral angiographies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluoroscopy mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose rate (mGy/min)</td>
<td>26±4</td>
<td>37±4</td>
<td>31±6</td>
<td>20±4</td>
</tr>
<tr>
<td>Image quality index</td>
<td>8±1</td>
<td>10±1</td>
<td>10±1</td>
<td>9±2</td>
</tr>
<tr>
<td>Spatial resolution (mm(^{-1}))</td>
<td>0.8±0.1</td>
<td>1.1±0.1</td>
<td>1.1±0.1</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td><strong>Radiography mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose per image (mGy)</td>
<td>1.6±0.2</td>
<td>3.7±0.7</td>
<td>6.0±0.8</td>
<td>3.6±0.9</td>
</tr>
<tr>
<td>Image quality index</td>
<td>12±1</td>
<td>17.1±0.8</td>
<td>17±1</td>
<td>16.8±0.7</td>
</tr>
<tr>
<td>Spatial resolution (mm(^{-1}))</td>
<td>1.1±0.1</td>
<td>1.4±0.1</td>
<td>1.4±0.1</td>
<td>1.9±0.1</td>
</tr>
</tbody>
</table>

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Reject film analysis in a pediatric radiological department of Tunis

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The analysis of rejected films forming part of a quality assurance programme in diagnostic radiology is a simple method, non-expensive and effective for technical auto evaluation. It makes the leaders of a service able to estimate with certainty the film wasting, reliability of the used techniques, equipment status, and training of their technicians. It also allows for responsible radiation protection an evaluation of the unnecessary exposure of the patients and manipulators.

After a study of quality control on the radiological equipment of the Pediatric Department of the Children’s Hospital of Tunis, the reject film analysis was done over a one month period in two different rooms. Standard X ray exams were conducted with different technicians. Processing was performed in the same machine. The film analysis was made by two radiographers and a radiologist.

A total of 4,750 radiological examinations were analysed with 7,100 films. The rejects were assigned to seven categories (“exposure”, “positionning”, “patient motion”, “equipment”, “processing”, “dark room Fog”, and “others”). In addition, they were classified according to the respective room of practice.

The reject film rate in relation to all performed X rays was 8.7\% of all the films taken during that period, totalling 621 films. The acceptable rate should not exceed 5\%. Between 5 and 10\%, monitoring is recommended to identify causes in order to undertake the necessary corrections.

For our study, frequency of various errors in the two rooms is shown in Fig. 1. These values are comparable to other similar data [1]. The more important cause is the error of exposure, followed by positioning. This makes us note that our technicians continue to work with the guess method instead of using the chart’s technique which is useful and non-expensive.

The error due to dark room fog caused by bad quality cassette was immediately corrected. On the other hand, faults related to patient immobilization are not frequent in this specialized radiological department with a well familiarized staff with children.

It is concluded that wasted films due to errors occurring during film taking, as well as technical film waste, are unavoidable. Their proportion should be estimated by the reject film analysis which is recommended within a quality assurance programme in diagnostic radiology. It permits the identification of errors and their correction, the reduction of costs and the respect of ALARA principle for patient protection from unnecessary radiation exposure.
FIG. 1. Frequency of the different sources of error in the reject X ray film analysis of two rooms in the pediatric radiological department.

REFERENCES

QC of X ray machines in the hospitals of the Medical Sciences University of Zanjan

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\textbf{Introduction}

Nowadays X ray machines play a significant role in medical diagnosis. Approximately more than 50\% of annul radiation dose to public population from man made sources is caused by medical applications. This fact implies that accurate performance of these systems are essential and periodic quality control tests should be carried out. The goal of this study is quality control of X ray machines in hospitals of the Medical University of Zanjan.

\textbf{Materials and methods}

Firstly, 14 X ray machines in the hospitals of Zanjan province in four cities were chosen. For each X ray machine, the manufacturer, installation year and workload were studied individually. In this study the following four parameters have been studied: 1) kVp accuracy 2) mAs linearity 3) timer accuracy 4) exposure reproducibility. A Mult-o-Meter model 303 made by UNFORS was used. This is a multipurpose instrument. Mult-o-Meter can measure dose, dose rate, kVp and exposure time. For each X ray machine, measurements were carried out between 12 to 15 p.m. in three successive days.

\textit{kVp accuracy:} For evaluating this parameter, Multi-o-Meter was put on radiography table and X ray field was opened as the same size as the detector. Then each kVp value was set on control panel, with fixed value of mAs and 100 SDD and one exposure was performed. Selected kVp values were 30, 40, 50, …90. Set values were compared with the measured figures. Actual kVp should be within ±5\% of set kVp.

\textit{mAs linearity:} In this test with fixed kVp and time, for each mA station one exposure was performed. In this test mR/mAs for each mA station was calculated. According to the JCAHO, linearity is:

\[
\text{Linearity} \quad \frac{1}{2}[(mR/mAs)_{\text{max}} - (mR/mAs)_{\text{min}}] < 0.1[(mR/mAs)_{\text{max}} + (mR/mAs)_{\text{min}}]
\]

This measurement was repeated for 30, 40, 50, …90 kVp.

\textit{Timer accuracy:} In this test with the fixed value of kVp and mA, each set time value was compared with the measured value. Actual time should be within ±10\% of set time.
**Exposure reproducibility:** This test is performed to evaluate exposure reproducibility. After each exposure with fixed value of kVp×mAs, selectors were reset. The reset was repeated three times a day. Maximum acceptable value for SD/mean exposure is 5%.

Joint Commission on Accreditation of Healthcare Organization (JCAHO) criteria were used to assess the results of this research.

**Results**

57% of X ray machines failed in kVp accuracy test and 42% failed in mAs linearity. 14% failed in timer accuracy, and exposure reproducibility was not satisfactory in 7% of cases.

**Conclusion**

The results show that the most effective factors that affect inaccuracy of those radiation parameters may be due to: non-compliance of the quality control programmes, overuse of equipment, carelessness in using maximum load of tube tolerance, equipment ageing and frequent equipment displacement. The quality control tests, therefore, should be carried out in existing X ray machines in the other provinces of Iran.

*Keywords: X ray machines, quality control, radiation parameters.*

**REFERENCES**


QC in imaging departments in São Paulo/Brazil: A 10 year experience at a public university

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In the beginning of the last decade, a work group composed of physicists and engineers was organized at the Institute of Electrotechnique and Energy of the University of São Paulo (IEE/USP) in order to start the development of technical procedures to be implemented as a Quality Control Programme for diagnostic imaging departments. The first years of this group dealt with personal qualification and education of the professionals in the area of quality control and radiation physics. After 1995, the QC Group of IEE/USP started to apply the programme at the imaging departments in public and private hospitals at São Paulo. The programme started to be implemented only in general, dental and fluoroscopic X ray equipment, but was quickly added to QC procedures for computed tomography and mammography equipment.

During that decade a state regulation [1] and a federal regulation [2] were published, and many hospitals started the QC programme in order to comply with these regulations. The programme was adequately adapted to these regulations and an effort to disseminate information was made in order to improve the efficiency of the application of the programme. In some cases, international standards [3] or standards from other countries have also been used as basis for the evaluation programme. The QC programme is implemented in a regular basis, with technical visits of the professionals for physical measurements following at least the periodicity established under the national regulations.

The development of new procedures and the optimization of some methodologies followed two research programmes sponsored by Brazilian agencies. These researches provided the opportunity to improve the technical qualification of the team in charge with the QC tests, as well as make available the acquisition of electronic instruments and phantoms to be used in QC routine. Also during these research programmes, methods were developed to implement the QC programme in ultrasound and resonance magnetic imaging equipment.

Nowadays, the QC programme of IEE/USP has been applied to a group of 266 pieces of equipment, including general radiology, fluoroscopy, mammography, interventionist procedures, computed tomography, dental, ultrasound and resonance magnetic systems. Table 1 shows the number of each of the equipment. Moreover, assistance in shielding design, radiation surveys, acceptance tests, training and organization of the technical documentation are performed in accordance with the customers’ requirements. Organization follows the technical requirements of the ISO/IEC 17025 standard [4] in terms of calibration of instruments, organization of documents, personal qualification, etc.

After ten years of implementation of the programme, some statistical data could be compiled which show the behaviour of the main problems (non-compliances) found during the evaluation of these imaging equipment. Fig. 1 shows some of the tests applied during the QC routine and the respective percentages of failures found in the systems under the QC programme of IEE/USP.

The next steps in the development of QC procedures for this programme are focused on the establishment of methods for evaluating multi-slice CT systems and bone densitometry systems.
TABLE 1. MEDICAL IMAGING EQUIPMENT UNDER RESPONSIBILITY OF IEE/USP INT TERMS OF QA

<table>
<thead>
<tr>
<th>Ionizing (MS-453/98 standard):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>General radiology</td>
<td>117</td>
</tr>
<tr>
<td>Fluoroscopy/interventionist procedures</td>
<td>61</td>
</tr>
<tr>
<td>Mamography</td>
<td>30</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>25</td>
</tr>
<tr>
<td>Dental</td>
<td>04</td>
</tr>
<tr>
<td><strong>No ionizing:</strong></td>
<td></td>
</tr>
<tr>
<td>Ultrasound</td>
<td>24</td>
</tr>
<tr>
<td>Resonance magnetic imaging</td>
<td>05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>266</td>
</tr>
</tbody>
</table>

**FIG. 1. Some of the tests applied during the CQ routine and the respective percentages of fails found in the systems under the CQ programme of IEE/USP.**

**REFERENCES**


Study on the performance of recommended standards in the diagnostic radiology units of the hospitals affiliated to the Mazandaran University of Medical Sciences

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Background and purpose

Providing health care is the basic right of people [1]. Diagnostic radiology is one of the main procedures in health care services and proper benefit from this technology comes only after good planning and management [1].

Supervision of the available conditions and its comparison with the recommended standards are key in assessing assurance from the benefit of these instruments [2]. Data show that more than 80% of patients referred to these hospitals need a radiology image [3]. Improper service causes repetition of radiography and even wrong diagnosis, with results threatening the health of the patients [3]. Lack of a protective barrier leads to the exposure of the staff to X ray which is obviously carcinogenous [4]. It happens that the instruments are not working properly, like of symmetry in X ray field, defects in collimators, lack of adjusting ray field and X ray, low quality or defective developing machine, lack of proper protective barrier, using low quality film and drugs, lack of protective barrier for children, all of which cause severe hazards for the patients and staff [4].

The crucial aim of medical services is to provide the public with their needs which are very important. The sensitivity of such services is such that in case of a lack of care, the hazards are too high. In the evaluation of health services, the first thing is to evaluate the device used. Methods, efficiency, outcomes and their combination for the prevention and eradication of diseases are also important. Therefore, to gain this goal it is necessary the obtain results comparable with recommended standards. The purpose of this study was to access the conditions of radiology units at Mazandaran University hospitals and compare them with the standards of ICRU NCRP and ICRP. The radiology unit is the most expensive section of any hospital for its instrument, manpower and space required. In a study conducted in 51 centres on radiology staff, radiography rooms and protective barriers, X ray leakage, the outcome were 89%, 82%, 77% and 37%, respectively. It was found that the condition of these centres regarding the protective barriers was very unsuitable due to unawareness of the leakage [23].

Materials and methods

The variables under study were categorized into six groups: Radiography room for space, light ray lockage, height and condition and piece of pass cast ventilation, entry door, alarming pester, X ray signal, preserving devices, loud speaker, minimum distance of tube from control room and patient’s lavatory condition. Condition of radiography instruments like, model and installation date, function of mA, kV. Bottoms of instrument rotation, film tray, key function, condition of tube arm and scopy condition.

Condition of control room for, size, situation towards radiography room light, size of lead glass, height of the lead glass from the floor, situation of lead glass towards X ray room and
control room hygiene. Condition of dark room for entry door, space of the place and distance to radiography room light leakage, internal decoration for reflection of light, ventilation (power and light resistant) bulb (type if filter distance from film, bulb power), film box (earth wire), charge of drug, needed light, developing device (type and duration of usage) of developing device condition of rollers, condition of installation, position of instrument, blank films and drugs storage for light, ventilation and humidity

Condition of the other facilities such as patients’ preparing room, waiting room hygiene, staff room (space, facilities and hygiene) staff’s lavatory (place, hygiene and space) Filing room and personal, classification of films.

In this study radiography units were visited and data were collected using a questionnaire comprising questions based on radiology standards and protection against X ray as well as interview and observation. Detective dose meter FJI model capable of detecting X and gamma rays in the range of 50 keV–103 keV with energy response of 40–80% was used. An accurate thermometer with measuring range -10°C to 150°C and accuracy of +1°C was used for the determination of developing chemicals and films temperature.

A meter was used to measure the space of radiography and control rooms, height of pass cast, size of lead glass, and height of floor to ceiling. Leakage of X ray from door when closed was noticed and lead covering of the wall for protection was considered.

Results

It was found that 76% of the radiology units had a direct Scopy problem, only 96% had thyroid shield – gonad shield, and lead spectacle and lead cover. Considering the significance of such devices to protect children and adolescents against X ray, such condition is very disappointing [20,21]. Regarding the study on the presence of alarming signals, some of the units lacked a warning poster for pregnant women and only 40% of the units were in good condition in this regard [10,11].

About the control of irradiation for staff it was found that 51% of the units had no medical filing system and periodic examination for the staff. Meanwhile 15% of them did not have a person in charge of physical health to supervise and follow issues related to the personal protection and periodic check-ups [11,12]. Investigation showed that 47% of the units under study showed X ray leakage, which demands a serious and prompt intervention. It is worthy to mention that, approximately all of such units lack preservative device and required hardware [13,14]. All of the units under study had pass cast, but it was found that 67% of them were not efficient and most of the dark rooms had evident leakage of light, and did not have bulb, in 48% the temperature of developing negative film was not suitable [15,16]. The overall score for the units regarding alarming signals in dark room, protection against irradiation, radiology space, protective shield, results of dosimeter and efficiency of different instruments were 50%, 50%, 50%, 40%, 51% and 51%, respectively [18]. Each staff could take 13 images per day during the first six months of 2002.

Generally, considering the results obtained from this evaluation and the repairable defects, regular periodic supervision by an expert is absolutely necessary (once every six months) in order to have better usage of the instruments and facilities

Keywords: Diagnostic radiology, dosimeter, radiology standards, protective barrier, ionizing ray.
REX phantom and CONNY II dosimeter as examples of applied tools for QA in diagnostic radiology

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To assess compliance with a recently introduced Polish regulation [1], we have compared quality assurance (QA) tests performed using the reference diagnostic phantom REX and dosimeter CONNY II manufactured by PTW Freiburg, Germany (A-series tests), with tests where optical density was measured using the Model 07-443 densitometer produced in Cleveland, USA (S-series tests). The body of the REX phantom (Fig. 1a), made of aluminium and PMMA, includes symmetric structures of well defined shapes and densities for X ray attenuation and transmission, enabling tests of resolution dose contrast areas to be performed. The CONNY II instrument (Fig. 1b) is a semiconductor detector calibrated in units of air kerma, which can be used to measure dose, dose rate and exposure time. The Model 07-443 densitometer measures the blackness of exposed films over the range from 0 to 4D units of optical density [2,4,5]. QA tests were performed for 28 conventional radiographic units produced by: Siemens (9 units), EDR (6 units), Shimadzu (4 units), Philips (4 units), TUR (2 units), Continental Dunlee (1 unit), Bennet Trex Medical (1 unit) and Atlas Swiss Ray (1 unit).

\textbf{FIG. 1.} a) REX phantom, b) CONNY II dosimeter [3,4].

The data gathered included X ray beam parameters (kV, mA), exposure time and entrance dose. Basic exposures were carried out under conditions of typical X ray examinations (urinary tract and chest in AP and LAT projections) with apropriate high voltage (HV) to enable checks of entrance doses, contrast and film blackness. Additional tests included efficiency of theX ray tube, reproducibility of dose, time and HV settings and accuracy of set parameters. Entrance dose measurements were made at focus-skin-distance (FSD) with the CONNY II dosemeter placed on the REX phantom. For image control the focus-film-distance.
(FFD) was that typically used in radiological departments. The A-series tests were carried out using typical kV settings. Supplementary tests were usually performed at 80kV. S-series tests were performed under typical conditions of urinary tract (AP, 80kV), chest (LAT, 100kV) and chest (LAT, 120kV) examinations [3,4].

Results of QA tests made over a period of two years in some hospitals of the Malopolska district were compared [3]. The values of entrance doses for 19 units were found not to exceed the recommended [1] values of 10mGy for the urinary tract, 1.5mGy for chest (LAT) and 0.3mGy for chest (AP) examinations. We have observed in our S-series of measurements [2] doses exceeding the recommended values in some older units. In our A-series measurements in one case the dose has significantly exceeded the recommended value. However, the reference levels are defined for a standard sized adult person (70 kg, 170cm), so even a properly done examination may result in excessive dose. In both series we found acceptable spatial resolution of the units tested, ranging from 2,4 up to 4,8 Lp/mm. In all cases, except for two units, dose and time reproducibility were found to be acceptable. In our A-series tests we found that in only three (3) units had the X ray tube efficiency fell below 25µGy/mAs. Bucky grids, blurred edges and artifacts were observed in images of the REX phantom. In our S-series measurements we included an estimation of linearity between dose and mA-product over the whole mA-range at a particular voltage. A report on measurements performed so far will be presented.

We found the CONNY II dosemeter to be useful for comparing real irradiation time with the set values in periodic QA tests of X ray units with the REX phantom. However, it should be emphasized that the described measurements constitute only a part of those required by the present law [1]. Additional equipment (densitometers, voltmeters and special devices for focus spot size estimation) is needed to perform more complicated and advanced tests now required by law.

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QA of film/screen general radiographic X ray systems: Mobile units and fixed installations


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Introduction

Optimization of patient dose and image quality is of primary concern in the field of diagnostic imaging. It is recognized that comprehensive quality assurance (QA) programmes are a vital component in the optimization process.

Commissioning and routine QA testing of diagnostic X ray imaging equipment is a requirement of European [1] and Irish [2] legislation. Detailed in-house QA protocols have been developed for the acceptance and routine testing of general X ray systems. Protocols are based on recommendations and guidelines published by International [3], European [4,6] bodies.

The Medical Physics and Bioengineering Department, St. James’s Hospital is responsible for the QA testing of approximately 100 film/screen general radiographic X ray systems, including mobile units and fixed systems. Although traditional film/screen is currently being replaced by computed radiography (CR) and digital radiography (DR), QA testing of systems that utilize film/screen combinations is still an important aspect of QA programmes.

The study presents a survey of general X ray diagnostic imaging equipment performance. It also highlights the importance of QA programmes in ensuring that diagnostic imaging equipment achieves optimal image quality with minimal radiation dose to the patient.

Methodology

The following parameters common to both mobile and fixed systems were tested: tube and generator performance, radiation output, half value layer, beam alignment, focal spot size and dose-area-product meter accuracy. For fixed systems, the performance of the Automatic Exposure Control (AEC) system was also assessed. At commissioning, electrical safety measurements were also performed. In addition, equipment condition and mechanical safety were assessed.

Results and discussion

For general mobile X ray units the output per mAs at one meter focus-chamber-distance varied significantly, and was measured in the range of 30.5–60.5µGy/mAs. While this lies within the recommended tolerance range, this has implications for patient dose and image quality, particularly within hospitals that have many mobile X ray systems at their disposal. A given mAs setting may produce an image of optimal quality on one unit, while the same setting will produce an image of poor quality on another. Not all mobile X ray units incorporate an AEC system and for those that do, it may not always be used. There is a
potential to under or over expose the patient. This may lead to repeat examinations. The output per mAs measured for a particular mobile showed a percentage difference of 20% from 2004 to 2005. This highlights the importance of trending data from year to year, as part of the quality assurance programme.

Problems were identified with respect to the AEC systems of a number of fixed systems. Measurements of mean optical density, and consistency with varying tube voltage and varying water phantom thickness were outside the limits of tolerance. In addition, the maximal focal spot charge (current) that could be selected was 800mAs, which exceeds the tolerance of 600mAs, as recommended by RP 91 [4]. This may result in incorrect termination of the AEC system, which will impact upon patient dose and image quality.

Typical faults identified included kVp and timer accuracy, dose area product (DAP) meter accuracy and X ray field to light beam alignment. X ray field to light beam alignment failures are a particular problem with respect to mobile X ray units, as constant motion of units may tend to dislodge the X ray tube.

Conclusions

The study presents a survey of general X ray diagnostic imaging equipment performance. Although general mobile units and fixed systems are not considered high dose modalities, a review of the QA results highlights the need to perform routine QA testing of these systems.

ACKNOWLEDGEMENT

This work was conducted partially within the frame of the European Commission 6th Framework Programme SENTINEL Contract No FP6 - 012909.

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QA in radiology: Local diagnostic reference levels and information to the patient

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In the context of optimization of radiological exposures, the European Directive 97/43/Euratom refers to the concept of diagnostic reference levels (DRL). These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied.

According to national legal requirements, the maximum responsible for a radiological installation must assure that the radiological exposures are in agreement with accepted dose reference levels. The dose information of each type of examination should be available to the doctor who prescribes it and also to the patient.

A measuring protocol has been established in terms of the most convenient dose indicators for each type of the more common examinations carried out in the Imaging Department of the Instituto Português de Oncologia de Coimbra (IPOC-FG, E.P.E.) \cite{1}.

The aim of this work is to compare the dose reference levels locally determined with the European DRLs \cite{2,3} in conventional radiology, computed tomography and mammography. Also, the relevant information to be given to the patient is discussed and a general model for that information is proposed.

DRLs are expressed either in terms of entrance surface dose (ESD), for conventional radiology and mammography, or in terms of computed tomography dose index (CTDI\textsubscript{w}) or dose length product (DLP) for CT examinations.

This dose information and the exposure parameters for each type of examination are used as input values to the code PCXMC, version 1.5.2. \cite{4}, in order to assess patient organ doses and effective dose values in conventional radiology. In the same way, the program CTDosimetry \cite{5} is used in computed tomography. The Average Glandular Dose (AGD) is determined in mammography \cite{6}.

In order to give to the patient and also to the doctor who prescribes the examination readily accessible dose information, the concept of BERT (Background Equivalent Radiation Time) has been used. The average value of effective dose for each type of radiological exposure was converted in time of natural background radiation having 1 mSv/year as a reference value. Also the estimated risk associated to each type of examination was included in the patient dose information form. The estimated risk was obtained using the nominal probability coefficient for stochastic effects of 7.3\% per Sv \cite{7}. An example of the patient dose information form is presented in Fig. 1.
REFERENCES


Patient dose reduction in single radiographs

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\textsuperscript{b}Hospital de Leza, Osakidetza - Servicio Vasco de Salud, Laguardia (Araba), Spain

Implementation of the aspects contemplated in the transposed European Directive 97/43/Euratom through the Spanish Legislation has supposed, among others, the estimation of the doses received by the patients in the most frequent explorations.

This topic should be contemplated in the Quality Assurance Programme where aspects settle down in this sense related to the regularity of the procedures used for the estimation and the index of evaluated explorations.

An initial reference settles down with the measurements that are made. For it, a portable dose-area product (DAP) meter is used to record the results in some specific formats, whether the exploration is radiography, fluoroscopy, computed tomography or mammography. With the aim of grouping in age and thickness intervals, some of these data are asked of every patient.

Actually, in all cases, comparing the average dose for the listed explorations, the estimated doses are below the reference values legally established diagnostic reference levels (DRLs). The dose indicator used in radiography is the entrance surface dose (ESD).

In agreement with the principle of optimization, and with the aim of reducing the entrance surface doses in single radiographs; some corrective actions are carried out in the radiology rooms of two hospitals, that will be identified like \textit{A} and \textit{B}, between which are included:

\begin{itemize}
  \item Optimization of the radiological techniques
  \item Replacement of cassettes with new faster film-screen combinations
  \item Adaptation of the collimation
  \item Continuous training to the operational staff.
\end{itemize}

For \textit{hospital A}, the first listed action separately, it has already supposed an important diminution of the doses. The optimization of the radiological technique has been able to reduce the \textit{Postero-Anterior Chest Projection} (Chest PA) ESD, from 0.39 mGy to 0.27 mGy on 46 radiographs evaluated.

Implantation of the second action is based on the replacement of the intensifying screens using, instead of the panchromatic film (blue emitting composed of calcium tungstate with speed-class 200 of the film-screen combination), the faster orthochromatic film (green emitting made of rare earth with speed class 400). This implantation has supposed a larger reduction in both hospitals. For \textit{hospital B}, the second action by himself has been reduced to more than half the ESD with dose indicators lower than 0.10 mGy for the \textit{Chest PA} and lower than 0.30 mGy for the \textit{Lateral Chest Projection} (Chest LAT).
On the other hand, and to be coherent with the Quality Assurance Programme, the detailed evaluation of the image quality with patients has been done, in addition to the tests of physical image quality in the controls using phantoms.

All these actions have supposed an improvement of the image quality, in addition to the dose reduction, as it was wished as a main objective.

REFERENCES


New technique for performing daily QC tests by using flatbed scanner

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Objective. To perform daily QC test for X ray film possessors and dark rooms by obtaining the characteristic curve by digitizing the stepped exposure image radiograph, by using the ordinary flatbed scanner instead of using the Densitometer in order to monitor deviation from a desired standard quickly, easily, accurately and in low cost.

Methods. Two ordinary flatbed scanners (Acer-ScanPrisa 640P and HP-Scan Jet 2200C) have been used to digitize stepped exposure image radiographs (21 step film strip and the standard film strips tablet consisting of several sections of known optical density (Victoreen QC step tablet P/N 010128, X-Rite QC step Tablet–S/N 108372) which are used for calibrated Densitometer) with different scanning settings by placing the step tablet and step exposed film on flatbed scanner and scanned. The images produced were analysed and the pixel values for each step were obtained by using the special software which has been designed and dedicated for these purposes in visual basic programming language [2,3], the software able to read the pixel value in form of RGB value separately or as one averaged value from the image’s data array in different format. The optical density has been obtained also by using two different conventional Densitometers (X-Rite Model 331, Victoreen-Model 07-443). All those data have been studied and analysed and the characteristic curve presented graphically for each.

Results and analysis. When the flatbed scanner has been used to digitized images, the resulting pixel value profile was not identical to the optical density profile measured on film. The relation between the optical density and pixel value of the known step tablet shows that the optical density increases as the pixel values decrease. Therefore, the pixel values should be inverted in order to keep increasing or decreasing between values (OD and pv) in the same direction.

The pixel value was then transformed to produce the optical density as a function of pixel value. We use the same approach used by Green [4], as in the following formula.

\[
OD_{\text{Digital}} = 2.273 - 0.918 \times \log(pv)
\]  

(1)

where \(OD_{\text{Digital}}\) is the digital optical density which is extracted from the \((pv)\).

The extracted value of optical density deviated from the known optical density significantly. The deviation values \((\Delta OD = OD_{\text{Known}} - OD_{\text{Digital}})\) were then plotted vs. \((OD_{\text{Known}})\) as shown in Fig. 1. and fitted to polynomial fitting, as follows:

\[
\Delta OD = a \times (OD_{\text{Known}})^2 + b \times (OD_{\text{Known}}) + c
\]  

(2)

where \(a, b, c\), are the fitting constants.

The pixel values for 21 steep are converted to optical density after digitize 21 step exposed film strips. The converted data show significant deviation from the known/measured optical density at the optical density value grater than 1, as shown in Fig. 2.
FIG. 1. $(\Delta OD)$ as function of $(OD_{\text{Known}})$.

The digital optical density was then corrected by applying Eq. 2, the characteristic curves become identical exactly to the characteristic curve obtained by conventional methods and the deviations become less significant, as shown in Fig. 2.

FIG. 2. A comparison of the characteristic curve obtained by using conventional densitometer and characteristic curves obtained digitally before and after correction.

By this new method, we can obtain the data for characteristic curve by using a flatbed scanner instead of a Densitometer. The data obtained digitally can be used also for furthering analyses in order to monitor the quality of performance of the whole process at the radiology department.

Conclusion. Flatbed scanner can be used to digitize stepped radiographic film after a proper calibration based on the known optical density tablet. The characteristic curve can be then obtained and analysed easily, quickly and reliably.

REFERENCES

Development of low cost integrated phantoms for optimization of QC programmes in accordance with Brazilian regulations

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Brazil

During the last decade, State and Federal Regulations related to topics on radiation protection in medical and dental areas were published in Brazil [1,2]. One of the approaches included in these regulations refers to the need to implement QC programmes by the imaging diagnostic departments in order to comply with the legal standards. The QC programme is one of the main tasks department managers must to do to introduce in their routines in order to assure an adequate environment and practices according to IAEA radiation protection requirements. Therefore, many professionals and working groups were introduced during the last years in Brazil in order to implement QC programmes. Most of these are technical groups who are professionally prepared to apply procedures related to the QC tests listed in the Regulations. One of these working groups is composed of physicist, engineers and technicians from the Institute of Electrotechnique and Energy of the University of São Paulo (IEE/USP), which has been working on QC in diagnostic imaging departments during the last ten years [3].

After many years of implementing the QC Programme developed by IEE/USP, it was noted the need of fitting the hardware used for implementing the tests in order to optimize the time spent for each test and to comply with the national Regulations. This need is important since most part of the QC’s phantoms and imaging devices are imported, and so do not fit completely to the national standards.

In addition, once it is very expensive to import the hardware, there are just a few private QC players settled in Brazil, and so most of the health facilities do not have yet a diagnostic imaging QC programme implemented. Therefore, most part of the population is not benefited by reduced doses and improved image quality that are achieved by implementing diagnostic imaging QC programmes.

To face these needs, a research project was submitted and approved to a State Agency (FAPESP), in order to get financial and technical resources for the development of low cost integrated QC phantoms. This project was proposed as a partnership with a Brazilian company, Física Médica, which intends to produce the phantoms after its testing and validating by the IEE/USP.

The proposed phantoms’ conception is performing the QC tests with the maximum accuracy and simultaneously by interrupting the imaging machines’ diagnostic use for the shortest time possible. In other words, the phantoms look for optimizing the QC procedures, but assure the quality of the obtained results. Therefore, the phantoms are designed to make available groups of tests simultaneously, obtaining results of different quality parameters by using just one X ray exposure, reducing the time and the films spent on QC procedure.

The features needed for testing Collimator/Beam Alignment, Grid Alignment and Focal Spot are integrated into two devices. Furthermore, there are also devices for testing HVL (conventional RX, mammography and fluoroscopy), low contrast and contrast detail (conventional RX and
fluoroscopy), high contrast (fluoroscopy) and an integrated support device for fluoroscopy collimator/beam alignment, film magazines and for using by all proposed devices.

In order to assure the prototype manufacture’s quality, the devices’ dimensional characteristics were carefully checked (focal spot slits’ width – Figs 1, 2) as were the used Al’s purity (Table 1). According to the obtained results, there are Brazilian industries able to produce the necessary features with the desired quality. The products in progress’ relevance is the national regulations’ fitting to and also the reducing costs at the whole sector’s value chain, driving to an increase of Diagnostic Imaging QC players in the market, extending the QC benefits to all Brazilians and supporting the compliance with federal and local laws.

Figs 1 and 2 present a partial measure imaging (100×) of the focal spot device developed:

![FIG.1 (10 lp/mm - slit width 0.05 mm). FIG. 2 (0.81 lp/mm - slit width 0.5952 mm).](image)

### TABLE 1. AL 1100 SHEET’S CHEMICAL ANALYSISYS
(NA = IMPORTED, CBA = NATIVE)

<table>
<thead>
<tr>
<th>Brand</th>
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<td>(%) Error</td>
<td>(%) Error</td>
</tr>
<tr>
<td>NA</td>
<td>0.10</td>
<td>99.3</td>
</tr>
<tr>
<td>NA</td>
<td>1.00</td>
<td>97.7</td>
</tr>
<tr>
<td>NA</td>
<td>2.00</td>
<td>99.1</td>
</tr>
<tr>
<td>CBA</td>
<td>0.50</td>
<td>99.2</td>
</tr>
<tr>
<td>CBA</td>
<td>1.00</td>
<td>98.9</td>
</tr>
<tr>
<td>CBA</td>
<td>2.00</td>
<td>98.5</td>
</tr>
</tbody>
</table>

**Expected values (%)**

- AL 1100 | 99.0 | 1.0 Si + Fe | 0.1 | 0.05 | 0.05 a 0.20

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Acceptance testing and QA in dental radiology


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Introduction. The HPA (UK) reported in 2002 [1] that although the effective dose from dental examinations is low, dental imaging is the most frequent type of X ray examination undertaken (approx. 30%); a similar situation is likely to exist in Ireland. It is most likely that this will increase further in the future as the dental X ray technology moves from film to digital equipment. Dental X rays are taken more frequently with digital equipment than film based technology [2]. The Department of Medical Physics & Bioengineering, St. James’s Hospital, Dublin is particularly interested in the area of dental quality assurance (QA) as a result of a significant medical radiation safety incident in Ireland occurring with a faulty dental X ray installation [3]. The implementation of a QA programme in Ireland has been enforced not only by the publication of the Dental Code of Practice by the Irish Regulatory Authority in the 1990s [4] but also by the publication of the European Medical Exposures Directive [5].

The current QA programme, which includes site visits in order to perform acceptance testing and routine QA checks on dental X ray equipment has been implemented in approximately 250 dental health centres to which the Department has provided radiation protection advisory services for approximately twenty years. In addition to the technical evaluation of the equipment, an assessment of the adequacy of the shielding in the X ray room and of the radiation protection facilities is performed. This paper identifies the findings from the dental radiology QA assessments.

Methodology. QA test protocols were developed in accordance with current national [4] and internationally accepted guidelines [6–10]. The tests include exposure time and kVp accuracy, radiation output consistency, filtration, irradiated field size, mechanical and electrical safety checks and measurement of tube output for specific X ray examinations to aid in the establishment of a national diagnostic reference levels, a requirement of the Medical Exposures Directive [4]. Assessment of the radiation protection facilities included identification of installation of mains isolation switches, availability of appropriate radiation warning signs and operation of radiation warning lights where appropriate, to name but a few checks. Shielding calculations were also performed for all new X ray rooms to ensure that an appropriate level of shielding was in place in each X ray room.

Results. The Irish survey found that approximately 75% of units failed to meet one or more of the required tolerances. This finding was evident despite the fact that the equipment was serviced between scheduled QA inspections. Upon analysis of the results this appears to be attributable to the fact that some systems cannot be adjusted back into tolerance, some suppliers lack the expertise required to rectify faults and some suppliers do not prioritize dental X ray equipment (Fig. 1).

As part of the QA programme, an inspection of the radiation protection facilities was performed. Many issues were identified in this part of the assessment which would not have been noted if a postal pack had been solely used for the QA assessment. Examples of issues noted during the QA visit include: potential access of members of the public to the exposure
handswitch, potential for X ray beam to be directed towards unshielded windows within close proximity of the X ray tube head, walls requiring shielding, lack of signs asking the patient to inform the dentist in case of pregnancy, X ray film being stored within the controlled area and non-electromedical equipment located within 1.5 m of the patient where digital radiology equipment was installed.

**FIG. 1. Histograms showing results obtained during a routine dental X ray QA inspection.**

**Discussion.** The Irish survey emphasizes the importance of performing routine quality assurance tests on dental X ray equipment and highlights the difficulties in achieving corrective action by the equipment suppliers. It also stresses the importance of visiting dental X ray rooms as part of the QA programme to evaluate the radiation protection facilities.

**ACKNOWLEDGEMENT**

This work was conducted partially within the frame of the European Commission 6th Framework Programme SENTINEL Contract No FP6-012909.

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The Sentinel Project

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Introduction

The past two decades have witnessed a technology-driven revolution in radiology. At the centre of these developments has been the use of computing in diagnostic imaging.

These developments have also been driven by the introduction of new detectors and imaging devices in radiology and nuclear medicine, as well as the widespread application of computing techniques to enhance and extract information from within the images acquired. However, these technological developments have not been matched by justification and optimization studies to ensure that these imaging devices and clinical techniques are as effective as they might be, or performed at the lowest possible dose.

The SENTINEL coordination action covers radiation protection, safety and related issues that arise from the introduction of digital technologies. SENTINEL covers 90% of patient examinations, 60% of the collective dose from medical sources and approximately 50% of the collective dose to European citizens from man-made sources. SENTINEL covers all of digital imaging in radiology, with the exception of computed tomography scanning.

The main objectives of the SENTINEL coordination action are:

1) Establish both physical and clinical image quality criteria, and link the two.
2) Perform a series of dosimetry studies to deduce reference levels.
3) Develop good practice guidelines for radiation protection and to publish training material.

The SENTINEL consortium comprises 22 members from 16 Member States. These are complemented by partners from candidate Member States and international organisations.
SENTINEL coordination action activities

Justification and optimization form the basic elements for the radiological protection of individuals in the case of medical exposures. Justification includes the development of referral criteria. Medical exposure for diagnostic applications is only justified in the case of a sufficient net benefit. This has its origins in the Hippocratic Oath, which most doctors swear, and may be summarized as doing more good than harm. In the case of medical exposures, this implies that the patient doses should be relatively low to restrict the detriment caused by ionizing radiation, whereas image quality should be sufficient to allow potential diagnostic benefits.

According to the Medical Exposures Directive, diagnostic reference levels should be established and used as an aid to optimization. This process is ongoing within the European Union Member States. Optimization should result in improved image quality at equal or lower dose to the patient or in a dose reduction at an image quality sufficient for obtaining diagnostic information.

The Medical Exposures Directive places special attention to the medical exposure of children, exposures received as part of a health screening programme, such as mammography and examinations involving high individual doses to the patient. Radiation protection of children is considered to be especially important, in view of the higher radiation risk factors for children. Health screening programmes, for example, for the early detection of breast cancer, involve a healthy population in which a small percentage of women have a malignant lesion which may be detected using mammography. Interventional radiology, cardiology and some nuclear medicine procedures result in high radiation doses to the patient.

Clinical image quality criteria, referral guidelines and reference doses will be established for the latest digital detectors by building on previous work and a series of consensus meetings. In nuclear medicine, there is a debate on the administered activity for various nuclide procedures. This debate will be addressed via consensus meetings and surveys of national practice.

The relationship between physical and clinical image quality indices will be addressed. This will assist in international standardization activities.

Patient dose surveys and quality assurance tests will be undertaken on various high dose procedures. Similar work will be undertaken in mammography, bone mineral densitometry and paediatric radiology. Ethical issues in radiation protection will be assessed.

Summary

The intended benefits of the SENTINEL coordination action are:

1) Safer, more effective procedures and examinations using new technology in radiology
2) Greater public acceptance of the use of radiation in medicine
3) Safer, more cost-effective health care
4) Supporting the legislative agenda of the European Union
5) Contribution to the training of researchers.
Quality control in diagnostic radiology in Bulgaria – Regulation, implementation, procedures, first results

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X-ray equipment in Bulgaria comprises about 1200 conventional radiography units, 650 image intensifier based fluoroscopy systems, 15 modern angiography systems, 110 computed tomography (CT) scanners, 140 dedicated mammography units, 610 dental units and 9 DEXA systems. Quality assurance (QA), as a means for optimization of patient radiation protection was legally introduced in the country in October 2005 with a new Ordinance of the Ministry of Health for Protection of Individuals at Medical Exposure [1]. It requires Quality control (QC) of imaging equipment and patient dose measurements to be implemented as an important physical and technical aspect of QA. QC programmes were elaborated and are presented here for each type of X-ray diagnostic equipment – for conventional radiography, fluoroscopy, mammography, CT and dental radiology [1]. They include a list of parameters to be tested, level of expertise needed, as well as two action levels: remedial and suspension. On the basis of the international experience, measurement protocols were developed for all parameters tested [2, 3].

This work presents the first results of implementation of the QC programme for a number of X-ray units of different types. The local protocols of three groups working independently were collected and this database was used to analyse the results by specially designed software. The survey comprises commissioning tests of 40 conventional radiography, 15 fluoroscopy and 10 mammography units of different ages and gives first overview on the status of the X-ray equipment in the country. The important parameters having suspension levels were analysed – tube potential accuracy and reproducibility, half value layer and corresponding tube total filtration, timer accuracy, absolute value and reproducibility of the tube output. Additionally for radiography equipment were tested the light and X-ray field alignment, film processor performance and dark room conditions. For fluoroscopy were included also tests of the image intensifier dose rate, patient entrance surface dose measured with a water or PMMA phantom as well as high contrast resolution and low contrast detectability, measured by means of Leeds FL18 object. For mammography additionally were included tests of the Automatic Exposure Control settings, high contrast resolution, and entrance surface air kerma measured on the surface of the standard 45 mm PMMA phantom.

About 80% of all tested units manifested diversion from the remedial levels for two or three tested parameters and about 30% – from the suspension levels for one or two parameters. In 9% of the units the total filtration was found to be lower than the limit of 2.5 mm Al and correction actions were initiated. The most problematic and critical for conventional radiography and mammography was found to be the film processing – in 60% of the units some problems were found in dark room and film processor conditions. This demonstrated the
importance of QC on a weekly basis. In 10% of the fluoroscopy units high contrast resolution was found to be under the required level.

This pilot survey demonstrated the important role of QC as an objective tool in finding the problems and in further improving the performance of the X ray systems.

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**DoseWatchers – A computer based X ray dose monitoring project in paediatric radiology**

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**Introduction**

Children, especially premature infants and neonates, are at a much higher risk to obtain an X ray induced disturbance of life – particularly cancer. On the one hand this is due to their longer life expectancy and on the other hand it is due to their higher cell proliferation rate.

The paediatric radiology unit of the Inselspital Bern recently installed some of the most advanced X ray equipment nowadays available. It is based on the two latest digital technologies: double read computed radiography (CR) and direct digital radiography (DR). Only the implementation of these digital radiography systems permits the digital acquisition and additionally the analysis of acquired data. The systematic analysis of large amounts of biometric data and exposition data is the basis for further dose reduction and a systematic quality control (QC).

Patients are increasingly critical concerning radiation exposure – especially parents regarding their children. Besides an established patient education, they expect radiography equipment optimized for paediatric purpose that allows an examination with doses as low as possible while maintaining diagnostic quality (ALARA principle).

**Aim of the project**

The primary purpose of the project is to minimize the individual dose of each patient. This means a controlled reduction of the paediatric exposure dose to the medical minimum based on detailed data from a vast amount of comparable patients. This shall lead to a general dose reduction for the paediatric population in our hospital region. In collaboration with the federal Swiss health authorities (Bundesamt für Gesundheit, BAG), publication of paediatric DRVs (dose reference values) for the principal X ray studies is in preparation.

Secondary, the project shall result in a teaching instrument: the recent generations of X ray technicians are in danger to loose the awareness for overexposure of patients as overexposure in digital X ray imaging does not result in “black” images anymore but in images of obviously (too) good quality. Radiologists in training as well as colleagues who are applying dose to children e.g. in the operating theatres can control the doses applied individually and learn to minimize the radiation exposure to patients, medical employees and themselves.

In addition, the X ray systems themselves can be subject to continuous automated QC.

**Equipment**

The central part is a flexible configurable server-based System (EasyDose (ED) QM-server; BMS Austria, Bayer Medical Solutions GmbH) which manages and executes a variety of parameters such as biometrical data of the patients, modality related information (DAP, kV,
mAs, SID, APR, etc.) as well as patient demographics from DICOM studies. In addition to the server and the database the DoseWatchers project is equipped with a digital balance and height measuring function as well as a device for the measurement of the thickness of the object (OTM) which will be exposed. All the acquired data are retrieved by the ED server automatically or sent to it.

The monitoring procedure

In each ante-room of our three examination rooms, the weight and height of the patient is measured. There is an ED device with 6.5" TFT touch screen showing the DICOM modality worklist. ED automatically gathers information accessing DICOM sources to acquire patient demographics for proper allocation of Dose Area Product values. The radiographer selects the patient from the worklist and starts the measurements at the balance. Before the exposition the thickness of the object (e.g. the diameter of the chest) will also be measured. Data from the balance are sent by serial interface, data from the OTM via Bluetooth technology to the database. Another ED process continuously retrieves measurement values (e.g. DAP from an external ionization chamber, film size, mAs, time, number of exposures, etc.). An additional ED device at the DICOM station instantly displays patient demographics, kV, mAs and Dose-Area-Product. At the end of the exposition, data will actively be saved and the patient’s name disappears from the worklist.

Database

After a study has been completed on the operating modality, the ED server receives data from its gateways and can perform analysis immediately. Querying the database can be carried out via web browser. The database can manage a multitude of patient- and exposition-parameters in the context of the long term project. The DoseWatchers project started in October 2005. Within six months the database recorded about 8000 entries of 4500 studies. Our purpose is to get the system to a high automation level to generate a comprehensive database over several years. These data will allow detailed conclusions concerning radiation exposure and its risks in an accuracy not known until now.
Session 10c:
Radiation Imaging
EANM PERSPECTIVES ON QUALITY MANAGEMENT IN NUCLEAR MEDICINE PRACTICE
Guidelines on QC for nuclear medicine instrumentation

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In 2005, a working group of The European Association of Nuclear Medicine (EANM) was set up to provide nuclear medicine practitioners with general guidelines on the quality control of equipment used in the practice of nuclear medicine.

In diagnostic nuclear medicine, the quality assurance objective is the provision of high quality, reproducible data that would provide the required clinical information with the smallest radiation burden to the patient. Quality assurance programmes must ensure the most effective use of available equipment and must ensure that processes are in place to minimize clinical risk. Our guidelines focus on the quality control (QC) procedures used in nuclear medicine with a special focus on new, sophisticated, digital technologies.

The guidelines have been written as a tool designed to promote the cost-effective use of high quality nuclear medicine instrumentation and to aid practitioners in ensuring accurate information is obtained from each nuclear medicine examination. The purpose of these guidelines is to assist practitioners in achieving their clinical objective and, as such, they are general recommendations on good practice which should be applicable across national boundaries.

Routinely, quality control procedures are required to ensure that nuclear medicine equipment is functioning correctly. These quality control tests are intended to detect problems of the systems before they impact on clinical patient studies. They are not intended to provide a full evaluation of equipment performance. Further tests may be required to trace the cause of the problem and to ensure that the equipment is performing properly after service or adjustment.

Our QC guidelines cover both imaging and other measuring (non-imaging) equipment including planar gamma cameras, multi-detector and SPECT cameras, PET and PET/CT imaging systems and dose calibrators, survey meters and gamma counters. Quality control of individual components is necessary to ensure that these devices are functioning correctly at each step in the chain. Specific quality control procedures vary between manufacturers and models, thus it is impractical to provide detailed procedures covering all types of equipment.

The first part of our presentation describes the aims and rationale of the recommended quality control procedures. In particular, it attempts to provide background information on the reasons for performing particular procedures and the types of problems detected. It defines measurement parameters and their influence on the resulting images or measurements. An understanding of the potential impact of system performance aberrations is a prerequisite for implementing an effective quality control programme.

Secondly, reference will be made to general procedures for carrying out the recommended quality control tests. These can be used as a basis for developing detailed protocols for individual makes and models of equipment. Recommendations are provided on the frequency of the quality control tests. As the frequency of tests depends on the equipment, criteria are provided for selecting appropriate test frequencies.
It is imperative that quality control procedures are carried out in a consistent manner (for example, same collimator, orientation, activity, energy window width, etc) and the quality control settings and results are recorded to enable meaningful comparisons to be made over time. Proper record keeping greatly facilitates detection of gradual deterioration of performance over an extended period of time, by analysing the results for degradation and initiating corrective action when necessary. A baseline set of quality control results should be recorded, after installation and acceptance testing, to serve as a reference for the life of the equipment.

Several parameters associated with a scanner system are critical to good quality image formation and in many cases are interdependent. A summarized reference of the quality control tests that must be performed follows:

1. **Calibration procedures for planar gamma camera**
   a. Gamma ray spectra and pulse height analysis
   b. Energy resolution
   c. System sensitivity
   d. Uniformity (intrinsic, extrinsic)
   e. Collimator performance
   f. Linearity-spatial resolution

2. **SPECT gamma camera quality control**
   a. Center of rotation
   b. High count field uniformity requirements
   c. Energy correction and spatial coordinates
   d. Pixel calibration
   e. Reconstruction of phantom studies

3. **Multi-detector gamma camera**
   a. Detector alignment
   b. SPECT /511keV coincidence calibration

4. **PET system quality control**
   a. Daily blank scan, normalization scan
   b. Photon detection/discrimination
   c. Resolution requirements
   d. Scatter reaction, count loss, randoms measurement
   e. Sensitivity, deadtime loss
   f. Random count correction accuracy
   g. Well counter (absolute activity) calibration
   h. Glucometer QA by high & low standards

5. **Hybrid PET/CT system**
   a. System alignment calibration
   b. CT system QA (scanning parameters-mA, kVp, helical scanning).

Practices are encouraged to call on the advice of experienced nuclear medicine physicists to draw up detailed QC protocols for their specific equipment based on the guidelines presented here. Advances in medicine occur at a rapid rate. The date of a guideline should always be considered in determining its current applicability.
Dosimetry in nuclear medicine (Quo vadis?)

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Dosimetry in nuclear medicine has been in the past mainly used for diagnostic applications. In that context, crude absorbed dose estimates are sufficient to evaluate the risk/benefit ratio of the intended medical procedure.

Targeted radionuclide therapy (TRT) is developing as a possible treatment modality for a range of cancers. The need for more accurate/refined dosimetric procedures has therefore increased over the past few years. Individual patient dosimetry is presently the only possible way to:

– establish an individual minimum effective absorbed dose and maximum tolerated absorbed dose to tissue,
– predict tumour response and normal organ toxicity on the basis of pre-therapy dosimetry,
– increase the knowledge of clinical radionuclide radiobiology by correlation calculations and observed effects post-therapy,
– relate and compare the results to the radiation dosimetry routinely performed for external beam radiotherapy.

However, to date, few treatments have involved the use of dosimetry.

The conventional formalism to perform absorbed dose calculations in nuclear medicine was proposed by the MIRD committee:

\[ \overline{D}_{(k\rightarrow h)} = \tilde{A}_h \times S_{(k\rightarrow h)} \]

where
\[ \overline{D}_{(k\rightarrow h)} \] is the mean absorbed dose (Gy) delivered to a target \( k \) from the source \( h \),
\[ \tilde{A}_h \] is the cumulated activity in source \( h \) (Bq.s), i.e. the total number of disintegrations in source \( h \);
\[ S_{(k\rightarrow h)} \] is the S factor or ‘absorbed dose conversion factor’ (DCF in Gy.Bq\(^{-1}.s^{-1}\)) that gives the absorbed dose delivered to the target \( k \) from radiation emitted from the source \( h \) on a per disintegration basis.

One of the main features of the MIRD formalism is that it splits the absorbed dose calculation into two components that are considered independently: cumulated activity and S factors. Activity

\textsuperscript{1} The authors are members of the EANM Dosimetry Committee.
determination that ultimately leads to cumulated activity is most often carried out through quantitative imaging. Tomographic methods permit the determination of the activity volume on a macroscopic scale at different time points. For a proper attenuation correction in tomographic imaging a patient-specific attenuation map is required. This can be obtained from scintillation-camera transmission scanning, CT or by using segmented scatter-emission images. Attenuation corrections can be performed either on the projection images, on the reconstructed images, or as part of an iterative reconstruction method. The problem of image quantification for therapy radionuclides, particularly for $^{131}$I, is exacerbated by the fact that most cameras are optimized for diagnostic imaging with $^{99m}$Tc. In addition, problems may arise when high activities are to be measured due to count losses and mispositioned events because of inadequate pile-up and dead time correction methods.

Sufficient image quantification, however, is only possible if all effects that degrade the quantitative content of the image have been corrected for. PET is probably the most accurate imaging method for the determination of activity concentrations in tissue. PET imaging can be considered for pretherapeutic treatment planning but ideally requires the use of a radioisotope from the same element as that used for treatment (e.g. $^{124}$I for $^{131}$I; $^{86}$Y for $^{90}$Y). Problems, however, are that

- some of the positron emitting isotopes have a shorter half-life
- non-standard quantification procedures have to be performed
- the availability of the radiopharmaceutical is presently limited.

S factors or DCFs are the other term of the dose calculation formalism. Historically – and for diagnostic procedures – DCF lookup tables have been published by the MIRD committee for several radionuclides and various source-target organ pairs from calculations performed for anthropomorphic phantoms. The use of lookup tables is not easily applicable to targeted radionuclide therapy, as they do not account for inter- and intra-patient morphological variations. Moreover, for cancer therapy applications, it is most often necessary to calculate the absorbed dose delivered to tumours that can vary in shape and location. Currently, there is intensive research to allow for patient specific geometries to be taken into account for targeted radionuclide therapy dosimetric procedures. Monte Carlo simulations are an appealing tool that can help to model interactions occurring in the patient or in the detector system. This is helpful to develop and test correction techniques, or to help to define detectors better suited to quantitative imaging. Another important application of Monte Carlo codes is in the field of patient specific dose calculation: using Monte Carlo techniques, it is possible to refine the anthropomorphic phantom characteristics to increase their likeliness to a real patient. Recent studies have also established the feasibility of Monte Carlo dose calculation in a clinical context, with the use of patient specific information (CT scan and SPECT based pharmacokinetics).

Many 3D tools and techniques are now available to the physicist and clinician to enable absorbed dose calculations to both target and critical organs-at-risk. The challenge now facing nuclear medicine is to enable this methodology to be routinely available to the clinic, to ensure common standard operating procedures between centres and in particular to correlate response criteria with absorbed dose estimates.

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The sense or non-sense of centralized radiopharmacy services

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Radiopharmaceuticals are considered a special group of drugs due to their radioactive nature and use solely in nuclear medicine departments. Especially because of their usually short half-life, resulting in very limited shelf life of the final drug preparation, it is necessary to meet special requirements in their distribution and use. Preparations with longer lived radionuclides such as $^{131}$I with 8d half-life are nowadays made and distributed by commercial producers based on corresponding drug manufacturing licence and marketing authorization.

For radionuclides with shorter half-lives, different approaches have been developed to guarantee reliable availability in good quality for the nuclear medicine department and for clinical use. This is exemplified by Technetium-99m ($^{99m}$Tc) radiopharmaceuticals. They are prepared from commercial kits and generators by comparable simple labelling procedures that can technically be performed in a clinical setting without specific drug manufacturing units involved. Kits and generators have been defined as drugs in practically all national and international drug regulations directives including the EC.

In the United States, $^{99m}$Tc radiopharmaceuticals are to a great extent prepared in centralized units. Starting from the early 70s [1] these units usually operate under pharmacy licences and are therefore called radiopharmacies or nuclear pharmacies. The radiopharmaceutical product is distributed to the adjacent nuclear medicine department on demand, usually as prescribed unit doses or possibly in multi-doses for dispensing. This system has defined the picture of radiopharmacy practice in the US and was introduced in some other countries more or less successfully. One major advantage of the system is definitely that costs can be reduced significantly by using one preparation for different hospitals. Additionally, this preparation practice in the US has not been considered to having to fulfill compliance with GMP regarding aseptic preparation. By using centralized units, radiopharmaceuticals can be prepared by and under the surveillance of highly specialized and dedicated staff. The clinical nuclear medicine department does not need to invest in hot laboratories and personnel for radiopharmaceutical preparation. Both from legal and and quality assurance perspectives, the responsibility for the quality of the radiopharmaceutical lies in the hands of the radiopharmacy.

Limitations of a centralized production system are: a) reduced flexibility for the nuclear medicine department to respond to acute clinical demand, and b) no development or research activity for new radiopharmaceuticals can be expected when no human resources with sufficient knowledge in radiopharmacy are available. Radiopharmacists or related experts from centralized units are usually not directly involved in clinical practice. Additionally this system does not allow the use of radiopharmaceuticals that have no marketing authorization.

In Europe, specifically in the UK, a centralized production system has been widely introduced. This change was not driven by commercial interests; it is because of the fact that in the UK any radiolabelling of a radiopharmaceutical is regarded as an aseptic pharmaceutical preparation requiring full GMP compliance. Recently similar development is observed in other countries such as Spain [2] and the Netherlands, where centralized GMP
compliant radiopharmacies for the production $^{99m}$Tc labelled radiopharmaceuticals have been established by large companies.

Another system has some tradition in Scandinavian countries. Here a central unit, usually under the auspices of the drug administration, carries the responsibility for the control and supply of radiopharmaceuticals around the country, whereas radiopharmaceutical preparation is conducted mainly in the hospital.

Majority of the European countries are operating an in-house system for preparing $^{99m}$Tc-radiopharmaceuticals. This implies that each nuclear medicine department is procuring generators and kits; radiolabelling in a majority of cases is performed by trained technicians under the supervision and responsibility of a physician. From the legal point of view, preparation of $^{99m}$Tc radiopharmaceuticals is not regarded as “drug manufacturing”, therefore is exempted from the strict legal requirements imposed on upon drug manufacturers. Only in a few departments usually located in larger university centres, radiochemists or radiopharmacists are available. Some countries such as France, however, recently introduced the requirement of a radiopharmacist in every hospital performing any radiopharmaceutical preparation.

For PET and other short lived radiopharmaceuticals, a somewhat different situation can be seen. Here regulatory authorities are demanding high standards, comparable to centralized manufacturers — whether for centralized or local production. Majority of PET radiopharmaceuticals nowadays are prepared “in-house”. Distribution of $^{18}$F-PET radiopharmaceuticals in Europe has mainly been taken over by specialized PET radiopharmaceutical manufacturers, whereas in the USA the provision of $^{18}$FDG is often covered by the “traditional” centralized radiopharmacies. Decentralized systems in this respect are necessary and play an essential role in clinical research in nuclear medicine particularly if extremely short lived diagnostic radiopharmaceuticals labeled with $^{11}$C, $^{15}$O are employed. The same are necessary for the exploration of radiopharmaceuticals for therapeutic applications.

Summing up, the current situation in Europe is heterogeneous. Historic variation in the evolvement of nuclear medicine practices and in implementing drug legislations have led to a different radiopharmaceutical practice. Recently we see increasing demands of both administrators as well as legislators in radiopharmaceutical regulation in almost every European country (e.g. introduction of the “Clinical Trial Directive” [3]). Whether this tightening of regulations will lead to a significant change in practice from decentralized to centralized radiopharmacy, it remains to be seen.

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Lunch Forum II:
REFRESHER COURSE ON RADIOBIOLOGY
Developments in applied and clinical radiobiology

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Part 1. Growing points in radiobiology research applied to radiotherapy

1) Modification of dose effectiveness: Many chemical tumour-radiosensitizing agents have been investigated previously with limited success in preclinical and clinical studies. The efficacy of new tumour radiosensitizers which interfere with various molecular pathways including DNA repair, apoptosis, and growth factor receptors, will be described and compared [1]. In addition, reactions in normal tissues can be reduced by the application of growth factors to increase cell repopulation rates, and by the use of new drugs that reduce the late vascular response to irradiation.

2) Modelling the effectiveness of IMRT and related techniques: Estimates of the effectiveness of new methods of dose delivery can be calculated using voxel and linear-quadratic dose-response models to calculate the Equivalent Uniform Dose [EUD, 2]. This does not take into account differential sensitivities of different parts of organs in the radiation fields. The difficulties in predicting the response to non-uniform dose distributions will be discussed. In addition, the increased risk of second cancers outside the target volume, because of the higher dose to larger volumes using multiple-beam approaches, has been argued recently in the literature.

3) Prediction of radiation response: The ability to predict the response of individuals or groups of patients might allow dose escalation for the resistant cases, and this has been an elusive goal for researchers for many years. Attempts so far will be reviewed, including the exciting finding of molecular signatures for particular responses, based on gene expression profiles or patterns of mutational polymorphisms in selected groups of genes [3].

REFERENCES


Part 2. Fractionation, treatment duration and dose-rate effects

The benefit of hyperfractionated treatments using low doses per fraction is now well established [1], although this has not yet led to wider application of this strategy in clinical practice. This technique spares generic late reactions (described by a high fractionation sensitivity that is characterized by a low $\alpha/\beta$ ratio in the commonly used linear-quadratic formalism), and it allows more biologically effective dose to be delivered to the tumour with still an acceptable low level of complications. Unfortunately, these new schedules are labour intensive for staff and often difficult to implement in conventional radiotherapy departments. Less modified schedules are being sought as a compromise. A recent interesting development that reverses this trend is regarding prostate cancer. In this case, the slowly growing tumour responds as if it were more sensitive to dose-fraction size than even a late-reacting normal tissue. Hence, high doses per fraction (hypofractionation) rather than low doses per fraction are suggested as beneficial, and current trials are underway to test this hypothesis.

Another aspect of fractionation is the duration of the schedule. Longer schedules are beneficial to allow regeneration of early-reacting renewing tissues and reduce any consequential late reactions. However, they may allow tumour cell repopulation, which is detrimental to tumour cure. It is now well established that for head and neck cancer, repopulation of tumour clonogens starts after 3–4 weeks of treatment [2]. On the other hand, accelerated (shorter) treatments can increase acute reactions and hence potentially may increase consequential late reactions as well.

Another aspect of this is repair occurring during delivery of a fraction. Brachytherapy treatments are one of the cornerstones of the treatment of cervix cancer, often in addition to external beam therapy. The brachytherapy is delivered either using low-dose-rate (LDR) or high-dose-rate (HDR) irradiation. By using HRD more patients can be treated with the same equipment, although more human resources are needed. LDR brachytherapy is being gradually replaced worldwide by HDR. Some randomized trials have shown that HDR can be equally effective as LDR in terms of tumour control and late complications [3], but no formal trials have been done to test different HDR schedules. Randomized trials will be necessary to determine the schemes with optimal dose and fractionation.

REFERENCES

Session 11a:

Radiation Treatment

APPLICATIONS OF DOSIMETRY AND QUALITY ASSURANCE IN RADIOTHERAPY
Clinical dosimetry and QA for radiotherapy: developments in methods, applications and accuracy

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Many new developments in instruments and methods for radiotherapy dosimetry and QA have appeared over the last few years, and this trend is continuing. These have arisen due to a range of different reasons, e.g.

1. Developments in dosimetry standards, dissemination chains and dosimetry protocols (codes of practice), e.g.:
   - for normal radiotherapy treatment modalities, in particular the universal moves to methods based on direct $D_w$ calibrations and protocols, whether using a single calibration quality and $k_Q$, or direct calibrations over a range of qualities, including calibration and cross-calibration methods and parameters
   - demands for similar robustness in standards for brachytherapy dosimetry
   - demands for improved dosimetry standards and methods of calibration where technology has progressed away from standard approaches, e.g. for linear accelerators which do not have conventional fields satisfying the requirements of normal codes of practice, or in the use of other radioisotopes in brachytherapy
   - the wider use of less standard modalities (e.g. hadron beams) and a need for consistency of dosimetry standards across all modalities.

2. Developments in equipment or clinical applications, for which standard dosimeters or methods for relative dosimetry are not appropriate, or not ideal, e.g.
   - stereotactic collimators, microMLCs and other small field definition or delivery systems and the requirements for beam characterization, treatment planning data and verification dosimetry for small field treatments, or small sub-fields in IMRT and novel delivery systems. Many small field dosimeters have been used, including micro and pinpoint ion chambers, diodes (standard and stereotactic), diamond, film (standard and radiochromic), TLD, etc. Measurement methods have required novel mini (micro) phantoms and careful consideration of the impact of changes in beam characteristics (e.g. loss of lateral electronic equilibrium) on measurements;
   - non conventional equipment such as tomotherapy units, IMAT delivery systems, robotic narrow beam units;
   - dynamic methods rather than static; and the requirement for 2D and 3D dosimetry, leading to the increasingly widespread use of;
     - initially 1-D, then 2D ion chamber or diode arrays
     - extended dose range silver based film and radiochromic film, both of which present particular problems in practical use
     - rapidly increasing use of EPIDs for QA and verification dosimetry, including transit dosimetry
     - 3D dosimetry from 3D arrays of point dosimeters, stacked films or 3D gel dosimetry, using MRI or optical CT to analyse the distributions.
   - high dose/pulse or high dose rate brachytherapy situations.
3. Developments in dosimetry applications, or systems, e.g.:
   - the need for increased QA and direct verification dosimetry in more complex treatments and for more complex equipment, both in phantom and in vivo;
   - the need for more frequent, and hence more efficient, QA for equipment, for techniques and for individual patient treatments and the introduction of more systematic approaches to QA and QC measurements, and to QA/QC data analysis, storage and manipulation.

4. The increasing demand for improved accuracy or for demonstration of achieved accuracy in delivery of both standard and newer complex treatments, e.g. in vivo dosimetry, verification dosimetry, audit dosimetry; requiring moves from single-point measurements to planar, including transit dosimetry and volume dosimetry.

5. A greater demand for direct dosimetry in brachytherapy applications. The development of new radiation detection instruments into potentially clinically useful dosimeters, (as well as all the above mentioned systems, there have been many others applied in radiotherapy dosimetry, e.g. alanine, MOSFETs, OSL, RPL glass rods, plastic scintillators) and the development of phantoms and methods for particular situations have generally been driven by specific practical clinical dosimetry needs, linked to one or other of the above listed requirements. These developments have also been affected by a synergy between modeling by Monte Carlo methods of both measuring devices and measurement situations, and measurement itself, where each informs and stimulates the other.

Generally the accuracy aimed for at different points of measurement in the radiotherapy dosimetry chain must be sufficient to support the following:
   - for beam calibration dosimetry in standard conditions, to achieve relative uncertainties approaching 2%, at the 95% CL, (1% at the one relative standard uncertainty level), taking into account chamber calibration, ($k_Q$ if relevant) and beam calibration
   - for relative dosimetry data measurements for beam characterization and treatment planning, to have uncertainties within ±1% for simple standard data measurements, and within ±2%, 95% CL, for more complex situations
   - for verification measurements of delivered doses in phantom, compared to planning system modelling to within ±2% for simple situations and to within ±3 or 4% (or an appropriate distance value, e.g. 3 mm) for more complex situations, although measurements and modeling in and close to inhomogeneities will increase this.
   - for verification measurements of delivered doses to patients, using in vivo techniques, to around ±5%.

These requirements are quite demanding and need careful QA at all levels, including QA of the dosimetric equipment itself. Measurement methods, dosimeter chosen and phantom used (if relevant) need to be well matched and appropriate to the situation under consideration, to be sure that measurements are adequate, acceptable and consistent both for the initial data required and at any verification. Critical consideration of the situation, of limitations of detector and measurement method, and of any corrections required, as well as sufficient repeated setups and measurements, are all necessary to get a clear understanding of realistic estimates of the measurement uncertainties which are applicable. Analysis of data should always take this context into account. The potential sources of errors need to be well analysed and understood if optimized uncertainties are to be achieved.

These areas of radiotherapy dosimetry and QA are summarized and reviewed.
Advances in calibration of high dose rate brachytherapy sources

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High Dose Rate (HDR) brachytherapy $^{192}$Ir sources have been in existence for more than 15 years. The calibration of this isotope was first developed at the University of Wisconsin, using what has come to be termed the seven-distance technique. A schematic of the apparatus is shown in Fig. 1, showing that repositioning of the distance is within $\pm 0.1$ mm. Since its inception multiple manufacturers of this source have entered the marketplace. The design of these sources consists of a single pellet or two pellets encapsulated in different materials. There are different afterloaders used to deliver the source through a catheter to a patient.

![Schematic of 7 distance apparatus.](image)

FIG. 1. Schematic of 7 distance apparatus.

Each of the manufacturer sources for $^{192}$Ir has been measured with this apparatus. In addition, another high dose rate source, $^{169}$Yb has been measured with the apparatus shown in Fig. 1. The calibration method for the energies involved for the ion chamber will be described, including the changes in the NIST air kerma standard for the cesium calibration point.

Another high dose rate source with low energy (50 keV) is a miniature X ray source. This source can be calibrated with a free air chamber.

Comparison of sources from different $^{192}$Ir manufacturers, including the new design versus the older design, and the subsequent use of well chambers to determine the air kerma strength will be explained. The calibrations for all the manufacturers of this source agree within $\pm 1\%$
and well chambers can be calibrated to air kerma strength within the total uncertainty of 2% (k=2).

New advances in sources used for HDR Brachytherapy utilize lower energies than the $^{192}\text{Ir}$ nuclide. The intent of the lower energy is a better dose distribution and less transmission through the patient into the room. The $^{169}\text{Yb}$ source was calibrated with the seven-distance technique using the apparatus shown in Fig. 1. A miniature X ray source was calibrated using a free air chamber designed for energies at 50 keV or less. The air kerma strength of both of these sources has been made allowing subsequent well chamber calibrations to be performed. These sources can now be calibrated to air kerma strength and used for clinical trials after other dosimetric parameters, such as dose rate constant, are determined.

REFERENCES

The use of plane-parallel chambers in electron dosimetry without cross calibration

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Modern IAEA, DIN and AAPM dosimetry protocols for external beam radiotherapy recommend the use of plane-parallel ionization chambers for the determination of the absorbed dose to water in (low-energy) electron beams. The recommended procedure relies on a cross-calibration of the plane-parallel ionization chamber, i.e. on the comparison with a calibrated cylindrical chamber in an electron beam of high energy, which has to be done by the responsible physicist in the hospital. The rationale for this is the assumed chamber-to-chamber variation of the perturbation factor \( (p_{\text{wall}})_{Co} \) for plane-parallel chambers of the same type (variations of up to 4% have been reported in early studies [1]) which forbids the specification of type-specific \( (p_{\text{wall}})_{Co} \) values in dosimetry protocols.

In routine measurements there is a certain risk that this cross-calibration procedure introduces erroneous results into the measurement of the absorbed dose in electron beams because all mistakes and uncertainties associated with one single dose measurement using a cylindrical chamber are carried on to the later dose measurement using the plane-parallel chamber. Due to this risk, it might be more advantageous to use plane-parallel chambers which have been calibrated directly at a PSDL or SSDL. This, however, requires the availability of type-specific values of the perturbation factor \( (p_{\text{wall}})_{Co} \) for plane-parallel chambers of frequently used types with adequate small uncertainty.

In an extensive study [2] we determined the overall perturbation factors \( p_{Co} \) (which are usually assumed to be equal to \( (p_{\text{wall}})_{Co} \)) for a total of 35 plane-parallel chambers of the Roos type (30 PTW 34001, 2 PTB FK6, 3 Scanditronix-Wellhöfer PPC40), 15 chambers of the Markus type (PTW 23343), and 12 chambers of the Advanced Markus type (PTW 34045). A total of 188 individual cross calibrations using these chambers were carried out at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, at the University Hospitals of the Universities of Freiburg and Tübingen, and at the German Cancer Research Center (DKFZ) in Heidelberg using different types of linear accelerators, different electron energies, and different measurement equipment. The measurements were analysed according to the revised version of the German dosimetry protocol DIN 6800-2 which is very similar to IAEA TRS-398. The results obtained from these measurements are shown in Table 1.

**TABLE 1. RESULTS OF ANALYSIS OF MEASUREMENTS ACCORDING TO DIN 6800-2**

<table>
<thead>
<tr>
<th>Chamber type</th>
<th>Number of measurements (cross-calibrations)</th>
<th>Mean value ( p_{Co} )</th>
<th>Relative experimental standard deviation ( \sigma(p_{Co}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roos</td>
<td>111</td>
<td>1.0198</td>
<td>0.24%</td>
</tr>
<tr>
<td>Markus</td>
<td>40</td>
<td>1.0175</td>
<td>0.24%</td>
</tr>
<tr>
<td>Advanced Markus</td>
<td>37</td>
<td>1.0155</td>
<td>0.20%</td>
</tr>
</tbody>
</table>

Despite the larger variety of experimental conditions occurring in our study and the much larger number of chambers investigated we did not observe such large variations of the \( p_{Co} \).
values for different plane-parallel chambers of the same type as reported in earlier studies [1]. The largest variation we observed was 1.0% for chambers of the Roos type; for chambers of the Markus and Advanced Markus types the variations were 0.9% and 0.6%, respectively. Furthermore we observed in our study that the variations of the $p_{Co}$ values which we obtained in repeated measurements using always the same plane-parallel chamber are comparable to the variation of the $p_{Co}$ values obtained for different chambers of the same type given above. This justifies the assumption that the mean $p_{Co}$ values obtained in our study from a large number of measurements are more reliable than a $p_{Co}$ value determined from a single cross-calibration measurement in the hospital.

An analysis of uncertainty gives for the relative standard uncertainty of the $p_{Co}$ values determined in our study $u(p_{Co}) = 1.1\%$, which includes the uncertainties of all correction factors involved in the data analysis. This results in a relative standard uncertainty of the beam quality correction factor $k_Q$ (which is eventually needed for dose measurements using a plane-parallel chamber calibrated at $^{60}$Co) of $u(k_Q) = 1.3\%$ – a value which is only 0.1% larger than the uncertainty given in TRS-398 for the beam quality correction factor for cylindrical chambers in electron beams.

Hence the (supposed) large variation of $p_{Co}$ values for different chambers of the same type and the uncertainty of the generic $p_{Co}$ values determined in our study are no arguments against a calibration of plane-parallel chambers at $^{60}$Co and a measurement of the absorbed dose in electron beams without cross calibration. A replacement of the cross calibration procedure by the $^{60}$Co calibration of plane-parallel chambers facilitates electron dosimetry without increasing the uncertainty of measurements, it provides the possibility of conducting consistency checks between measurements with cylindrical and parallel plate chambers and thus represents an important contribution to QA in clinical dosimetry. The $p_{Co}$ values determined here will be recommended in the revised version of the German dosimetry protocol DIN 6800-2.

**REFERENCES**


Use of radiochromic films to calibrate a high dose-per-pulse electron accelerator for intraoperative radiation therapy (IORT)

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The electron beams of some accelerators dedicated to Intraoperative Radiation Therapy (IORT) are characterized by a doserate of the order of some cGy/pulse, much higher than the typical values less than 1 mGy/pulse of conventional linacs. Thus doserates attain values of some tens of Gy/min reducing considerably the treatment time, but, at the same time, introducing a problem in the use of ionization chambers in beam calibration because of the significant lack of complete charge collection due to ion recombination. At very high dose-per-pulse values the standard “two voltage” method for $k_{sat}$ [1] evaluation is no more valid and yields overestimates of $k_{sat}$ up to 20% [2].

To overcome the problem, doserate independent dosimeters (such as chemical or film dosimeters) should be used. Indeed, the most commonly used chemical Fricke dosimeters (ferrous sulphate in glass ampoules) have some disadvantages such as their cost and post-irradiation process that limit their use in routine clinical dosimetry. Radiochromic film dosimeters seem more suitable for the purpose as they may be easily managed also by users not acquainted with unconventional dosimetry methods.

In this paper we report on the use of radiochromic films [3] for the absolute dose calibration of the high dose-per-pulse electron beams of a mobile accelerator (LIAC, Info&Tech, Italy), and on its validation by comparison with chemical Fricke dosimeters supplied by the Italian Primary Standard Dosimetry Laboratory (ENEA-INMRI, Rome).

**Material and methods**

LIAC is a mobile linear accelerator which produces electron beams of nominal energy 4, 6, 8, 10 MeV. The beam collimation is carried out through cylindrical Perspex applicators with different diameter (3–12 cm) and bevel angles (0, 15, 30, 45°).

As anticipated, in absolute dosimetry we adopted two different methods: chemical Fricke dosimetry for a limited set of applicators and energies, and radiochromic film dosimetry (Gafchromic films HS, ISP Tech. inc.) [4] for all the applicator-energy combinations.

Forty-eight (48) Fricke dosimeters were irradiated in water, with the centre of the dosimeters placed at the reference depth $R_{max}$, with doses ranging from 49 to 92 Gy, preliminarily estimated by means of plane-parallel ionization chambers (Exradin A11, NACP-02) corrected for ion recombination according to the “two voltage” method. Dose values assessed by Fricke dosimeters had an uncertainty of 1.6% ($1\sigma$). Just after Fricke dosimeters, irradiations of radiochromic films followed for all applicator-energy combinations. In all cases 3 film cutouts (1.5×1.5 cm$^2$ size), one at a time positioned at $R_{max}$ depth in a solid water phantom (Virtual Water Phantom, VWP, Standard Imaging), were irradiated at doses of the same values. Film readouts were carried out by using a transmission densitometer. To account for post-irradiation time effect on readings, all films were read between four and five days after irradiation. Film sensitivity to temperature was not taken into account as environment conditions were normally stable.
Optical density calibration curve was obtained by exposures at the 8 MeV electron beam of a conventional radiotherapy linac (ELEKTA SL18). Dose values ranged from 0 to 92 Gy. Experimental data were fitted by two 3rd degree polynomial functions merging at 10 Gy (Fig. 1). Dose uncertainty of less than 3% was estimated.

![Optical density calibration curve](image)

**FIG. 1.** Gafchromic film calibration in terms of absorbed dose vs optical density. The films were irradiated by an 8-MeV electron beam supplied by a conventional linac.

**Results and discussion**

Good agreement between Frickel and Gafchromic dosimetry results has been shown for every energy and applicator, with maximum deviation less than 3%. Also in the most critical setup, the 4-cm-dia applicator, where the dimensions of both kinds of dosimeters could affect measurement, the maximum deviation was 1.4%.

Dose rates ranged from 5 Gy/min (0.4 cGy/p) for the 4-MeV beam to 28 Gy/min (4.6 cGy/p) for the 10 MeV beam. The comparison between Frickel dosimetry results and ionization chamber estimates of doses evidenced once more that \( k_{\text{sat}} \) derived by the dosimetric protocol “two voltage” method is largely overestimated (up to 14%) for such high dose rates, thus demanding more sophisticated corrections for ion recombination.

After a major maintenance of the LIAC unit a second absolute dose calibration has been performed by means of GAF-chromic films only. Subsequently, this calibration has been validated by comparison with alanine dosimeters supplied by the Italian National Institute of Health (ISS) in the context of an intercomparison exercise. Maximum deviation of GAF-chromic film dosimetry from alanine dosimetry resulted 1.4% for reference conditions (10 cm dia applicator).

In conclusion, GAF-chromic films allow to carry out absolute dosimetry of high dose-per-pulse electron beams with sufficient accuracy and good ease of execution representing a valid alternative to the problematic use of ionization chambers and to the less available chemical dosimeters.

**REFERENCES**


Assessment of optical computed tomography for polymer gel dosimetry

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\textsuperscript{b}Department of Chemical Engineering, Queen’s University,

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Modern radiation therapy particularly with intensity modulation techniques (IMRT) offers the potential to improve patient outcomes by better limiting high doses to the tumour alone. IMRT delivery is technically complex, and precise verification of the resulting three dimensional (3D) dose is required to ensure that the objectives of the treatment are achieved [1]. Currently no convenient dosimetry system exists for such 3D dosimetry. Gel dosimetry can provide the required verification system but is often limited because of access to imaging for dose determination [1,2]. We present here results from the investigation of cone beam optical CT (optCT) [3] for reading dose information in polymer gel systems.

Various polymer gel dosimeters based on polyacrylamide gelatin (PAG) were prepared for this study; including some with the acrylamide replaced by N-vinylFormamidine (PVFG), N-isopropyl acrylamide (NIPAM), or diaceton acrylamide (DAAM). The dosimeters incorporated an antioxidant to enable preparation in a conventional fumehood. Phantoms were irradiated with different conformal doses one day after dosimeter preparation with a Cobalt-60 tomotherapy benchtop on an MDS Nordion T-780 unit. Optical CT measurements were made on a prototype cone beam CT scanner (Vista Scanner, Modus Medical, London, ON). The scanner uses LEDs (at 590 or 633 nm) with a diffuser to provide a 9° cone at a 1024×768 pixel, 10-bit, CCD camera. The acquisition time is roughly 8 min and image reconstruction (via a Feldkamp backprojection) takes a further 8 min. Each CT measurement consists of a pre-irradiation scan on the gel dosimeter phantom followed by scanning of the irradiated dosimeter at various times post irradiation. Each polymer gel phantom exhibited clear radiation induced polymerization apparent in visible light. Typical results of the optCT scanning are reviewed in Figs 1 to 3 and discussed in the individual figure captions.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{The inset shows a transverse CT image of a PVFG dosimeter irradiated with 3 pencil beams. The graph shows the corresponding profiles through the gel at each beam. The dotted curve gives the expected curve based on film measurements. Error bars of +/- 10 CT units are not indicated on the graph.}
\end{figure}
FIG. 2. Measured OptCT number vs dose for the PVFG, NIPAM, and DAAM dosimeters. OptCT numbers depend linearly on dose, save for a threshold region for doses less than ~8 Gy (PVFG). In all formulations, the dose dependence varies with time after the irradiation as the dosimeters undergo further polymerization. The error bars are within the symbol size.

In summary, the optical CT numbers are dose dependent and the reproducibility between multiple scans is very good. Thus, the Vista OptCT scanner with polymer gel dosimeters has the potential for convenient clinical application in IMRT dose-delivery validation. Further characterization is currently underway.

This work was funded through the Canadian Institutes of Health Research and the Ontario Consortium for Image Guided Surgery and Therapy.

REFERENCES


A 1000 cc ion chamber has been designed and fabricated for the measurement of reference air kerma rate (RAKR) of brachytherapy LDR and HDR $^{192}$Ir sources used in radiotherapy centres in India. RAKR value thus obtained is used to calibrate the Well type chambers of the hospitals. The ion chamber is cylindrical in shape and is made of high density, high purity graphite. The chamber sensitivity has been computed theoretically for $^{192}$Ir ($\overline{E} = 97$ keV) and $^{137}$Cs(662 keV) the two commonly used brachytherapy sources in India. Sensitivity calculations are based on Burlin’s general cavity theory [1] in view of the large size of the chamber cavity. The ion chamber is being used in conjunction with an electrometer NE2670 (U.K.)

The experimental set-up for the measurement of RAKR consists of a jig for mounting the ion chamber and the source at three distances viz. 50 cm, 75 cm and 100 cm. The use of jig ensures the precise positioning of the chamber and the source. The measurements at three distances are used to set up three equations of which any two equations are solved to obtain the room scatter. The mean scatter value obtained by solving the three sets of equations is subtracted from the chamber output for three distances. The corrected chamber outputs are used to compute the RAKR from which the average RAKR value is calculated. The uncertainty in RAKR has been estimated to be ±3% at 1σ level for LDR sources and 2% at 1 σ level for $^{192}$Ir HDR sources.

The measurement of $^{192}$Ir LDR wire sources prepared and supplied by BRIT, India was carried out with the help of a special source holder. Measurements were carried out using 1, 2, 3, 4, and 5 sources each of 5 cm length from which the RAKR for 1cm long $^{192}$Ir wire source was calculated. A 1 cm long wire source was then used to calibrate the Well type chamber of the hospital. Similarly special source holders for various types of $^{137}$Cs LDR sources was prepared and used for RAKR measurements.

The source holder for HDR $^{192}$Ir source was chosen depending upon the type of HDR system for compatibility with source transport tube used. Generally a 30 cm long stainless steel tube having a wall thickness of about 0.05 cm used by the hospital in the clinical application was found to be most suitable for this purpose and hence no special source holder was made for HDR sources. A correction for the attenuation in the source holder was applied in each situation. Other correction factors used are, as follows:

1. Charge recombination correction (only for HDR sources)
2. Temperature and pressure correction factor Kt, p
3. Geometrical correction factor as given by Kondo and Randolph [2].

Calibration of Well type chambers was done at the position of maximum sensitivity as determined by positioning the source at various distances from the chamber bottom in steps of 2.5 mm. Table 1 gives the results of some recent measurements and, for comparison purpose, the value of RAKR quoted by the source manufacturer/vendor has also been given. Table 2
shows the calibration factors of the Well type chambers determined with the help of the 1000 cc graphite chamber.

**TABLE 1. RESULTS OF $^{192}$IR HDR SOURCE MEASUREMENTS WITH THE 1000 CC GRAPHITE CHAMBER**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Hospital</th>
<th>Source</th>
<th>$\text{RAKR}_{\text{measured}}$ 2 Gy.m$^2$.h$^{-1}$</th>
<th>$\text{RAKR}_{\text{vendor}}$ 2 Gy.m$^2$.h$^{-1}$</th>
<th>% Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>H1</td>
<td>Nucletron MS</td>
<td>2.1590</td>
<td>2.187</td>
<td>-1.28</td>
</tr>
<tr>
<td>2.</td>
<td>H2</td>
<td>Nucletron MS</td>
<td>1.0946</td>
<td>1.096</td>
<td>-0.13</td>
</tr>
<tr>
<td>3.</td>
<td>H3</td>
<td>Nucletron MS</td>
<td>0.1265</td>
<td>0.1311</td>
<td>-3.51</td>
</tr>
<tr>
<td>4.</td>
<td>H4</td>
<td>Nucletron MS</td>
<td>3.441</td>
<td>3.432</td>
<td>+0.26</td>
</tr>
<tr>
<td>5.</td>
<td>H5</td>
<td>Alpha-Omega</td>
<td>3.3377</td>
<td>3.3675</td>
<td>-0.88</td>
</tr>
</tbody>
</table>

**TABLE 2. CALIBRATION FACTORS OF WELL TYPE CHAMBERS**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Hospital</th>
<th>Source</th>
<th>Well Chamber Type/Electrometer</th>
<th>$\left(N_{\text{RAKR}}\right)^{192}\text{Ir}$ 2 Gy.m$^2$.h$^{-1}$.A$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>H1</td>
<td>Nucletron MS</td>
<td>Nucletron SDS/PTW Unidos</td>
<td>9.519×10$^5$</td>
</tr>
<tr>
<td>2.</td>
<td>H2</td>
<td>Nucletron MS</td>
<td>SI HDR-1000/Scanditronics Wellhoffer</td>
<td>4.570×10$^5$</td>
</tr>
<tr>
<td>3.</td>
<td>H3</td>
<td>Nucletron MS</td>
<td>Nucletron SDS/PTW Unidos</td>
<td>9.0239×10$^5$</td>
</tr>
<tr>
<td>4.</td>
<td>H4</td>
<td>Nucletron MS</td>
<td>Nucletron SDS/PTW Unidos</td>
<td>9.559×10$^5$</td>
</tr>
<tr>
<td>5.</td>
<td>H5</td>
<td>Alpha-Omega</td>
<td>SI HDR-1000/CDX-200A</td>
<td>4.686×10$^5$</td>
</tr>
</tbody>
</table>

**REFERENCES**


Evaluation of three calibration techniques for amorphous silicon EPID dosimetry

K.E. Malkoske, B.M.C. McCurdy, D.W. Rickey

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In order to account for differences in pixel-to-pixel sensitivity in the detector, images from a Varian amorphous silicon (aSi) electronic portal imaging device (EPID) are corrected with division by a flood field. This operation has the undesired effect of introducing the non-uniform energy fluence profile (present in the flood field) into the image correction process. This results in the systematic removal of the off-axis “beam horns” from corrected images. Consequently, there is inaccurate dosimetry in quality control and IMRT verification applications. Several authors have presented methods to account for this effect by calculating the EPID response to the flood field [1,2] or using measurement based approaches to isolate the pixel sensitivity effect from the conventional flood field [3–5]. The latter of these techniques have the advantage of requiring no specialized EPID response calculation methods (e.g. Monte Carlo) thus providing simpler implementation for the user.

We have evaluated three recently published measurement based approaches. Two of these techniques involve placing various amounts of water equivalent material upstream of the detector to provide an approximately uniform energy fluence at the EPID detection plane during flood field acquisition. The third technique uses a series of lateral detector displacements to sweep the EPID pixels across a uniform energy fluence. The measurement conditions are briefly described below:

(A) 6 cm water equivalent plastic is placed directly atop the EPID touch guard. Source to EPID distance is 105 cm (Greer and Popescu, 2003) [3]

(B) 20 cm water equivalent material is located on a foam support at an SSD of 91.25 cm. Source to EPID distance is 183 cm (Siebers, et. al., 2004) [4]

(C) The central 2.5 cm of a 10×25 cm$^2$ field is assumed to have a uniform energy fluence. Source to EPID distance is 105 cm. The detector is translated laterally in 2.5 cm steps through the field to generate a pixel sensitivity profile (Greer, 2005) [5].

To independently assess the accuracy of these methods, we have constructed a point detector that exhibits an energy response similar to the clinical EPID (aS500 Varian Medical Systems, Palo Alto, CA). The main components of the detector consisted of a 1 mm thick copper buildup plate backed by a phosphor screen (Kodak Lanex Fast B). The lateral extent of these materials was reduced relative to the clinical EPID (40×40 mm$^2$ for the copper and 15×15 mm$^2$ for the phosphor). A single photodiode (Osram BPW 34) with a 2.65×2.65 mm$^2$ active area was optically coupled to the phosphor. The detector was scanned in-air with a beam scanning tank (Multidata Systems International Corp., St. Louis, MO).

For methods (A) and (B) above, the accuracy in the calibration was quantified by 1/FF$_{pointD}$, where FF$_{pointD}$ is the in-air profile measured with the point detector (normalized to central axis) at the EPID detection plane under the flood field calibration conditions specified above. For method (C) we performed Greer’s procedure to reconstruct an open field EPID profile,
OF\textsubscript{Greer}, corrected for the non-uniform flood field and pixel sensitivity differences in the detector. This was compared with an open field profile measured with the point detector in the same geometry, OF\textsubscript{pointD}. The ratio, OF\textsubscript{Greer}/OF\textsubscript{pointD} was used to quantify the accuracy of this method.

Through comparison with direct measurement with a point detector, we found the method proposed by Siebers, et. al. [4] to provide the most accurate calibration of the Varian aSi EPID for dosimetry purposes (Fig. 1). For field sizes less than $30\times30cm^2$, this technique provided a calibration accurate to within $\pm1\%$ of the central axis response.

![Graph showing calibration accuracy ratio](attachment:graph.png)

**FIG. 1.** Accuracy of the investigated calibration procedures along a crossplane profile through the beam central axis.

### REFERENCES


Evaluation of radiophotoluminescent glass rod detector for small field dosimetry; measurement of output factor in water for CyberKnife

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\textsuperscript{b}Radiation Health Research Institute,
\textsuperscript{c}Department of Radiation Oncology, College of Medicine, Kyung Hee University,
\textsuperscript{d}CyberKnife Center, The Catholic University of Korea,
\textsuperscript{e}Department of Radiation Oncology, St. Mary's Hospital, The Catholic University,

Korea, Republic of

The CyberKnife stereotactic radiosurgery (SRS) is composed of a miniaturized 6 MV LINAC attached to a computer driven robot arm with six degrees of freedom and real-time image correlation system. The CyberKnife SRS system can deliver with a high precision, a single or several fractions of radiation doses to a well defined small intracranial or extracranial target. Unlike the gamma knife, there are collimators of 12 different sizes in the CyberKnife SRS system, ranging from 5 to 60 mm in diameter. Accuracy of the output factor, defined as the ratio of the dose rate for a given collimator to that of the 60 mm collimator, directly affects the accuracy of dose delivery in CyberKnife SRS system. This is of obvious importance for any SRS system, particularly when a single large radiation dose is delivered to a small selected target with the 5 mm collimator, as in the treatment of trigeminal neuralgia.

The measurements of such small output factors are generally difficult due to the sharp radial dose fall-off, the small size of the dose plateau region and the lack of lateral electron equilibrium. A radiophotoluminescent (RPL) glass rod detector (GRD) system has recently become commercially available. The dosimeter system is composed of small, rod shaped, silver activated metaphosphate glass detectors and readout system. The weight compositions of the GRD is as 31.55% P, 51.16% O, 6.12% Al, 11.00% Na and 0.17% Ag. The effective atomic number and density of GRD is 12.039 and 2.61, respectively. The advantage of GRD over TLD is that GRD can be read an infinite number of times whereas TLD can be read only once. This is because repeated pulses of the UV beam excitation do not eliminate the RPL centers in the GRD. Consequently, each individual GRD measurement allows many readouts, whose average value has higher reproducibility than TLD. Like TLD, When the stable RPL centers disappear by annealing (400°C, 30 min), the accumulated dose in a GRD is reset and the GRD can be used and read repeatedly. In this study, the model GD-301 glass rod dosimeter (Asahi Techno Glass Corporation, Shizuoka, Japan) and FGD-1000 automatic reader are used. The size of the model GD-301 is 1.5 mm in diameter and 8.5 mm in length. The effective GRDs readout size is 1 mm in diameter and 0.6 mm in depth.

The output measurements for 12 circular collimators of 5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50 and 60 mm diameter are performed in this study. The output factor measurements of the
GRD are compared with those of a PTW 60008 p-type Si diode detector and normalized to that of a 60 mm circular collimator. All measurements are performed at a depth of 1.5 cm in water phantom. The GRD are irradiated in a water phantom using a holder stand. The holder is the PMMA tube with a hole for GRD at 1.5 cm from its top. The water level is adjusted precisely to the top of the holder and the axis of the beam aligned with holder axis. The robot is adjusted so that the radiation beams point down vertically. The center of the GRD is set to be the center of the radiation field by alignment with a point laser built into the LINAC. The measured output factors for GRD and diode are very similar except for the three smallest collimators (5, 7.5 and 10 mm) which is demonstrated in Fig. 1. The measured difference between the above methods is approximately 3%. The mean value of the output factor for GRD in the 5 mm collimator is 0.691±0.006.

![Graph of output factors vs. collimator size](image)

**FIG. 1.** Plot of the output factors as a function of collimator size.

**REFERENCES**


Practical approaches to small field dosimetry for radiotherapy

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The dosimetry of small fields has become increasingly important in recent years, for both stereotactic radiotherapy and for sub-fields for IMRT, using MV photon beams\cite{1}. There is also interest in small fields in other modalities. However, measurements are difficult because of the sizes of available detectors, as well as other problems such as lack of lateral equilibrium.

A range of measurement methods and detectors have been investigated and are summarized here, where the aim is to acquire data with accuracies of at least ±2%\cite{1} and to verify delivered doses to ±3%\cite{2}. These studies include exploring the limitations and methods required for in-air measurements (with build up caps and mini phantoms for small field use, e.g. for \(S_c\)) and in-phantom measurements for \(S_{c,p}\) and then for extraction of \(S_p\), as well as comparing different small detectors. Detectors include a range of ‘micro’ and ‘pinpoint’ ion chambers, standard and ‘stereotactic’ semiconductor detectors, diamond detectors, and conventional and Gafchromic film. The ion chambers used are all of basic thimble design, but varying in volume from 0.01 to 0.06 cc, in length of collecting volume from 2 to 4 mm, in outside diameter from 3 to 6 mm and also in the detail of the design of the collecting cavity (miniature chambers, micropoint chambers and microchambers). For solid state detectors, their construction details have been clarified or verified by imaging\cite{3}.

The main measurements in this series have been carried out on Varian 600CD 6 MV X ray beams, in small fields set with conventional collimators down to \(1\times1\) cm\(^2\), similar fields set with MLC down to 0.5×0.5 cm\(^2\) and in circular stereotactic fields down to 0.5 cm diameter. Head scatter factors and total scatter factors at \(d_{\text{max}}\), 5 cm and 10 cm depth, depth doses and profiles have been investigated, as well as verification of delivered doses for stereotactic beams using a specially designed and constructed ‘head’ phantom. For head scatter factors, a number of approaches to forward and side build up/electron equilibrium have been investigated, using plastic and brass build up caps and miniphantoms, with minimum thickness side-walls and ultimately no side walls. Additional measurements have been carried out on other linacs (including Elekta Beam Modulator 0.4 cm MLC systems), other beam qualities and also in electron beams and kV X ray beams.

Practical observations from the experimental work in small fields include the need for very careful alignment of detectors with both the field centre and direction, including accurate determination of the true centre of the radiation field by finding the point of maximum signal across the field. Also for highest accuracy results, it is necessary to determine correction factors based on the size of the sensitive area relative to the small field dose distribution. For dose delivery verification measurements, further correction factors need to be considered, based on angular sensitivity of the detector under consideration. For \(S_c\) measurements, the recommended practical approach is to use plastic build up ‘tops’ of width equal to the width.
of the detector, with no additional side walls, and of thickness equivalent to build up depth of the beam. These values are not significantly different to those measured with 5 cm of material overlying the detector, but are easier to accurately set up and align. Higher atomic number materials introduce some small differences. Using Gafchromic film, significant changes in observed dose, of around 5%, were apparent depending on the orientation of the film as it passes through the scanner, which requires further investigation. For $S_c$ and $S_{c,p}$ for the MV X ray beams, different point detectors agree within measurement uncertainties down to field sizes around 1.5 cm width, but then the results show increasing divergence of up to 10% or so at the smallest fields investigated. Most of the solid state detectors can be used for the range of standard measurements in fields down to around 1 cm, but below this, it is still unclear which system is best, or what the detailed reasons are for the differences [4,5,6].

The results can be used to model and evaluate correction factors for detector sizes and to separate out effects. Monte Carlo modeling is necessary to fully understand the behaviour of practical systems in these situations and can be used to compare to the measurements. Comparison of the results and of the characteristics and performance of the different detectors, phantoms and measurement methods in small fields can be used to produce a range of practical recommendations on approaches, limitations, methods and problems, which can be applied in these situations. The objectives of dose parameter determination for treatment planning and also dose delivery verification to within uncertainties of around 2% can be readily met.

REFERENCES


Evaluating the performance of commercial systems of QA for radiotherapy facilities: A case study

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In order to provide quality control in radiotherapy practice in the hospital routine and reduce the time used for the implementation of established protocols \cite{1}, quality control systems have been developed by manufacturers of clinic instruments. Their use is more and more common but their performance is not always ensured by an independent certification.

This study presents a performance evaluation of the QC6-Plus quality control system, developed by PTW-Freiburg, about which the available accuracy and performance information has, until now, been provided only by the manual of the equipment.

The obtained results point out the limitations of the use of this equipment in the quality control routine of the hospitals as well as its possible use in the regulatory inspections performed by the Comissão Nacional de Energia Nuclear (the Brazilian regulatory body responsible for the safety and security use of the ionizing radiation) in radiotherapy facilities. The photon beams were provided by the INCA’s (Instituto Nacional do Câncer, in Rio de Janeiro) Clinic Linear Accelerator - Clinac 2300C/D. The dosimetry of the beams produced by the Clinac 2300C/D was carried out by the QC6-Plus system. In order to evaluate the dosimetry of the QC6-Plus system, the beams were also measured conventionally by using an ionization chamber IC-70 Welhofer Farmer type associate with electrometer Keithley and with a phantom CNMC Co 30 cm×30 cm × 40 cm of water \cite{2}. The symmetry and flatness of the beams was evaluated by using both the QC6-Plus system and an ionization chamber IC-15 s3400 Welhofer associated with electrometer PTW Unidos E and with a phantom CNMC Co 40 cm×40 cm×40 cm of water. The INCA’s Co-60 Theratron irradiator was also used to verify the calibration procedures proposed by the manufacturer of the QC6-Plus system. The Theratron irradiator allowed the characterization of the QC6-Plus system in terms of constancy and reproducibility.

The presented results indicate that the QC6-Plus system is able to evaluate the reference clinic parameters, flatness and symmetry, in the routine of a hospital. On the other hand, the observed deviation in the dosimetry measurements, when compared with the results obtained from the conventional dosimetric method, does not allow the recommendation of the use of the QC6-Plus system for the dosimetry purpose.
### TABLE 1. FLATNESS AND SYMMETRY OBTAINED VALUES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>6 MV Photon beams</th>
<th>15 MV Photon beams</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Tolerance (%)</td>
</tr>
<tr>
<td>Flatness (%)</td>
<td>1,2</td>
<td>2,0</td>
</tr>
<tr>
<td>Symmetry in plane (%)</td>
<td>0,1</td>
<td>3,0</td>
</tr>
<tr>
<td>Symmetry cross plane (%)</td>
<td>0,6</td>
<td>3,0</td>
</tr>
</tbody>
</table>

**FIG. 1. Dose measurements in central axis after and before the calibration procedures – 6 MV and 15 MV.**

**REFERENCES**


A modern radiotherapy department equipment QC system

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Introduction. Until recently, the Regional Medical Physics Department (RMPD) in the UK has run a radiotherapy equipment quality control system for the Northern Centre for Cancer Treatment (NCCT) based on paper recording of tests designed for conformal therapy equipment and initially constructed for the treatment techniques used in the early 90s. RMPD/NCCT are ISO-9002 accredited and with 7 linear accelerators, 3 CT scanners, 1 superficial X ray therapy unit and 1 high dose-rate selectron unit, the paper work system was significant.

Although periodically updated when new equipment was installed, and new treatment techniques adopted, a redesign of the system was required to allow the following improvements:

- Collect data electronically directly into a DB application to facilitate computerized analysis of QC data
- Simplify the process of modifying tests by using generic tests and storing the test definitions electronically to be accessed by the QC DB application
- Calculate individual test reference values, tolerances and frequencies using Statistical Process Control (SPC) and Failure Mode Effect Analysis (FMEA) principles rather than qualitative assessment or outdated published recommendations
- Separate test frequencies, tolerances and reference values from the test definitions, even for nominally identical machines to allow tailoring to each machine’s clinical use and ageing process.

Data collection. A database application to collect data manages the tests required at a given time, allowing tests to be defined at different frequencies. Data are entered into a DB application in a wireless networked laptop to allow the central DB to be updated without additional processes. All tests due at the time of the QC session are presented including any tests outstanding from earlier sessions. A test session then might include a mixture of monthly, six-monthly and annual tests. Annual tests can then be spread out over the years if required and appropriate.

Generic test definitions. A generic test is the smallest individual test associated with a single measurement that is compared with a reference, or target, value. In practice, QC session checks will comprise groups of tests performed with the same set-up or same measurement. For instance, a single dose measurement is used for two tests: a check that it is within tolerance of the target and a test that the variation over the course of a day is within tolerance. In that case, the target value would be a measurement made earlier in the day. The test definition includes all information required to be able to perform a periodic evaluation of the validity of the test to facilitate QC system maintenance as the equipment and clinical usage changes over time.
Title Time to deliver standard dose

**Purpose**
To check the measured dose rate to confirm virtual wedge delivery

**Equipment**
- Machine specific standard output measurement equipment:
  - WT1 blocks: 5 cm backscatter, 6 cm chamber, 5 cm buildup
  - Machine/dosemeter-specific correction factor (CF) from current certificate

**Preconditions**
- WT1 blocks are at same temperature as the air in the room/chamber
- Dosemeter is in high range unless extra precision is required for low MU measurement on the edge of tolerance

**Setup**
- Gantry 0°, collimator 0°, 10×10cm collimator setting
- Centre of chamber at 10 cm deep at isocentre in WT1 blocks

**Measurement**
- Measure the time (min) to deliver the output using the same method as used at the start of the day
- If assessing stability from output measurement, enter pressure, P (mbar) and temperature, T (°C) to electrometer and record these factors and the corrected dosemeter reading (Gy)

**Evaluation**
- Check that the measured output agrees with the reference value within specified tolerance

**Normal frequency**
- Monthly

**Notes**
- If done in combination with output check calibration, the measured output value can be used for this test.

### Statistical process control (SPC)
Reference values for each piece of equipment are stored along with information which justifies its choice and can be different for each unit, even if the equipment is nominally the same. This is useful if, for instance, they are different ages and one can be expected to change use and tolerances as it nears the end of its life.

Manufacturing industry standard SPC system is used to define reference (target) values and control limits. Control charts, are used to check that a process remains stable and in control. Analysis of measured value distribution allows the capability of the machine to achieve its target value to be assessed. Adjustments can then be made to centralize the spread around the target value and indicate if changes are required to reduce the spread of output values. Frequencies of tests can be set at appropriate levels according to the principles of Failure Mode Effect Analysis (FMEA) where a numerical indication of the importance of testing can be determined after analysis of the severity, occurrence rate and detection likelihood of failures.

**Conclusion.** A radiotherapy equipment QC system based on modern computerized data collection, database storage and processing, industrial process control and failure analysis systems has been designed to address the needs of a modern, large, radiotherapy department. Initial implementation of the elements have already shown benefits in terms of reduced maintenance overheads. The continued development will focus on introduction of the simplified generic tests and on further development of the data collection application.
Periodic QC of linear accelerators with an electronic diode matrix

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Introduction

The MapCHECK™ (Sun Nuclear Corporation) is an instrument developed as a tool for quality control of IMRT treatments in radiotherapy. It is a 2D instrument with a grid of 445 diode detectors placed at 2 cm water equivalent depth. It comes with a software where IMRT treatment plans can be imported, field by field, to be compared with measurements made with the MapCHECK™. The instrument can easily be calibrated for absolute dose. The aim of this work is to evaluate whether the instrument can replace radiographic film for relative measurements of beam symmetry, beam flatness and electron energy.

Method

To obtain measurements, the detector is placed on the treatment couch with the detector plane at isocenter (SAD =100 cm). Best resolution over the largest area is obtained by positioning the detector with its diagonals aligned with the major axis (Fig. 1). The relative response of the detector is calibrated separately for photons and electrons. Raw data are imported into an excel worksheet. For photons and electrons, a macro\(^1\) extract profiles along the major axis, calculates flatness, symmetry and field size. Initially during commissioning, the electronic detector and radiographic film (Kodak EDR) were used in parallel to compare the results of the new method with the well verified film method. We have used the device for all our photon (4, 6, 10, 18 MV) and electron (4, 6, 8, 10, 12, 15, 18, 20 MeV) beams at seven linear accelerators. To measure electron energy we have modified the system we used with film. It consists of two brass wedges placed with their thinnest parts 2.1 cm apart at the central axis of the beam. From the profile beneath the wedge, the distance from centre to 50% penetration is determined. This distance is correlated to the mean electron energy at the phantom surface, \(E_0\), which in turn is directly related to \(R_{50}\) in water.

\(^1\) Originally written by Dr Paul Jursinic (Medical College of Wisconsin).
Results and discussion

The profiles for symmetry and flatness were comparable with film, with a few exceptions. The photon energies of 4, 6 and 10 MV do all compare with film, no extra build up material was needed to obtain acceptable profiles. Fig. 2 gives an example of the resemblance. To get the same results for 18 MV, an additional slab of 1 cm build-up was required.

![Image of graph showing 6 MV crossplane](image)

*FIG. 2. The two yellow lines represent flatness and the blue lines symmetry.*

For electrons the results did not show the same level of compliance. A problem was that 4 MeV hardly reaches the diodes at 2 cm depth and therefore results in rather noisy profiles. This problem was slightly less for 6 MeV. For the higher energies, the results compare well with film.

Since January 2006, the detector has been used as the only device for routine QC of beam symmetry, beam flatness and electron energy. Until March 2006, two occasions of measurements outside tolerance have been detected. These deviations were verified by a diode array (BMS from Schuster) and the accelerators were adjusted accordingly.

Conclusions

The overall stability of the MapCheck™ detector system has been very good. The system has detected deviations on occasions which also have been verified with a second system. The results shows that the electronic detector system can, in most cases, replace radiographic film in periodic QC procedures for linear accelerators. The only exception is the lower electron energies where the diode detectors are positioned to deep in the device. The advantage of this system compared with film is that the time spent at the accelerator is essentially shorter (QC is performed during normal working hours). The time for processing, evaluation and analysis has also been decreased mainly due to elimination of handling of radiographic film, e.g. developing and scanning. The latter is also an environmental advantage.
Dosimetric characterization of an ion chamber matrix for radiotherapy QA

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\textsuperscript{d}Seoul National University, Bundang Hospital, Seongnam,
\textsuperscript{e}School of Medicine, Catholic University of Korea, Seoul

Korea, Republic of

A commercial ion chamber matrix was examined of its characteristics and performance for radiotherapy quality assurance. The device was the \textsuperscript{1}mRT MatriXX (Scanditronix-Wellhofer, Schwarzenbruck, Germany). The MatriXX device consists of a 1020 vented ion chamber array, arranged in 24×24 cm\textsuperscript{2} matrix. Each ion chamber has a volume of 0.08 cm\textsuperscript{3}, spacing of 0.762 cm and minimum sampling time of 20 min. For the investigation of the characteristics, dose linearity, output factor, short term reproducibility and dose rate dependency were tested. In the testing of dose linearity, it has shown a good signal linearity within 1\% in the range of 1–800 cGy. Dose rate dependency was found to be lower than 0.4\% (Range: 100–600 MU/min) relative to a dose rate of 300MU/min as a reference. Output factors matched very well within 0.5\% compared with commissioned beam data using an ionization chamber (CC01, Scanditronix-Wellhofer, Schwarzenbruck, Germany) in the range of field sizes 3×3–24×24 cm\textsuperscript{2}. Short term reproducibility (6 times with an interval of 15 min) has also shown a good agreement within 0.5\%, when the temperature and the pressure were corrected by each time of measurement. In addition, we compared enhanced dynamic wedge (EDW, Varian, Palo Alto, USA) profiles from calculated values in the radiation planning system with those from measurements of the MatriXX. Furthermore, a non-uniform IMRT dose fluence was tested. All the comparison studies have shown good agreements. In this study, the MatriXX was evaluated as a reliable dosimeter, and it could be used as a simplistic and convenient tool for radiotherapy quality assurance.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Dose linearity ranging from 1 to 800 cGy for 6 MV photon. Response of the MatriXX as a function of the delivered dose. The MatriXX signals are an average of the four ion chambers in the center of the MatriXX.}
\end{figure}
FIG. 2. Comparison of profiles from an 60° enhanced dynamic wedge (2D-MatriXX versus Varian Eclipse planning system).

REFERENCES


QA programme based on clinical dosimeter with diamond detector

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\textsuperscript{b}Central Research Institute of Roentgenology and Radiology, St.Petersburg, Russia \\
\textsuperscript{c}Joint Institute for Nuclear Research, Dubna, Russian Federation

The devices with ionizing chambers as the primary converters are traditionally used for dosimetry of the ionizing radiation in medicine and beam therapy. The application of the semiconductor detectors based on silicon is limited due to the high energy dependence of detection sensitivity, small radiation resource, dependence of the sensitivity on ambient temperature.

Among the solid detectors, the diamond detectors are the most similar to the ionizing chambers as the carbon atomic number is close to the effective atomic number of air and biological tissue.

The clinical dosimeter DKDa-01-”IPTP” based on the natural diamond detector [1] was developed at the Institute in Physical and Technical Problems with the purpose of absolute and relative measurements in radiotherapy beams.

The known properties of natural diamond detector provide high registration sensitivity, high radiation resistance and independence of the sensitivity on temperature, pressure.

The small sensitive volume of the detector (1–6 mm$^3$) allows measuring relative dose distributions with high spatial resolution.

**TABLE 1. BASIC SPECIFICATIONS OF THE DOSIMETER**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement range of photon, electron, and proton absorbed dose rate, Gy/s</td>
<td>0.001–1.0</td>
</tr>
<tr>
<td>Recorded energy range, MeV:</td>
<td></td>
</tr>
<tr>
<td>- for photos</td>
<td>0.08–25</td>
</tr>
<tr>
<td>- for electrons</td>
<td>4–25</td>
</tr>
<tr>
<td>Limit of basic tolerable measurement error, %</td>
<td>±2</td>
</tr>
<tr>
<td>Energy dependence of recording sensitivity, %</td>
<td>±2</td>
</tr>
<tr>
<td>Preliminary radiation dose, Gy</td>
<td>≤10</td>
</tr>
<tr>
<td>Detector radiation resource, Gy</td>
<td>$10^7$</td>
</tr>
<tr>
<td>Thickness of the detector sensitive volume, mm</td>
<td>0.1–0.4</td>
</tr>
</tbody>
</table>
If calibrated in terms of absorbed dose to water in a Co-60 beam, the clinical dosimeter DKDa-01-"IPTP” provides determination of the absorbed dose to water of photon and electron beams in the radiotherapy dose rate and energy ranges without any additive corrections usually required during the ionizing chamber measurement. The relative error of these dose determinations is within ±2% that includes inherent features of the natural diamond detector (small energy dependence and dose rate dependence).

The clinical dosimeter DKDa-01-"IPTP” was tested for the absolute measurements of proton radiation dose rate in the medical phasotron beam at the Joint Institute for Nuclear Research (JINR, Dubna). At the beginning, the dosimeter was calibrated in terms of absorbed dose to water against the secondary standard of gamma radiation absorbed dose to water (Co-60). The measurements were carried out at different proton energies in the range from 80 to 200 MeV. Comparison of the results obtained with the diamond detector dosimeter and the results of dose determination using the standard ionizing chamber and TRS 398 dosimetry Code of Practice has shown the differences in the measured absorbed dose within 1.8 %.

The possibility of the quality control checks with the clinical dosimeter has been investigated in the clinical practice of the Central Research Institute of Roentgenology and Radiology for the periodic checks of ELEKTA PRECISE medical linear accelerator and PRECISE PLAN 3D treatment planning system.

The following QA tests recommended by ESTRO [2] were implemented and performed:

– Check of output factors for X ray and electron beams,
– Check of wedge factors,
– Check of bolus, block and tray insertion factors,
– Verification of calculated dose in the selected points in the phantom with inhomogeneities.

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*Radiation Imaging*
INTERVENTIONAL RADIOLOGY
Quality assurance programmes in diagnostic radiology involve a system of quality control checks on the imaging equipment to ensure that images of sufficient clarity for the diagnostic task are obtained every time, and regular patient dose assessments to ensure that the radiation risks to the patient are minimized. Patient dose assessments are particularly important with modern digital imaging equipment where exposure factors are selected automatically and the appearance of the image provides no indication of the dose levels used to obtain it. Whereas radiologists subjectively assess the adequacy of their images every time they report on them, they cannot intuitively assess the patient dose. Which is why it is so important to have a system for alerting radiology practitioners when the radiation doses that they are using for a particular examination become unusually high.

The concept of diagnostic reference levels (DRLs), as a simple indication of unusually high doses, has evolved from work in the USA, UK and Europe over the past 30 years. The concept became recognized internationally by the ICRP in Publications 60 (1991) and 73 (1996) and by the IAEA, as ‘guidance levels’, in its Basic Safety Standards published in 1994. In 1997, the requirement for Member States of the European Union to establish and use DRLs for patient dose management was written into the EC Medical Exposure Directive.

Most countries have adopted the approach of setting DRLs at the third quartile values of the distributions of doses observed for a particular X ray examination on representative samples of patients in national patient dose surveys. In subsequent local surveys, hospitals finding that their mean dose for a particular examination exceeds the national DRL, should investigate the reasons why they are in the top quartile and if they can find no clinical justification for using such high doses, should take corrective action to reduce them. The investigation and consequent corrective action will involve a detailed analysis of the quality control checks on the imaging equipment that should already be in place, as well as a study of how the equipment was being used in comparison with national and international guidelines on good practice.

National DRLs are usually set by appropriate national authorities in collaboration with the professional medical bodies involved in diagnostic radiology. They should be reviewed at intervals that represent a compromise between the necessary stability and long term changes in observed dose distributions. National reference doses have been reviewed three times over the past 20 years in the UK and it is interesting to observe the trends in patient doses over that period.

Table 1 shows the third quartile values of the mean entrance surface doses (ESD) or mean dose-area product values (DAP) used by each hospital for the types of radiograph or X ray examination that have appeared in all three UK reviews [1].
TABLE 1. THIRD QUARTILE VALUES FROM 3 REVIEWS OF UK NATIONAL PATIENT DOSE DATA SINCE THE MID-1980S

<table>
<thead>
<tr>
<th>Radiograph or Examination</th>
<th>Rounded third quartile values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-1980s</td>
<td>1995</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>Survey</td>
<td>Review</td>
<td>Review</td>
</tr>
<tr>
<td>ESD per radiograph (mGy)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull AP/PA</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Skull LAT</td>
<td>3</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>Chest PA</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Chest LAT</td>
<td>1.5</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>Thoracic spine AP</td>
<td>7</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>Thoracic spine LAT</td>
<td>20</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Lumbar spine AP</td>
<td>10</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Lumbar spine LAT</td>
<td>30</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>Lumbar spine LSJ</td>
<td>40</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>Abdomen AP</td>
<td>10</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Pelvis AP</td>
<td>10</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>DAP per examination (Gy cm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVU</td>
<td>40</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>Barium meal</td>
<td>25</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Barium enema</td>
<td>60</td>
<td>35</td>
<td>31</td>
</tr>
</tbody>
</table>

There has been a continuing reduction of these values with time, for nearly all types of radiograph. The average reduction between 1995 and 2000 has been about 20% and they have approximately halved in the 15 years since the original survey in the mid 980s.

This substantial reduction in patient doses has been possible because of increases in the sensitivity of imaging equipment (e.g. the introduction of rare-earth intensifying screens and sodium iodide phosphors in image intensifiers) and the exploitation of dose-saving techniques (e.g. the use of higher tube voltages, additional filtration and tighter beam collimation). However, it is doubtful whether these would have been implemented so quickly and so widely if it were not for the raised awareness of patient doses and how they compare with national and international norms that was brought about by the adoption of DRLs.

Now that film-screen radiography and sodium iodide image intensifiers are being replaced by digital imaging systems, DRLs will play an increasingly important role in ensuring that the benefits of these new imaging modalities are not achieved at the expense of an unacceptable increase in patient doses.

REFERENCE

Acceptance testing and QA in interventional cardiology


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Introduction. Interventional radiology has seen rapid growth in the field of cardiology over the past decade. This growth has been facilitated by advances in imaging technology and the development of increasingly sophisticated dedicated radiological equipment [1,2]. Interventional cardiology (IC) procedures are complex and may involve prolonged irradiations, which may subject patients and operators to higher levels of risk than those, which normally prevail [1–4]. Currently interventional cardiology contributes over 10% to annual collective dose in the UK in spite of contributing to a total annual frequency of 0.68%. [4]. The EU Medical Exposures Directive, 97/43/Euratom, identifies interventional radiology as an area of special concern [5].

Acceptance testing and routine quality assurance (QA) programmes are particularly important in the field of interventional cardiology given the above. The requirements for acceptance testing and QA are underpinned in the EU Medical Exposures Directive and consequent national legislation.

Methodology. A QA survey of 16 interventional cardiology systems in Ireland was carried out by the Department of Medical Physics and Bioengineering, St. James’s Hospital, Dublin. This is the continuation of a recently published survey [6] and represents over half of the interventional cardiology systems in Ireland including new technology digital flat panel systems and dedicated mobile equipment in trailers.

Acceptance testing and QA protocols were developed and reviewed in accordance with current international and national guidelines, standards and literature [7–10]. Testing included assessing the performance of the X ray tube and generator, the automatic exposure control (AEC) device in fluoroscopy and digital acquisition modes and a subjective assessment of image quality using the Leeds test objects. Radiation shielding calculations and measurements were performed to determine the structural shielding required by new installations and electrical, mechanical and general radiation safety was also assessed.

In addition to the above, dose area product (DAP) measurements were recorded in some centres to aid in the establishment of European Diagnostic Reference Levels as part of the EU SENTINEL research programme.

Results. Sample results are presented below. These include the measured detector entrance dose rates for a range of systems tested using the pulsed fluoroscopy setting (12.5/15 pulse/s) (Fig. 1) and the patient entrance dose rates on the same setting (Fig. 2).
Detector entrance dose per exposure and patient entrance dose per exposure in the digital acquisition modes are presented in Figs 3 and 4.

**FIG. 1. Detector entrance dose rates.**  
**FIG. 2. Patient entrance dose rates.**

**Discussion.** In summary, a significant range of problems were identified during acceptance testing. In addition, it is evident from the results that the AEC detector entrance dose rates and patient entrance dose rates are manufacturer dependent with no perceived improvement in image quality for the higher dose systems using the standard accepted subjective test objects. This is consistent with the findings of the previous study demonstrating the need for revised equipment standards in the area [6].

Several issues relating to DAP meters were identified and, in general, it was found that the DAP meters were not calibrated to the radiology systems in question.

**Conclusions.** The results of this study are consistent with the findings of previous commissioning surveys by the authors [6]. Problems were identified with all radiological systems commissioned, with up to 50% of systems demonstrating significant problems. This emphasizes the importance of commissioning radiological equipment and interventional cardiac equipment, in particular, given the associated levels of risk [1–5]. The results also demonstrate the importance of including electrical safety testing in a commissioning programme.

**ACKNOWLEDGEMENT**

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**REFERENCES**


Technical factors influencing patient received dose in interventional cardiology

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France

Interventional cardiology is widely recognized as a radiological practice likely to be leading to high level of patient skin dose thus requiring a particular attention to radiation protection aspects [1]. There are several technical factors which may be considered as to influencing the patient exposure, their knowledge is an essential part of any quality assurance programme since it can contribute to the improvement of such a medical practice from the radiological protection point of view.

Within this context a patient dosimetry study was carried out in 2005 in France by the INVS in collaboration with CAATS to assess skin doses received by patients during either diagnostic or therapeutic coronary procedures performed at the Saint Gatien Clinic of Tours.

About 170 patients examined on the same installation (Philips Integris Allura 9C) were included in the study, 20% woman and 80% men. Among them, 50 patients underwent a diagnostic cardiac angiography examination and 120 were addressed for a PCTA procedure. Very few examinations (less than 10%) were simultaneously dealing with diagnostic and therapeutic aspects (angiography + angioplasty). Three different cardiologists took part in the study, each one of them dealt with an equivalent number of patients, i.e. almost 50 patients each.

As far as the patient skin dosimetry is concerned, a GafChromic XR type R film put on the table top close to the patient’s back was used to directly measure this dosimetric quantity during each procedure. At the same time, all the relevant physical parameters which are likely to influence the patient received dose were recorded: DAP values (fluoroscopy and cine modes) kV, field size, focus to detector distance, I.I. diameter, number of images, frame rate, fluoroscopy time, X ray beam geometry, etc. Some additional parameters were also collected in order to better analyse the dosimetry results: patient morphology, type of pathology, number of occluded arteries, number and type of stent used during the procedure.

Beyond allowing a comparison to be made between dosimetric reference values and the actual on-site results in terms of DAP, fluoroscopy time and number of images, the study enabled us to better explore the major component upon which the patient dose might depend: the equipment settings, the way of using the equipment and the complexity of the procedure.

Table 1 illustrates the variation of the average patient peak skin dose among the cardiologists for the categories of procedures considered. All examinations together, a factor of two in dose can be noticed from the lowest average value to the highest one; the angioplasty procedures being the most irradiating technique.
TABLE 1. AVERAGE PATIENT PEAK SKIN DOSE (mGY) BY OPERATOR AND BY TYPE OF PROCEDURE

<table>
<thead>
<tr>
<th>Operator</th>
<th>C</th>
<th>A</th>
<th>C+A</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>450 (17)</td>
<td>1390 (24)</td>
<td>1450 (6)</td>
<td>1060 (47)</td>
</tr>
<tr>
<td>C2</td>
<td>221 (14)</td>
<td>622 (47)</td>
<td>387 (5)</td>
<td>516 (66)</td>
</tr>
<tr>
<td>C3</td>
<td>521 (15)</td>
<td>1080 (35)</td>
<td>645 (5)</td>
<td>886 (55)</td>
</tr>
<tr>
<td>All</td>
<td>404 (46)</td>
<td>951 (106)</td>
<td>867 (16)</td>
<td>951 (168)</td>
</tr>
</tbody>
</table>

(*) Associated number of procedures in (); C = cardiac angiography; A = cardiac angioplasty.

As already mentioned there are technical factors which can help to explain the observed differences among the practitioners; these are detailed in table 2. As it can be seen, the percentage of use of the beam collimation may significantly vary among the cardiologists, the total number of frames per examination spans by a factor of two among them and the use of high acquisition frame rate may markedly range from one cardiologist to another.

TABLE 2. CHARACTERISTICS OF EQUIPMENT USED BY CARDIOLOGIST (ALL INTERVENTIONS)

<table>
<thead>
<tr>
<th>Operator</th>
<th>Beam collimation</th>
<th>Number of frames</th>
<th>Frames/sequence</th>
<th>Cine frame rate</th>
<th>Cine mode</th>
<th>I.I. diameter [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12,5 fr/s</td>
<td>25 fr/s</td>
<td>STD* HI**</td>
</tr>
<tr>
<td>C1</td>
<td>19,4 %</td>
<td>988</td>
<td>73</td>
<td>89%</td>
<td>11%</td>
<td>93%</td>
</tr>
<tr>
<td>C2</td>
<td>80,9 %</td>
<td>611</td>
<td>39</td>
<td>96%</td>
<td>4%</td>
<td>66%</td>
</tr>
<tr>
<td>C3</td>
<td>45,8 %</td>
<td>1179</td>
<td>75</td>
<td>62%</td>
<td>38%</td>
<td>84%</td>
</tr>
</tbody>
</table>

(*) STD : standard mode (**) HI : high dose mode.

In order to illustrate the obtained results exclusively for the angioplasties, the peak skin doses were plotted against the DAP measured values for each cardiologist. There was no significant correlation between the two considered parameters (r = 0.5), the maximum measured skin dose was higher than 4Gy and about 5% of the examinations led to a peak skin dose higher than 2 Gy.

FIG. 1. PTCA Patient peak skin dose as a function of the DAP (N=104).

REFERENCE

Patient dose surveys: Improving and utilizing the data

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The collection of patient dose data is important for the establishment of, and comparison with, diagnostic reference levels (DRLs) and for optimization of radiation dose and risk to the patient. In many countries these are now legal requirements. In the north of England a regional patient dosimetry programme has been maintained and developed for over ten years, and currently records around 25 thousand doses per year. The experience gained has enabled a number of improvements in the quality of the data obtained and in the way in which it is presented to, and used by, radiology staff to ensure compliance with the regulations.

One of the most important aspects of fluoroscopic data collection is the examination specification. Some similar procedures may be significantly different in terms of dose, for example nephrostogram and nephrostomy examinations, and if not distinguished may lead to artificial differences between departments, or to difficulties in complying with DRLs. This problem is likely to be compounded if making comparisons between centres in different countries when translation discrepancies may also occur, and protocols may be very different. Terminology needs to be standardized and checked with individual centres. Validity checks also have to be made on all data to ensure that typographical errors or incomplete examinations are excluded.

Sample sizes are critical in order to make meaningful comparisons of data and as the complexity of procedures increases the sample size should go up correspondingly, so that results are not influenced by the complexity of individual patient examinations. One important method of improving sample statistics is to apply size correction factors to the data so that all patient examinations can be utilized, rather than just those for patients close to standard size. This is particularly important for paediatric examinations. A previously developed method of size correction [1] has been extended to incorporate a wide range of more modern X ray equipment and examination specific programmes. The experimental methodology consisted of observing the variation in dose area product (DAP) with tissue equivalent thickness, while performing either fluoroscopy or digital image acquisition on clinically used programmes. Fig. 1 shows results for a Philips Integris Allura, using five different programmes –2 fluoroscopy settings and 3 digital acquisition modes. The slopes of the graphs vary between 0.10 and 0.20, and give values for the variable, k,[1] used in the exponential size correction factors specific to this room.

Application of these size correction factors to routinely collected DAP data can be demonstrated to significantly reduce the dose variability due to patient size, and all valid patient data can be used in the initial setting of appropriate DRLs and further comparisons with them.
DAP data for complex examinations are routinely reported to individual departments, according to individual operator, with an annual report summarizing results for all centres. Current national and regional DRLs are indicated on the graphs for comparison. All data are stored electronically and the database is linked to that for equipment QA, to aid in interpretation of anomalous results. An example of this was observation of high doses, usually close to or above the national DRL, for peripheral angiography examinations in one particular department, which linked to above average measurements of image acquisition dose on annual QA. The combined report of these measurements enabled local radiology staff to initiate dialogue with the appropriate engineers and resulted in adjustment of the equipment to give doses reduced by around 30%, without significant loss in image quality. This highlights how the routine provision of high quality patient dose data can be a fundamental tool in the optimization strategy of an X ray department.

REFERENCE

Patient and staff exposure during cardiac catheterization

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Radiation doses from 159 patients have been studied, 101 of which had undergone coronary angioplasty (CA) and 58 percutaneous transluminal coronary angioplasty with stenting (PTCA-ST). All procedures were undertaken on a biplane angiocardiographic system. The system performed under automatic exposure control using continuous fluoroscopy and cine frame rate of 12.5 frames s\(^{-1}\). The result of the entrance surface dose (ESD) on the forehead and neck of a cardiologist underwent CA/PTCA-ST procedure was given in Table 1. Dose–area product values and fluoroscopy times were collected for each patient. Median values for dose–area product were 39.3 Gy cm\(^2\) for CA and 146.7 Gy cm\(^2\) for PTCA-ST. Median fluoroscopy time was 3.8 min and 17.7 min for CA and PTCA-ST, respectively. Comparison of our results with results found in the literature (Tables 2 and 3) showed that during CA; Van et al [1], Broadhead et al [3], Zorzetto et al [4] and Tsapaki et al [5] had higher DAP values but Padovani et al [2] had slightly lower DAP values owing to lower fluoroscopy times (28%). During PTCA-ST, DAP and T values in the literature for PTCA were lower than ours. Except Van De Putte et al [14] reported, mean DAP was 8% higher but for 3\(^{rd}\) quartile DAP was 14.7% lower than our report. The higher DAP and T values in our report for PTCA-ST can be explained by the fact that it is a therapeutic procedure that depends on the pathology of the patient. Padovani et al [7] found an increase of about 50% in radiation dose for medium complex procedures and an increase of 100% for complex procedures. However, these comparisons may have limited value, as in recent years a considerable effort has been made in Europe to improve radiation protection of the patient in interventional procedures through optimization programmes and technical improvement of the X ray systems. It is recommended that, continuous monitoring of patient radiation dose should be encouraged, not only for patient safety, but also for the staff involved.

**TABLE 1. DATA ON ENTRANCE SURFACE DOSE (ESD) TO THE EYE AND OF CARDIOLOGIST PER CA OR PTCA-ST PROCEDURE**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Sample size</th>
<th>Range</th>
<th>Mean ± SD</th>
<th>1(^{st}) quartile</th>
<th>Median</th>
<th>3(^{rd}) quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>Eye</td>
<td>129.1-267.4</td>
<td>218.7 ± 55.2</td>
<td>168.9</td>
<td>253.9</td>
<td>261.7</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>158.6-272.8</td>
<td>227.4 ± 52.5</td>
<td>170.7</td>
<td>261.0</td>
<td>270.6</td>
</tr>
<tr>
<td>PTCA-ST</td>
<td>Eye</td>
<td>65.8-291.6</td>
<td>211.2 ± 96.1</td>
<td>150.0</td>
<td>264.5</td>
<td>267.8</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>163.1-281.4</td>
<td>232.2 ± 52.6</td>
<td>188.5</td>
<td>256.5</td>
<td>266.5</td>
</tr>
</tbody>
</table>

SD-standard deviation.
TABLE 2. COMPARISON OF THIS STUDY WITH RECENT LITERATURE, IN CORONARY ANGIOGRAPHY

<table>
<thead>
<tr>
<th>Author</th>
<th>N</th>
<th>DAP (Gycm²)</th>
<th>T (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>This study</td>
<td>101</td>
<td>42.4</td>
<td>19.8</td>
</tr>
<tr>
<td>Vano [1]</td>
<td>288</td>
<td>66.5</td>
<td></td>
</tr>
<tr>
<td>Padovani [2]</td>
<td>13</td>
<td>39.3</td>
<td>18.0</td>
</tr>
<tr>
<td>Broadhead [3]</td>
<td>2174</td>
<td>57.8</td>
<td></td>
</tr>
<tr>
<td>Zorzetto [4]</td>
<td>79</td>
<td>55.9</td>
<td></td>
</tr>
<tr>
<td>Tsapaki [5]</td>
<td>195</td>
<td>47.3</td>
<td>27.9</td>
</tr>
</tbody>
</table>

N-number of patients; DAP-dose-area product; T-fluoroscopy time; F-total number of cine frames; SD-standard deviation.

TABLE 3. COMPARISON OF THIS STUDY WITH RECENT LITERATURE, IN PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY (PTCA)

<table>
<thead>
<tr>
<th>Author</th>
<th>N</th>
<th>DAP (Gycm²)</th>
<th>T (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>This study</td>
<td>58</td>
<td>152.4</td>
<td>82.1</td>
</tr>
<tr>
<td>Vano [1]</td>
<td>45</td>
<td>87.5</td>
<td></td>
</tr>
<tr>
<td>Padovani [2]</td>
<td>54</td>
<td>101.9</td>
<td>84.9</td>
</tr>
<tr>
<td>Broadhead [3]</td>
<td>214</td>
<td>77.9</td>
<td></td>
</tr>
<tr>
<td>Zorzetto [4]</td>
<td>31</td>
<td>91.8</td>
<td></td>
</tr>
<tr>
<td>Tsapaki [5]</td>
<td>97</td>
<td>68.0</td>
<td>48.7</td>
</tr>
<tr>
<td>Van De Putte [6]</td>
<td>165.9</td>
<td>131.6</td>
<td>185.8</td>
</tr>
</tbody>
</table>

N-number of patients; DAP-dose-area product; T-fluoroscopy time; F-total number of cine frames; SD-standard deviation.

REFERENCES

Optimization of radiation protection in pediatric cardiac catheterization procedures

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Cardiac catheterization is among the interventional radiology procedures considered to give high doses to adult and pediatric patients. However, almost every year, the number of pediatric patients undergoing these procedures tends to increase. The King Faisal Specialist Hospital & Research Centre (KFSH&RC) is a tertiary level medical center in Riyadh, Kingdom of Saudi Arabia with a 600 bed capacity. Diagnostic X ray procedures (radiography and fluoroscopy) average to about 150,000 annually. Pediatric cardiac catheterization procedures average to about 2,000 cases annually. Due to the limited published data on radiation doses to pediatric patients undergoing these procedures, a study was conducted to assess the doses in pediatric patient undergoing cardiac catheterization procedures and to determine the factors contributing to high doses. Patient and occupational doses during interventional procedures depend on procedure type, fluoroscopy time, number of images, equipment performance and training of the interventionist [1].

KFSH&RC has four X ray rooms in its Cardiac Catheterization Laboratory. There is only one X ray room that is dedicated for pediatric procedure and it was selected for the study. This room is equipped with a Siemens Bicor + biplane X ray unit with HVL of 3.5 mm Al each for the two X ray tubes. The equipment geometry allows the system to have X ray beams in the vertical, horizontal and oblique directions. The system has a built-in DAP meter. Data on quality control tests and DAP calibration performed by the in-house biomedical engineer of Siemens was retrieved. The DAP calibration data supplied by the engineer were verified using a Diamentor M1 (PTW, Freiburg, Germany) DAP meter and following the NRPB protocol. Results of the quality control tests on the X ray machine generator were investigated.

The dose area product values from records of pediatric patients in the age groups of 0 (neonates), 1, 5 and 10 years on four common procedures were used in the dose assessment. The procedures considered in the study are: diagnostic, pulmonary stenting, COA dilatation and PDA occlusion. The average of the total dose area product (DAP) value per procedure was determined and the factors that affected the DAP were investigated. The cumulative dose (CD) of each patient and the effective dose were estimated from the DAP values corrected for patient size. The Pearson correlation of the DAP values with patient equivalent cylindrical diameter (ECD), weight and fluoroscopy time was determined and evaluated.

The study shows that the exposure parameters (kVp, mA and fluoroscopy time) and the contribution of cineradiography affected the total DAP values. The calibration of kVp and the timer have contributed in the dose reduction. The estimated average effective doses obtained for each group showed that the neonate doses are 50% less than the dose of one year old age group and this is due to the low exposure factors used for neonates. The five year old age group obtained the highest average effective dose of about 4 Sv. The mA, fluoroscopy time and the dose of patient due to cineradiography contribute to the high average dose of 2,851 cGy-cm² for PDA occlusion. Although COA dilatation procedure has the shortest average time (16.6 min), the high dose of 1,765 cGy-cm² is due to the high kVp and mA for...
fluoroscopy and to the contribution of cine radiography. The five year age group obtains the highest DAP and effective dose. The primary cause of this high dose is the cineradiography dose of one patient and about 60% underwent either PDA or COA interventional procedures. This study shows that PDA and COA are high dose procedures (Fig. 1) that could approach and exceed the threshold dose for skin deterministic effects and that fluoroscopy time alone cannot be used as an indicator of individual doses because of the contribution of cineradiography.

The routine quality control tests of the generator and the X ray machine output measurement should be closely considered in the evaluation for dose reduction. The use of longer fluoroscopy time for complex procedures should be investigated. A review of the training needs of operators is an essential component for the radiation protection programme in interventional radiology. Although the patient entrance skin dose will be less than the estimated CD due to the 30 to 40% uncertainty in DAP [2], it is expected to approach the value of 2 Gy. The ICRP recommendation of recording the dose data in a patient's record when the maximum skin dose is estimated to be 3 Gy or greater (1 Gy or above for procedures likely to be repeated) should be implemented. It is important for dose reduction that procedures and doses of neonates be monitored [3].

FIG. 1. Measured ECD of Saudi children and the standard NRPB value. FIG. 2. Mean dose-area product values for each pediatric cardiac catheterization procedure.

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Basic QC to support a national survey on patient dosimetry in interventional radiology

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A national survey on patient dose in interventional radiology was launched during 2005 by the Spanish Society of Vascular and Interventional Radiology (SERVEI) under the coordination of the Complutense University of Madrid. Ten hospitals distributed around Spain from six different Autonomous Communities were included. A chief interventional radiologist and a medical physicist were appointed to take the responsibility to gather data from the different centres.

The agreed objectives of the survey allowed obtaining representative results of patient dose values in fluoroscopically guided procedures. Other collateral aspects were also gathered to profit from the effort of the survey and to promote the interest of the interventionalists (e.g. performance of the X ray systems involved, staff doses for the different procedures, image quality and diagnostic information, amount of contrast agent injected to the patients, protocol of the procedures, DICOM implementation levels in the different X ray systems, etc). The medical society SERVEI expects to offer to its members at the end of the project a set of dose
values representative of good interventional practice and a practical guideline to optimize the interventional procedures.

The goodness of any patient dose survey requires a strong quality control programme of the X ray systems involved, including calibration of the ionization transmission chambers. The survey included the following systems: 6 Philips, 2 Siemens, 1 GE and 1 Toshiba. Supervision of the received dose data to avoid mistakes that could distort the results has also been included. In our case, and in addition to a possible complete characterization of the X ray systems, a measurement has been proposed of the entrance surface air kerma rate for the different fluoroscopy modes for a field size of 22 cm and for a PMMA thickness of 20 cm in the typical geometry used in clinical procedures. Also, the dose per acquired image in the most common operation modes has been tested. The correction factor for the dose area product (air kerma area product) meter, when the table and the mattress attenuation is included, has also been measured. If the system displayed the cumulative dose (CD), a correction factor for this parameter was also obtained in these conditions.

Results of the QCs allowed to properly compare the set of patient dose values reported for the different centres and to derive a provisional set of reference levels. It also allowed detecting some abnormal setting in some of the X ray systems (e.g. the same fluoroscopy dose rate for the low, medium and high modes). QC of the individual patient dose data received from the centres is also a critical point. DAP values are correlated with the number of acquired images and the fluoroscopy time in order to detect some inconsistencies and to correct or eliminate the wrong data.

Calibration factors for DAP range from 0.51 to 1.17. Dose rate values in the different fluoroscopy modes give mean values (and st dev) of: 12.0±6.0; 17.0±6.0 and 26.2±12.3 mGy/min.

Median dose values for the selected diagnostic procedures (fistulography, lower limb arteriography and renal arteriography) are 3.7; 61.0 and 39.1 Gy.cm$^2$ respectively. For therapeutic procedures (biliary drainage, hepatic chemoembolization and iliac stent) median values are: 23.7; 181.7 and 56.7 Gy.cm$^2$, respectively. The large range in median dose values for some procedures between the different centres can not be justified by the complexity of the procedures or the size of the patients. Thus first results of the survey suggest a certain margin for optimization.

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Patient doses assessment in diagnostic radiology: Preliminary guidance levels in Madagascar (GLs)

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Entrance skin dose (ESD) is one of the basis dosimetric quantities for measuring the patient dose and, hence, an excellent tool for optimization purposes and for comparison with the international reference values. ESD measurement for a patient is also an essential component of a Quality Assurance Programme for individual X ray Department.

The International Basic Safety Standard (BSS 115) for Protection against Ionizing Radiation and for the Safety of Radiation Sources, published by the IAEA in 1996, requires that guidance levels (GLs) for medical exposure shall be established and these are intended to give reasonable indication of doses for averaged patients.

In Madagascar, dose delivered to the patients assessment undergoing different X ray procedures was planned in 2005 under the project RAF/9/033 entitled “Strengthening Radiological Protection of Patients and Control of Medical Exposure”. We performed a pilot study to develop a protocol for dose assessments and for establishing national guidance levels. For this purpose, one private hospital and two public hospitals were selected.

In this study, ESDs were performed for the most common types of X ray examination. The main investigated types are: chest PA, abdomen, Lumbar Spine PA and LAT, and skull.

Patient data including exposure parameters were collected during two weeks. For this purpose, 250 patients were selected for each of the hospital 1 and 3, and 110 for hospital 2 (private).

ESD assessments were conducted by measuring air kerma under standardized conditions. Air kerma was measured with the dosimeters of type Radcal and Radcheck. The dosimeters were calibrated at the Secondary Standard Dosimetry Laboratory of Institut National des Sciences et Techniques Nucléaires (Madagascar – I.N.S.T.N), using an X ray machine with characterized qualities. The machine output expressed in mGy/mAs was derived from air kerma. The ESD for each examination was calculated from the machine output by taking into account of the Back Scatter Factor, the exposure parameters and the focus patient distance.

Before measurements of the air kerma, quality control tests were carried out on each radiological equipment used for the examinations.

The average calculated ESD for each examination and the international guidance levels (GLs) recommended by the IAEA are listed in Table 1.
The results show that there is a large variation of patients doses for common examination in different hospitals. From this preliminary study, it was derived that the obtained values can be useful for establishing national guidance levels and for implementation in the regulation concerning the patient protection from medical exposure.

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QA in interventional cardiology: The lessons learned

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\textbf{Purpose.} This presentation describes the methodology, shows the results and analyse the difficulties presented during implementation of the QA programmes in two Interventional Cardiology (IC) Centers of Uruguay in the context of an IAEA coordinated research project that explored the possibility of establishing guidance levels for interventional radiology procedures.

\textbf{Materials and methods.} First, cardiologists, technicians and nurses received specific information about the QA programme. X ray system tests methodologies were based on the DIOND European Research Project. Characterizations were performed of the two X ray systems (Picker CV-PRO-1997- and Philips Integris 3000-1995). In clinical conditions (with couch and mattress), for all image intensifier diameters and all fluoroscopy and cine modes, Kerma rate and Kerma per frame (entrance patient dose) were measured with an ionization chamber (10×5–6 E, Radcal) at the entrance of four Plexiglas (PMMA) phantom thicknesses (16, 20, 24 and 28 cm). Simultaneously, spatial resolution and low contrast were evaluated at clinical distance to the monitor by a cardiologist and a physicist, using TOR [\textsuperscript{18}FG] Leeds plate located in the center of the PMMA phantom and in the isocenter of the C-arm [1]. In the same conditions, but for 10, 20 and 30 cm PMMA thicknesses, Kerma rate and Kerma per frame and image quality were studied with NEMA phantom (Standard XR21-2000) [2]. Constancy tests were performed with Leeds object test using 4 mm Cu attenuators and Leeds image plate [3].

\textbf{Results and analysis.} Kerma rates and Kerma per frame for the same conditions (geometry, cine or fluoroscopy modes, dose modes, image intensifier diameter, FOV and PMMA thickness) were different for each X ray system. As can be seen in Table 1, values are high in the Philips unit. However, direct (subjective) observation of low and high contrast details of the Leeds test showed similar results (Table 1). That would require objective evaluation (MTF, noise, contrast and SNR), but they consume more time. Differences in Kerma rate and Kerma per frame are probably due to a difference in HVL (3.7 mm Al in Philips and 5.4 mm Al in Picker), and to the difficulty in reproducing exactly the same geometry (distance between X ray source and PMMA phantom entrance, and distance between image intensifier and PMMA phantom). When Kerma rates at the entrance of image intensifiers were determined, it was found that values are also higher in the Philips unit than in Picker unit, maintaining similar relation values obtained during the characterization (and shown in Table 1). It was also found that, in the same conditions, Kerma rate and Kerma per frame increased between 25 and 35% when Leeds test was used (located in the center of PMMA phantom and at the isocenter of the C-arm). Differences are probably due to the presence of lead in spatial frequency evaluation pattern of the Leeds test. It is important to note that ionization chamber location in relation with CAE device, may introduce another factor in Kerma readings. Finally, Kerma rates and Kerma per image determined using Leeds and NEMA test were similar, as can be seen for 20 cm PMMA thickness in Figs 1 and 2.

\textbf{Conclusions.} Kerma should be obtained with no image test object inside PMMA phantom, or the contribution of image test object in Kerma should be taken into account in order to evaluate
entrance patient dose. Relating to image quality evaluation, despite the fact that NEMA test was manufactured simulating clinical conditions (iodine contrast to evaluate low contrast), low contrast steps do not allow an easy differentiation between X ray systems. So, its use may not be recommended for routine tests. Characterization results should be given and explained to cardiologists and technicians due to its influence in patient dose. Besides, cardiologists should be encouraged to participate in high and low contrast evaluation since they establish, every day, operation modes of the X ray system. Geometry set-up for all the tests (characterization and constancy) required a deep knowledge of the X ray systems. Then, professionals who will perform them should be made aware that at the beginning some tests may need to be repeated. Communication between professionals of other centers or countries that have experience in these tests is an essential tool to guarantee the results, because they should allow cardiologist the knowledge of the X ray equipment operation modes to optimize the practice, the goal of a QA program.

TABLE I. CHARACTERIZATION OF BOTH X RAY SYSTEMS FOR 24 CM PMMA FOR DIFFERENT IMAGE INTENSIFIER DIAMETERS AND FLUOROSCOPY MODES

<table>
<thead>
<tr>
<th>X ray system</th>
<th>Image intensifier diameter (cm)</th>
<th>Fluoroscopy mode</th>
<th>Kerma rate (mGy/s)</th>
<th>Low contrast (number of circles)</th>
<th>High contrast (spatial requery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picker CV-RO</td>
<td>14 High (15 /s)</td>
<td></td>
<td>0.79</td>
<td>12</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>18 High (15 /s)</td>
<td></td>
<td>0.61</td>
<td>11</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>21 High (15 /s)</td>
<td></td>
<td>0.49</td>
<td>11</td>
<td>1.25</td>
</tr>
<tr>
<td>Philips Integris</td>
<td>14 High (12.5 /s)</td>
<td></td>
<td>2.80</td>
<td>14</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>17 High (12.5 /s)</td>
<td></td>
<td>2.30</td>
<td>14</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>23 High (12.5 /s)</td>
<td></td>
<td>1.87</td>
<td>11</td>
<td>1.25</td>
</tr>
</tbody>
</table>

FIG. 1. Philips X ray system. Kerma per frame for different PMMA thickness and image intensifier diameters, measured with NEMA located in the middle of the PMMA phantom and in the isocenter of the C-arm.

FIG. 2. Philips X ray system. Kerma per frame for different PMMA thickness and image intensifier diameters, measured with Leeds test.

REFERENCES

Assessment of the level of optimization of the interventional cardiology practice – The Sentinel Project

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Interventional cardiology procedures are the most frequent fluoroscopy image guided invasive procedures. In Europe there is a continuous increase in procedure frequency but also large variability in practice between countries. For example: pacemaker implant frequency range from 200 to 1000 per million of inhabitants per year and, coronary angioplasty (PTCA) from 200 to 2500. Cardiac interventional procedures are frequently complex, requiring an extensive use of fluoroscopy which, coupled with the acquisition of a large number of images, has the consequence that patient and staff doses can be high [1, 2]. In addition the same patient can be submitted to multiple procedure in a short period of time [3].

In recent years a research group, in the context of the European research projects (Dimond III and SENTINEL) is developing methodologies to assess the optimization level of the interventional cardiology practice, including methods for image quality evaluation [4], establishment of reference (guidance) levels [5], assessment of angiography equipment performance. The content of the DICOM header of the archived images and the dose report are also relevant in the evaluation of the X ray systems [6]. These methodologies have been also successfully applied in IAEA coordinated research projects in some countries in South America and Asia.

In addition to the standardized acceptance tests, a methodology to characterize the X ray systems has been adopted. Entrance surface air kerma rate and image quality of a test phantom for fluoroscopy and acquisition modes are measured for 16, 20, 24 and 28 cm of PMMA, allowing to optimize the clinical procedures with the knowledge of the dose increase for improving image quality and detecting some abnormal setting of the X ray systems. The calibration of the KAP meters, including the attenuation of the table, is also included.

The methodology has now been applied in the SENTINEL project that includes partners from 20 European countries. Data collection, completed in April 2006, comprises: (i) collection of frequency of interventional cardiology procedures, (ii) assessment of equipment performance in a sample of installation, (iii) collection of data on a sample of procedures including patient dose and samples of coronary images. Sample of patient doses will be used to derive a set of
reference (guidance) levels expressed in terms of kerma area product, fluoroscopy time and number of acquired images. The sample of images will be submitted for evaluation by a panel of experienced cardiologists, adopting a set of image criteria, derived from DIMOND study. The Dicom header of images will be also analysed for the comparison of the technical parameters adopted in the different centres. As an example, preliminary results available today are showing a large variability of KAP and fluoroscopy time for coronary angiography procedures in five centres (Fig. 1).

![Graph showing variability of patient dose (KAP) and fluoroscopy time in a sample of coronary angiography studies collected in five European centres.](image)

**FIG. 1.** Variability of patient dose (KAP) and fluoroscopy time in a sample of coronary angiography studies collected in five European centres.

The study will provide an overview of the interventional cardiology practice across Europe, together with: (i) a revised set of reference (guidance) levels for cardiac interventional procedures; (ii) an updated set of quality criteria for coronary angiography images; (iii) an overview of the angiographic equipment performance across Europe, with particular emphasis on the performance of the equipment with new dynamic flat panel detectors, and (iv) a revised method for constancy tests for new digital angiography systems.

**REFERENCES**


Patient and staff doses in interventional cardiological procedures

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The purpose of the study is to explore the radiation hazard to patients undergoing interventional cardiological procedures, as well as to study the typical doses to the staff performing the procedures, and to attempt to establish a correlation between them.

The study was conducted in a catheterization laboratory in the National Cardiac Center in Sofia, on an X ray unit BICOR T.O.P. (Siemens, Germany). So far a total of 69 procedures are recorded, of which 51 CA and 18 PTCA; the research is still in progress.

The data collected comprise the total dose area product (DAP) per procedure, DAP in cine and fluoroscopy mode separately, fluoroscopy time (FT), and total number of series (N), as well as clinical data for the patient. For some patients undergoing more complex PTCA procedures the maximum skin dose (MSD) was also assessed.

DAP was measured using a DIAMENTOR E2 (PTW Freiburg) transmission ionization chamber, externally mounted on the tube housing for the purposes of the study. The DAP meter was calibrated on the same X ray unit against a UNIDOS E (PTW Freiburg) dosimeter for different values of the tube voltage ranging between 60 kV and 100 kV for the two available fluoroscopy modes and for the three image intensifier field sizes. MSD was measured using KODAK X-OMAT V X ray films for therapy verification and a matrix of 90 LiF TLD 100 (Harshaw) detectors (30×27 cm; TLDs positioned at 3 cm intervals) attached to it. The TLDs were calibrated free in air at the National SSDL for X ray qualities typical for diagnostic radiology. The X ray films were subsequently calibrated against the TLDs.

The staff doses were evaluated by means of TLDs – a combination of LiF MTS-N (Poland) and CaF$_2$:Dy TLD 200 (Harshaw) was used, positioned on the ankle and the shoulder of the staff. For individual cases supplementary direct measurements with an Unfors EDD-30 personal dosimeter were performed, with sensor attached to the protective collar of the cardiologist in close proximity to the TLD.

Patient dose measurements in terms of DAP, fluoroscopy time and total number of series per procedure are presented in Table 1, separately for CA and PTCA procedures. Data for MSD from the X ray films and TLDs are still in process.

As expected, the results for the three quantities that were recorded for PTCA procedures exhibit higher average, median and 3$^{rd}$ quartile value than those for CA, as well as a broader range of values. This can be attributed to the fact that, even though the results were classified according to the complexity of the procedure, there is still a great dependence on the particular characteristics of the pathology of the patient, which cannot be strictly accounted for. The individual contribution of cine and fluoroscopy mode to the total DAP value was roughly determined to be 0.68 for CA and 0.40 for PTCA. The correlation of DAP with FT and N for CA procedures was found to be clearly weak ($r = 0.64$ and 0.56 respectively). For PTCA procedures while the correlation with N remained feeble ($r = 0.47$), the correlation with FT was relatively good ($r = 0.91$), which to a certain degree is to be expected, given that the dose to patients in PTCA procedures is primarily accumulated in fluoroscopy mode.
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Range</th>
<th>Average</th>
<th>Median</th>
<th>3rd quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$DAP_{tot}$  Gy.cm$^2$</td>
<td>11.42 – 100.86</td>
<td>40.78</td>
<td>35.44</td>
<td>43.55</td>
</tr>
<tr>
<td>$DAP_{fluoro}$ Gy.cm$^2$</td>
<td>3.75 – 50.57</td>
<td>14.44</td>
<td>9.64</td>
<td>17.54</td>
</tr>
<tr>
<td>$DAP_{cine}$ Gy.cm$^2$</td>
<td>6.00 – 70.31</td>
<td>26.86</td>
<td>24.44</td>
<td>32.41</td>
</tr>
<tr>
<td>$FT$, min</td>
<td>1.2 – 11.9</td>
<td>4.8</td>
<td>4.1</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>Number of series</strong></td>
<td>2 – 19</td>
<td>9</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td><strong>PTCA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$DAP_{tot}$  Gy.cm$^2$</td>
<td>9.41 – 324.58</td>
<td>92.82</td>
<td>78.91</td>
<td>141.48</td>
</tr>
<tr>
<td>$DAP_{fluoro}$ Gy.cm$^2$</td>
<td>4.45 – 281.18</td>
<td>61.82</td>
<td>48.36</td>
<td>90.71</td>
</tr>
<tr>
<td>$DAP_{cine}$ Gy.cm$^2$</td>
<td>4.96 – 98.03</td>
<td>31.02</td>
<td>24.94</td>
<td>44.61</td>
</tr>
<tr>
<td>$FT$, min</td>
<td>2.3 – 59.3</td>
<td>19.5</td>
<td>18.3</td>
<td>31.8</td>
</tr>
<tr>
<td><strong>Number of series</strong></td>
<td>5 – 52</td>
<td>17</td>
<td>14</td>
<td>26</td>
</tr>
</tbody>
</table>

As the study is still in progress, the results for the staff doses from the TLDs are not yet available. However, some conclusions can be drawn out of the readings of the Unfors EDD-30 dosimeter, performed independently from patient dose measurements for a total of 26 procedures, of which 13 CA and 13 combined (CA/PTCA) procedures. The average values of the shoulder dose to the cardiologist, performing the procedure, are 0.035 mSv and 0.047 mSv for CA and CA/PTCA, respectively. No correlation was observed between the shoulder dose and the fluoroscopy time of the procedures. The preliminary analysis of the results from the combined measurements with Unfors EDD-30 and DIAMENTOR E2 reveal that for CA/PTCA correlation with fluoroscopy time and DAP in fluoroscopy mode (and consequently with the total DAP value) was very poor. However, the shoulder dose values seemed to correlate moderately with DAP in cine mode and number of series ($r = 0.82$ and 0.93 respectively). For CA procedures the correlation between the shoulder dose and all explored quantities with the exception of the fluoroscopy time was moderate to good ($r = 0.98; 0.9975; 0.91$ and 0.99 for DAP in cine mode, total DAP, number of series and fluoroscopy time respectively). A comparison between the results for the shoulder dose of the cardiologist from TLD and Unfors EDD-30 readings are scheduled as part of the study.

*The study was performed within the SENTINEL (Safety and Efficacy for New Technique and Imaging using New Equipment to Support European Legislation) project under the Sixth Framework program of the European Commission.*
Management of patient and staff doses in interventional radiology

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Interventional radiology (IR) is a specific part of radiology, increasingly used for diagnostic as well as for therapeutic purposes. Powerful equipment and new techniques make it possible to treat the patient with radiology guided techniques instead of surgery. The interventional examinations are preferred in connection with the fact that these methods are less invasive and less expensive than surgery. They also reduce the time for hospitalization of patients, the risk for patients and their discomfort. Therefore, the number of IR examinations annually is increasing.

The most interventional procedures are performed using fluoroscopy, involving prolonged fluoroscopy times, exceeding one hour or more. The number of types of the interventional radiological procedures rapidly increases, reaching nowadays more than 400 types. IR procedures are requiring highly specified and sophisticated equipment, modern pulsed systems and high quality detectors. IR examinations are however associated with high individual doses of patients as well as of the staff. The levels of doses to patients and staff in IR vary highly as a function of the procedure type, the fluoroscopy time, the number of images acquired and equipment characteristics.

In our study there were monitored medical doctors who are performing the interventional radiology procedures on different departments for the various IR procedures. The examined patients were monitored considering their weight and sex, and the obtained doses. The selected cardiology departments that were subject of the study, and the number of IR procedures per year are given in Table 1.

Basic dosimetric equipment used for measurement of the individual doses of the patients and the medical staff comprises of the following:

- Educational direct dosimeter – Unfors EDD-30 for measurement of the medical staff doses on the various locations at the body
- Patient skin dosimeter-Unfors PSD (4 channel) for the on-line measurement of the patient doses (entrance dose, skin dose) on the various locations at the body
- Dose area product meter (component of the X ray equipment)
- PTW Unidos – for the measurement of the primary beam radiation parameters
- Thermoluminiscence dosimeters for the measurement of the personal doses and doses on hands.

In the framework of SENTINEL research project we tried:
- to establish the frequency, type and number of selected interventional procedures, gathering all technical parameters of the examination procedures details, etc.;
- to estimate the dosimetric parameters of used X ray equipment;
• to elaborate standard protocols for monitoring of doses of patients and staff for the cardiology departments;
• to measure the individual doses of medical doctors and other medical staff members for various IR examinations;
• to measure the patient doses for various IR examinations.

TABLE 1. SLOVAK CARDIOLOGY INSTITUTE, BRATISLAVA. TYPE OF INTERVENTIONAL PROCEDURE

<table>
<thead>
<tr>
<th>Department of Diagnostic and Interventional Radiology</th>
<th>Total angiography</th>
<th>Aortic and limb angiography</th>
<th>Thoracic and abdominal angiography</th>
<th>Selective carotic angiography</th>
<th>Renoangiography</th>
<th>Other angiography</th>
<th>PTA</th>
<th>Stent implantation</th>
<th>Trombolysis</th>
<th>PTCA</th>
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<td></td>
<td>3900</td>
<td>1600</td>
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<td>Invasive electrophysiological studies</td>
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<tr>
<td>Implantation of pacemakers</td>
<td>Implantation of defibrilators</td>
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<td>Endomyocardial biopsies</td>
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<tr>
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<td>250</td>
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<tr>
<td>Endomyocardial biopsies</td>
<td>Percutaneous mitral valvuloplasty</td>
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<tr>
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</table>

REFERENCES

Comparison of radiation doses in permanent cardiac pacemaker implantation in three Greek hospitals

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Permanent cardiac pacemaker implantation is a simple Interventional Cardiology (IC) procedure during which fluoroscopy is employed for aiding in the manipulations required for the successful placement of the pacemaker. However, it is also known that these procedures involve high radiation doses due to long fluoroscopy times. During the SENTINEL European project, radiation doses were measured in three major hospitals in Greece in order to: (1) investigate the levels of dose imparted to the patient, (2) explore the various factors that could have an impact on patient dose, and finally (3) compare the results of this study to corresponding values found in the recent literature.

One hundred and eighty four (184) patients participated in the study, 24 of which were treated in Hospital A, 52 in Hospital B and 108 in Hospital C. The radiation dose imparted to the patient was measured in terms of dose area product (DAP) measured in Gycm\textsuperscript{2} by using DAP meters, all calibrated according to the National Protocol of the National Radiation Protection Board (NRPB) of the United Kingdom. Other patient data collected were the following: age (A), weight (W), height (H), body mass index (BMI), which is the ratio of patient weight in kilogram (kg) to square height in meters (m) (BMI = W/H\textsuperscript{2}), the kilovoltage (kV\textsubscript{p}) and the fluoroscopy time (T).

It was found that results did not exhibit a normal distribution in any of the hospitals and, therefore, DAP and T were calculated in terms of median values. According to our results, median values of DAP and T were: 6.7 Gycm\textsuperscript{2} and 2.6 min (Hospital A), 9.0 Gycm\textsuperscript{2} and 3.0 min (Hospital B), 7.7 Gycm\textsuperscript{2} and 6.5 min (Hospital C). It appears that Hospital A gave the lowest dose to the patient with the lowest fluoroscopy time. However, at comparable fluoroscopy time with Hospital A and even less than half the fluoroscopy time of Hospital C, Hospital B presented the highest DAP. The results show that probably its X ray equipment is calibrated in higher dose rate than the other two hospitals. The correlation between every patient clinical and technical factor collected (W, H, BMI, kV\textsubscript{p} and T) and DAP were investigated separately. No correlation was found between DAP and patient weight, height or BMI. No correlation was also found between DAP and kilovoltage. Finally, significant correlation was found in all three hospitals between DAP and T (r=0.72 Hospital A, r=0.87 Hospital B, r=0.87 Hospital C). Comparison of results with recent literature such as those
reported by the National Radiation Protection Board (NRPB) (27 Gycm\(^2\) and 10.7 min) showed that radiation doses are lower for all three Greek hospitals.

The results of the study showed that comparable radiation doses are given in the three hospitals participating in the study. These doses are lower than internationally established reference levels. It was found that patient dimensions do not affect patient radiation dose. The limitation of the study was that the X ray equipment dose rate was not investigated in detail to explain small differences between hospitals and this should be done in the near future.

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Radiation medicine in Montenegro - Regulatory control first!

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After major constitutional changes in 2003, which redefined Serbia and Montenegro as a loose confederation of two constituent states, and their subsequent separation/independence in June 2006, all radiation/nuclear related issues went separately into the portfolios of the Republic of Serbia and of the Republic of Montenegro. In establishing the radiation protection regulatory framework (both legal and institutional) in Montenegro, and towards meeting the international requirements (e.g. IAEA Basic Safety Standards and the Code of Conduct on the Safety and Security of Radioactive Sources), the need for setting appropriate legally binding requirements for the safe use of radiation medicine, as the basic step towards its proper practice, is discussed.

1. Establishing nuclear regulatory framework in the Republic of Montenegro

Following the decision of its Assembly on 4 February 2003, the former Federal Republic of Yugoslavia (FRY) was transformed into a new entity, called State Union of Serbia and Montenegro – a loose confederation, in effect, of the two constituent states: the Republic of Serbia and the Republic of Montenegro. Only very few competences were retained at the level of the Union, including mainly defence and foreign affairs and trading issues, and were conducted on the parity-of-the-two principle. It was agreed that within three years the constituent states were to decide whether to go on together or to continue separately, which eventually led to separation by mid 2006.

Among the vast majority of competences which were passed by then from ex-federal level to the two republics, as a consequence of this political change, were radiation and nuclear related issues — to start with the creation of the regulatory framework(s) for nuclear, radiation, radioactive waste and transport safety.

While in Serbia there was quite a long tradition, as well as the experience and expertise in the field — originating mainly from “Vinca” nuclear research institute in Belgrade — it was not the case for Montenegro. Therefore, the transition of competences were not being felt so drastically in Serbia, as it was the case in Montenegro.

In Serbia, ex-federal legal and governmental nuclear safety infrastructure continued to operate without much change, just under the new administrative umbrella, the Ministry of Science and Environment.

In Montenegro, however, a similar transition was not possible. Therefore, an informal group of professionals in the field, being aware of the legal and institutional vacuum created after the above constitutional changes, initiated formation of an adequate framework for the radiation protection and for the security and safety of radiation sources. With the help of IAEA experts, a draft of the law was written and, with minor changes, passed subsequently to
the Government. It is now in the procedure which should - hopefully shortly - lead to its promulgation.

Eventual separation/independence of the two countries, which took place in June 2006, did not make any further substantial change in the the above sense. As to the membership of the IAEA, the place was inherited by Serbia (according to a previously made agreement), while Montenegro applied for, and has been admitted as a new member state at the IAEA General Conference in September 2006.

2. Radiation medicine in Montenegro

Being a small developing country (650,000 people), the scope of radiation practices in Montenegro is pretty limited. The vast majority of them, however, is in medicine. Since there is no official inventory list, we estimate there are about 100 large X ray machines, some 500 dental ones, few CTs, few bone densitometers, one 6 MeV linear accelerator for radiotherapy, an angiography department and a newly re-established nuclear medicine department about to start with its practice. There are plans for another accelerator(s), a brachytherapy unit and blood products gamma sterilization.

As to nuclear medicine, let us mention that there was previously a small department active within the Clinical Centre of Montenegro in Podgorica. Basic Technetium $^{99m}$Tc and Iodine $^{131}$I diagnostic and therapeutic applications were performed. The supply of radiopharmaceuticals was predominantly from the “Vinca” Institute, Serbia. Regulatory aspects were covered by a federal radiation protection law, and implemented by a federal regulatory authority in Belgrade.

Following the difficulties caused by political instability and economic collapse in the country, the department ceased its activity in 1993. By June 2006, a new gamma camera was obtained with the help of the IAEA, the department was reconstructed and is now about to restart.

However, before doing so, the most fundamental issue should be fixed - the regulatory aspects of the practice, both legal and institutional. Namely, there is no radiation protection regulatory authority in the country, while provisions of the old radiation protection law (from 1996, is still in force) and subsequent medical practice regulations are obsolete and not in accordance with international standards (e.g. IAEA Basic safety Standards and the Code of Conduct on the Safety and Security of Radioactive Sources). As an intermediate step, an interim regulatory body, the Radiation Protection Commission (RPC), has been established within the Ministry of Health by the decision of the Minister.

3. The need for setting an appropriate regulatory framework for the safe practice of radiation medicine

Obviously, operating the existing devices and starting with new ones (nuclear medicine, in particular) in Montenegro before setting an appropriate regulatory framework is unacceptable. Working without licensing procedures and/or regular inspections - to mention just the most notorious regulatory aspects, could lead to serious harmful mishappenings to all: patients, staff, public and environment. Following the promulgation of the new radiation protection law, a regulatory authority should be urgently established and adequate regulations brought into force. In this respect, the assistance of international bodies, especially that of the IAEA, to the newly established RPC, will be of the utmost importance.
Radiation exposure to patient and staff in interventional radiology of hepatoma: A preliminary study

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\textsuperscript{b}Pertamina Hospital Center, Jakarta, Indonesia

Entrance surface dose (ESD) to patient and dose equivalent received by staff in radiology interventional hepatoma were measured using thermoluminiscence dosimeters (TLD).

In this work 11 patients were involved, and the procedures performed were TAI (Transcatheter Arterial Infusion) for 10 patients, and TAE (Transcatheter Arterial Embolization) for one patient.

Among the 10 TAI patients, six patients were on the first procedure, two patients were on the second, and one was on the third. The X ray unit was Siemens Angioskop D33 and unfortunately the DAP meter was out of order during the whole series of measurements.

Examination time of each procedure that is used for fluoroscopy and radiography depended upon the target position in the liver, the size of hepatoma, and the complicated anatomical structure of arteries particularly for the route of catheter. The irradiated TLDs were measured by the National Nuclear Energy Agency (BATAN), Jakarta.

For ESD measurements, 21 TLDs were used for each patient, 18 TLDs were located at the posterior side at the hepar area and divided into six different points (3 TLDs at each point), namely point A, B, C, D, E, G, and 3 TLDs located at the posterior side of the entrance catheter at arteri femoralis (point F). It was found that the average ESD was 327±304 mGy at point A, 224±282 mGy at point B, 205±228 mGy at point C, 207±276 mGy at point D, 293±380 mGy at point E, 7.8±20 mGy at point F, and 13.6±19 mGy at point G.

The ESD value at these points reached a maximum of 720 mGy at point A, 955 mGy at point B, 747 mGy at point C, 952 mGy at point D, 1.078 Gy at point E, 65.1 mGy at point F, and 44.3 mGy at point G. These maximum values were comparable with the maximum values obtained from cardiac interventional procedures [1]. The highest ESD value that occurred at point E exceed the threshold recommended value by US FDA (1Gy) that should be well documented, even though it was still lower than the dose threshold of skin erythema [2].
REFERENCES


Hungarian contribution to the Sentinel Project

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In our days, X ray diagnostic radiology and nuclear medicine are essential part of medical treatment of patients in Hungary. The use of conventional film-screen radiography and fluoroscopy with image intensifiers is widespread. However, a slow but quite promising spread of new digital techniques can be seen. The safe and efficient application of the new equipment presents the Hungarian radiologists, radiographers and medical physicists a big task.

Hungary as a Member State of the EU is obliged to bring into force the laws, regulations and administrative provisions necessary to comply with the Medical Exposure Directive (97/43/Euratom). In Hungary, Order No. 31/2001 (X. 3.) EüM of the Minister of Health is the regulation which contains detailed requirements on radiation safety of individuals in relation to medical exposures. The ministerial order contains the most important aims, namely the reduction of the frequencies of unjustified exposures, the optimization of diagnostic procedures with good diagnostic value of the images and acceptable patient doses. The order regulates the responsibilities concerning medical exposure, training requirements of the personnel. The implementation of physical and technical quality assurance and quality control programmes is one of the most important requirements of the regulation.

Investigations of patient doses arising from the procedures in diagnostic radiology and nuclear medicine as well as quality control activity has been in progress since 1989 in the NPHC National Research Institute for Radiobiology and Radiohygiene (NRIRR) under the framework of the National Patient Dose Evaluation Program.

The SENTINEL Project, co-funded by the European Commission in 2005, deals with radiation protection, safety and related issues that arise from the introduction of digital technologies to replace film and fluoroscopy equipment in different work packages.

The NRIRR, as one of the SENTINEL partners, contributes to almost all work packages of the project. Under the framework of work packages of 3. and 4. (Efficacy and Safety in Cardiology and Interventional Radiology) patient and staff dose measurements were
performed and an intercomparison of KAP meters, organized by the SENTINEL partner from Poland, was completed. The activity of the other work packages were contributed by an extensive data collection (dental equipment, nuclear medicine, DEXA, pediatric examinations, ethical permission and consent issues and their impact on research, medico-legal exposures, ethical issues in pregnancy).

The authors in their presentation will review the results in connection with their participation in the SENTINEL Project.
Acceptance testing of fluoroscopy systems used for interventional purposes


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Introduction. Acceptance testing and routine quality assurance (QA) of X-ray systems is a requirement of the European Medical Exposures Directive (97/43/EURATOM) and this requirement was implemented into Irish legislation in 2002. The legislation also states that special consideration should be given to the QA and dose assessment of high dose procedures such as interventional fluoroscopy. International [1] and European [2–7] guidance documents are available, containing testing methodologies and criteria against which equipment may be judged. These guidelines have been used to develop in-house QA protocols for testing fluoroscopy systems. Protocols are reviewed on a regular basis as part of the QA programme. New developments in diagnostic imaging technology are providing challenges for those involved in fluoroscopy QA. Flat-panel detector (FPD) digital fluoroscopy systems are beginning to replace Image Intensifier (II) technology in the interventional fluoroscopy room and are often marketed as a “low dose” imaging modality. Mobile C-arm II/TV systems are becoming increasingly more complex, with numerous options and software settings which may have significant dose and image quality implications. The time required to perform comprehensive testing, analysis and reporting of all variables on complex fluoroscopy systems is a real challenge in a busy hospital environment. The aim of this study was to compare the results of acceptance testing for several different fluoroscopy configurations and highlight some recurring problems.

Methodology. Acceptance testing was carried out on sixteen fluoroscopy systems (interventional II/TV, interventional FPD, mobile C-arm II/TV) in a number of hospitals in Ireland from 1999 to present. Tests included assessment of tube and generator performance, radiation dose, image quality, electrical and mechanical safety, equipment design and radiation protection features. Tests were performed using a calibrated ionization chamber and kVp/exposure time meter, Leeds image quality test objects and other standard test tools.

Results. The results for sixteen fluoroscopy systems will be presented (Table 1). All systems were found to have failed one or more acceptance tests (Table 2). Dose rate, image quality and radiation protection issues were identified on the majority of systems tested.

<table>
<thead>
<tr>
<th>TABLE 1. NUMBER AND TYPE OF FLUOROSCOPY SYSTEMS TESTED</th>
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<tr>
<td>Type of Fluoroscopy System</td>
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<td>-------------------------------------------------------</td>
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<tr>
<td>II/TV Interventional fixed system</td>
</tr>
<tr>
<td>FPD Interventional fixed system</td>
</tr>
<tr>
<td>II/TV Interventional mobile C-arm system</td>
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</table>
Radiation dose and image quality results for a new vascular interventional FPD system will be presented. The results have been compared against two conventional vascular II/TV systems. Results show that patient entrance dose rate measurements are comparable on all three systems (approx. 4mGy/min). Image quality results are also comparable (noise, threshold contrast detail detectability and limiting spatial resolution); however, the limiting spatial resolution was slightly greater on the FPD system. For the FPD in digital acquisition mode, it was found that the dose per frame at the detector entrance was greater than that measured on the majority of fluoroscopy systems, and this was most likely due to the relatively high default clinical “dose” setting. Results will also be presented for a number of modern mobile C-arm II/TV systems. The systems were found to have a wide variety of user-selectable fluoroscopy modes and filtration options, many of which had a noticeable impact on the measured dose and resultant image quality.

**Discussion.** This study highlights the importance of comprehensive acceptance testing for complex fluoroscopy systems. It would be beneficial to liaise with the system applications’ specialist and the clinical users prior to acceptance testing, to ascertain the user’s requirements and clinical settings. This will assist with efficient testing of the relevant modes of operation. The default clinical “dose” setting should be optimized to ensure that it is as low as reasonably achievable. Comparative studies of new systems will assist with the on-going development of testing guidelines and criteria of acceptability for modern fluoroscopy equipment.

**ACKNOWLEDGEMENT**

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**REFERENCES**


Session 11c:

Radiation Imaging

NATIONAL QUALITY ASSURANCE IMPLEMENTATION IN NUCLEAR MEDICINE
SPECT: How much acceptance testing is reasonable?

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Whereas in radiology national standards for acceptance testing of medical instrumentation are available, in nuclear medicine this is not the case. This resulted in some kind of uncertainty, so that the Austrian Societies for Nuclear Medicine and for Medical Physics decided to establish a task group for developing guidelines for acceptance testing [1].

One important item that has to be kept in mind is the fact that acceptance testing of radiological equipment has to assure the observation of prescribed limits of radiation. Otherwise there would arise the risk of increased radiation exposure of the patient. On the other hand, the aim of acceptance testing of gamma cameras is only to assure that the specifications are observed. There are no prescribed limits and there is no risk for the patient.

There are two standards for defining specifications of gamma cameras: the NEMA standards [2] and the IEC standards [3,4]. Most of the manufacturers determine the specifications of their gamma cameras according to the NEMA standards, so if we want to check the specifications in the field, we have to use the same methods as the manufacturer, that is the NEMA standards. The questions are: Should we check all parameters defined in the NEMA standards? That would not be possible in the field. Which parameters should we select? In which extent and how precisely should we check? In any case, there must be a reasonable balance between time and financial effort and technical information obtained.

Facing these problems our task group decided to propose the following procedure:

First, we apply all tests which are called "primary tests" in the NEMA standards:

1. Intrinsic spatial resolution
2. Intrinsic energy resolution
3. Intrinsic flood field uniformity
4. System spatial resolution without scatter
5. System alignment
6. SPECT reconstructed spatial resolution without scatter
7. Wholebody system spatial resolution without scatter.

All these tests are basically performed according to the NEMA standards. Nevertheless, for saving time and effort some modifications are applied. For example, we use the same point source arrangement for Tests 5 and 6, and in Tests 4 and 7 we omit the second line source which serves for the calibration of pixel size, because we calibrate the pixel size with the transmission line phantom of Test 1.

Furthermore we performed the following tests, which in the NEMA standards is called "secondary tests", but some with major simplifications:

1. Intrinsic spatial linearity
2. Multiple window spatial registration
3. System planar sensitivity
4. Detector shielding
5. Detector-detector sensitivity variation.

Tests 8 and 9 are performed according to the NEMA standards. In Test 10 we restrict ourselves to the measurement with a distance of 10 cm between phantom and collimator. Test 11 we perform simply by moving a strong source around the detector shielding and looking for increased count rate, the detector-detector sensitivity variations are determined from the result of Test 10.

In addition, the following tests, not included within the NEMA standards, are performed:

1. Maximum count rate in air
2. System uniformity
3. Pixel size
4. Visual assessment of spatial resolution with a four-quadrant bar phantom

Test 13 is performed instead of the very complicated determination of system count rate performance in air described in the NEMA standards. We check approximately the maximum count rate in air in a very simple way by repeatedly approaching and removing a source to and from the detector. Test 14 is very useful for testing the uniformity of collimators, but it has to be omitted if no flood source is available.

Tests 16 and 17 are part of the first routine quality control which has to be done immediately after the acceptance testing to establish the reference values. This first routine quality control includes also a simplified measurement of the intrinsic flood field uniformity and a center of rotation offset calibration.

This procedure we have now applied in more than ten acceptance tests of new gamma cameras as well as cameras already in use for several years. The whole procedure takes not more than one and a half day. Evaluation of results is done by a software that was developed at our institute according to the NEMA standards.

REFERENCES


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Inter-comparative study to evaluate the current state of gamma cameras and SPECT systems in Cuba

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Cuba

The aim of this study was to perform an inter-comparative study to evaluate the current state of the gamma cameras and SPECT systems in Cuba. In situ measurements were carried out in all the nuclear medicine departments participating in the study. This work was performed as part of a global project to establish a national programme for quality control of nuclear medicine instruments. The Cuban regulatory authorities (CCEEM) participated and supported this job.

Firstly, a survey was carried out in order to collect data about the features of the instruments and availability of accessories for the quality control procedures. The selected tests and procedures were based on international standards for quality control of nuclear medicine instruments [1–4]. Evaluations of uniformity, spatial resolution, sensitivity, energy resolution, linearity, tomographic uniformity, center of rotation, tomographic resolution and total performance for SPECT systems were carried out in the five gamma cameras and five SPECT system available in the country. Nuclear medicine services and equipments were codified in order to maintain anonymity. Table 1 summarizes the parameters measured in all the equipment.

In general, the outcome of the quality control measurements showed that most of the evaluated equipment was working in an appropriate and acceptable technical state. As a rule, the instruments with longer period of use showed higher irregularities in the evaluated parameters. Some detected problems were solved by means of corrective procedures during the measurement period; otherwise, suggestions were provided to the engineering services in order to fix them. Outcomes were recorded in a technical report and a formal information was provided to hospital authorities and the national regulatory authorities.

In spite of the results showing that majority of the equipment had acceptable non-uniformity values (integral and differential) below 5\% for UFOV and CFOV, two gamma cameras (PH-3) and (SH-2 ) had non-uniformity values over 5\%, which were appropriately corrected. Alterations in the linearity were also found and corrected on these systems.
Sensitivity, spatial system resolution and energy resolution measurements showed satisfactory results in the evaluated system.

The tomographic uniformity, center of rotation and tomographic resolution of the SPECT systems were calculated and evaluated after the planar parameters were tested and optimized, showing acceptable values in all the departments. Total performance was estimated using a Carlson phantom filled with a homogeneous solution of $^{99m}$Tc. Reconstructed slices of the different sections (uniformity, resolution/contrast, linearity, etc.) were also evaluated qualitatively and classified as acceptable for all the SPECT systems.

The results of this work were presented to the Cuban authorities. Currently, some gamma cameras and SPECT systems are being replaced or updated in order to optimize the quality of the nuclear medicine services.

**REFERENCES**


Survey on QC measurements of nuclear medicine imaging equipment in Finnish hospitals

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Detailed requirements on quality assurance in nuclear medicine in Finland are given by the STUK – Radiation and Nuclear Safety Authority in the guide ST 6.3, Use of Radiation in Nuclear Medicine, 2003. In this guide it is regulated that documentation must also exist in respect of each equipment, as follows:

1. Inspections and measurements to be performed and the purpose thereof,
2. Methods of inspection and measurement, apparatus and instruments to be used, intervals for performing inspections and measurements,
3. Acceptability criteria for inspections and measurements (action levels), and
4. Measures to be taken when the acceptability criteria are exceeded.

The European Council Directive MED (97/43/Euratom) requires the establishment of criteria of acceptability for radiological installations. In the guide ST 6.3 the acceptance criteria given for performance parameters of NM imaging equipment are the same as given by the European Commission in its publication Radiation Protection 91. However, these are only minimum requirements.

The most common standards for nuclear medicine imaging equipment are the NEMA standards. Manufacturers normally use the NEMA specification when giving the performance characteristics of gamma cameras. For acceptance testing the performance measurements of a gamma camera are usually made using the NEMA methods. For regular checks a minimum level of measurements of performance is required to ensure that the equipment is functioning properly. These measurements are not intended for full evaluation of performance. Therefore, only some of the NEMA tests are suitable for the routine QC.

To harmonize the routine QC of the nuclear medicine equipment in Finnish hospitals, the STUK will publish guidance on the QC of the NM equipment (planar gamma cameras, SPECT, coincidence gamma cameras, PET) in collaboration with several hospital physicists. Recommendations on the regular QC measurements and frequency of the tests will be given. At first the meaning was to give acceptance criteria for performance parameters, too. Because it was not known what performance parameters of the NM equipment are measured in hospitals, in what frequency they are measured and what acceptance criteria is used for the different performance parameters, a survey was made on the QC of the NM equipment.

The survey was made together with the survey on the use of radiopharmaceuticals in diagnostics and therapy in 2003 in Finland. This survey is made every three years by the STUK. The hospitals were asked about the performance measurements made, the frequency of the measurements, persons (physicist, technician, etc.) performing the measurements, and acceptance criteria used for different performance parameters for each imaging equipment separately.
Twenty-six (26) hospitals answered, and data was given for 50 gamma cameras (for 98% of gamma cameras in Finland in 2003). In addition, QC of all three PET cameras in Finland in 2003 was also reported.

Most often, regularly measured performance parameters in Finnish hospitals for gamma cameras in 2003 were: the photopeak check, uniformity, linearity, resolution, sensitivity and centre of rotation.

The photopeak check (and adjustment if necessary) was made every day before clinical imaging in every hospital. The uniformity check is in most cases made once per week. The frequency of linearity tests varies much more depending on the gamma camera - it varied from one month to one year. The frequency of testing of the centre of rotation varied from once per week to once per year. The resolution and sensitivity are in most cases tested once per year although in some cases it was done once every three months or even more often.

The daily photopeak check was done by a technician. The intrinsic uniformity checks were also usually done by technicians. The other QC measurements on the other hand were usually done by a physicist.

The uniformity checks included in some hospitals the measurements of the intrinsic and extrinsic integral UFOV and CFOV and differential UFOV and CFOV. In some hospitals only the intrinsic integral CFOV or UFOV was determined. The resolution was in some hospitals checked visually by using a bar lead phantom. Some hospitals regularly determine the FWHM. Few hospitals reported to check spatial resolution for SPECT images.

To decide when to take remedial actions, i.e. what are the action levels for imaging equipment, is one of the main problems in quality control. The acceptance criteria used for different performance parameters in different hospitals in Finland in 2003 will also be presented more closely.

REFERENCES


Implementation of a trace document as part of a QA programme in a nuclear medicine department

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Introduction. The focus of the health care sector internationally is rapidly moving towards client satisfaction and quality product delivery. Quality assurance and quality management in nuclear medicine is of utmost importance to obtain optimal examination results and to ensure consistent client, i.e. patient and referring physician satisfaction.

Several factors influence the optimal functioning of any nuclear medicine department. An initial survey of current practices should address all these processes and procedures, with the aim of progressing to a comprehensive quality assurance and management system. A standardized programme should be customized and managed according to the quality policy, individual needs, objectives and requirements of a specific department. The successful implementation of a quality management system (QMS) represents sound practices and should be developed using scientific findings and national and international guidelines.

Achieving high levels of customer satisfaction, top performance and traceable records and patient information should be the aim of any nuclear medicine department and is a significant challenge for most organizations. Failures to achieve departmental or organizational goals are usually more related to management and quality control than to technology. Proper planning, preparation and attention to detail are the principles of achieving these goals. This can be achieved by designing of processes and protocols and ensuring the standardization and implementation of a maintainable quality management system (QMS) \cite{1}. To monitor the effectiveness of this QA system and ensure that it follows good medical practice, regular audits should be performed. This process can be defined as conducting repeated self inspections as part of the QA system, monitoring the implementation of and compliance with good practice and proposing any necessary corrective measures. Records of such self inspections and any subsequent corrective action should be maintained \cite{2}.

All staff members should be actively involved in the QMS to ensure that they are aware of all quality issues in their areas of responsibility. Similarly, they should be considered responsible for and owning the quality of the products and processes, including any problems which might arise. Good documentation practice constitutes an essential part of the QA system.

Materials and methods. A traceability document was designed and implemented in the Nuclear Medicine Department of Tygerberg Hospital. This custom designed TRACE document included all aspects influencing the functioning of the department. It comprised different sections including: patient information, radiopharmaceutical preparation and injection details, additional information including availability of X rays, imaging details, pre-reporting patient and image evaluation, reporting sequence, typing, sending and archiving.
of reports, and information for departmental statistics. An introduction period of one month was used to “streamline” the document design. The auditing process of the newly implemented TRACE document took place one year after the implementation thereof. A randomly selected sample of two hundred trace documents were used for data analysis. The data analyses were performed by allocating a zero score (0) to areas left blank while a score of one (1) was allocated to completed areas. Graphs and statistical analysis of the data were performed using an Excel software program. The different areas of each of the categories were analysed individually and an average score for each category calculated. By using this method, nonconformities could be identified and corrective measures proposed.

**Results.** None of the selected TRACE documents were completed accurately (Fig. 1). The overall audit score was 62%. The highest scoring category (77%) was where radiopharmaceutical preparation details were requested. The reason for this could be that staff members were accustomed to the documentation of these specific details. The categories regarding injection details and imaging information, and the final handling of the reports were also completed reasonably well (>70%). Several of the categories had a very low average score (22–54%).

![FIG. 1. Results of the audit of TRACE documents.](image)

**Discussion.** A lack of accuracy in completing the TRACE document in Tygerberg Hospital’s Nuclear Medicine Department was identified. Corrective and preventative measures must be implemented to ensure compliance with this important QA aspect. The importance of including all the categories in such a TRACE document should be discussed with all staff members, as every category can be directly linked to a specific important aspect eventually leading to consistent client, i.e. patient and referring physician satisfaction. It is also necessary for external accreditation to meet all criteria regarding the traceability of the patient and the report.

**REFERENCES**

Five-year experience in the Czech Republic with the State Office for Nuclear Safety (SONS). Recommendations for QA system at the Departments of nuclear medicine, instruments, and intended amendments

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Introduction. Law No. 18/1997 Coll. which came into force in the Czech Republic in the middle of 1997 requires every department of nuclear medicine (NM) to set up a QA Programme containing a section devoted to quality control of equipment performance [1]. In order to facilitate the implementation of this demand into the practice, the detailed guidelines mentioned in the title was prepared [2].

Contents of the SONS recommendations. The guidebook covers all devices used in nuclear medicine for diagnostics, therapy and radiation protection: radionuclide calibrators, single and multi-detector instruments for the measurements in vitro, SPECT scintillation cameras operated in both planar and tomographic regime, dose and dose rate meters and contamination monitors. As an aid to writing the SONS Recommendations the following international and national recommendations were used: IAEA-TECDOC-602 (1991), NEMA (1994), NCRP (1998), IPSM (1992) and others. Considering the extent of SONS Recommendations a compromise was made among comprehensive and too detailed publications (NEMA, IAEA, IEC) and somewhat simpler ones published in Germany and UK. Also, many years of experience was exploited with the quality control of instruments carried out at the Clinics of NM in Olomouc and other departments in our country.

The SONS Recommendations consist of 23 sections devoted to the number of tests such as stability, spatial resolution, sensitivity, uniformity, spatial linearity, etc. Each section is divided into the following items: definition, procedure, calculation and analysis including tolerances of parameters (in several tests), test frequency, remedial measures and commentary.

Benefits. Immediately after its publication SONS Recommendations became the effective help for departments of NM because such publication in Czech had not been available before. Benefits derived from it are, as follows: (1) a practical guide to both acceptance and regular performance testing, (2) a guide to write standard operation procedures which are required by SONS as part of the documentation of QA system for use with specific instruments, (3) a support for renewal of devices which do not satisfy demands on the quality of diagnostic and therapeutic procedures in NM because of their obsolescence and other reasons, (4) support for the adherence to diagnostic reference levels of administered activities of radiopharmaceuticals introduced in the Czech Republic in 1997, (5) a manual for pre-graduate and post-graduate
teaching of radiological physicists and technologists, (6) an auxiliary aid for postgraduate teaching of NM physicians.

Shortcomings. Five year experience with SONS Recommendations has also shown some problems. In case of several tests there is the difficulty in establishing tolerance limits on which the examined parameter can lie without affecting the diagnostic value of clinical examinations. With advancement of instruments and tendency on the part of manufactures to perform tests automatically by means of suitable software, the extent of tests somewhat changed. Also, SONS Recommendations do not involve PET cameras because these devices did not exist in the Czech Republic in 1999. It appears that the part of the QA Programme concerning instruments should be liable not only to internal audit but also to independent external audit. The spectrum of tests seems to be too wide; however, the role of SONS Recommendations is to be an instruction and a user can choose acceptable tests according to his equipment, his possibilities and, of course, the recommendation of producers of equipment or facilities.

The facts mentioned suggest that shortages of SONS Recommendations ensue mainly from instruments’ progress and also, to some extent, from the improvement of testing methods.

Amendments. The intended amendments to SONS Recommendations will be aimed, besides well tried sections, at the following issues:

– list of requisites necessary for performing tests emphasizing its simplicity,
– a more complete definition of tolerances for each test and the action to be taken when tolerances are exceeded,
– description of tests of PET and PET/CT imaging devices the number of which has recently increased in our country,
– guidance will be given containing information that permits a physician, in cooperation with physicist, to examine patients normally or to request the equipment be serviced or to stop patient studies until the system is repaired,
– besides the complete set of QA programme tests a part of the minimum number of performance measurements will be selected which would be suitable for a quick routine assessment of instrument quality and also suitable for planned external audit by the group of independent experts (physicists).

Conclusion. Attention is paid continuously to QA of NM instruments in accordance with Czech legislation and IAEA publications in our country.

REFERENCES


Quality control programme established in the Nuclear Medicine Department of the Vancouver Coastal Health Authority Hospitals

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Background and objectives. The Vancouver Coastal Health Authority (VCH) covers a large area of Southern British Columbia that includes 14 hospitals. Five of them have Nuclear Medicine (NM) departments with a total of 18 cameras of different ages and produced by different manufacturers. A flawless operation of these cameras is of paramount importance for the accuracy of diagnostic studies. Consequently, a comprehensive quality control (QC) programme has been designed to detect changes in their performance that might degrade the accuracy of clinical images. The most extensive testing is done at acceptance of the new equipment, simpler tests continue regularly throughout the whole period of camera operation. The tests are based on the National Electrical Manufacturers Association (NEMA) recommendations [1] on how to perform QC experiments and how to analyse the results. The QC programme in all five NM departments follows the same principles. It is supervised by a ‘regional’ physicist. Initially, however, problems were encountered. At first, analysis of the QC data coming from these different cameras was seriously hindered by the lack or rigidity of the proprietary manufacturers’ software. In particular, it was very difficult, if not impossible, to reliably compare the performance of different systems. An additional problem was caused by the large distances between hospital departments which made regular consultations by the physicist and test supervision difficult. In this paper, we present a practical solution to these problems and discuss our particular implementation of a QC programme that covers 18 cameras and unites five busy NM departments.

Methods. To address the first problem and make the analysis of test results reliable and camera-independent, we have developed a software application ‘Nuclear Medicine QC’ (NMQC) [2] which implements the basic scintillation camera QC analyses and follows exactly the most recent NEMA standard. Our software allows multiple types of QC tests to be analysed within a single application, and enables comparison of different cameras in a uniform way. Both planar and tomographic tests are implemented, allowing examination of camera performance in a number of important areas. Our application is written using the Matlab environment, which has several benefits, foremost of which is cross-platform compatibility. Since Matlab runs on Windows, Linux, Mac OS-X and Solaris, so does our software. By installing the free Matlab Common Runtime (MCR), anyone can run our software, even if they do not have Matlab or the Image Processing Toolbox. Our application reads and analyses DICOM or Interfile format files. In addition to the QC analysis functions, the programme has features for examining and searching file headers, viewing magnified images or sections of images, and exporting results. All of the application's features are accessible through a unified graphical user interface (GUI). Our second problem is just being addressed as VCH is in the process of connecting all its imaging departments, including NM, into a single PACS network, thus allowing for transfer and joint storage of patient data files. The same system is being used to transfer QC data files. In each NM department and for each camera, QC data are being saved with a unique name and stored in a dedicated QC file folder.

Results. Our software implements all of the basic nuclear medicine camera QC tests, such as:

(a) calculation of planar uniformity
(b) intrinsic resolution and linearity calculation
(c) profile analysis (full width at half maximum/full width at tenth maximum)
(d) center of rotation calculation
(e) sinogram/linogram display and calculation of COR deviations
(f) tomographic uniformity calculation
(g) display of planar uniformity test history.

In the VCH implementation, the NMQC software runs on a dedicated PC computer which has access, through PACS, to all five NM departments in different hospitals. As a routine operation in each department, the daily and weekly QC tests are performed and analysed by a technologist in the department. In parallel, the files are being stored on PACS. These data occasionally, and the results of monthly, quarterly and annual tests – always, are analysed centrally by the physicist using NMQC software (Fig. 1).

![FIG. 1. Example of an NMQC analysis screen showing substantial camera non-uniformity.](image)

Experience gathered during the first six months of using the QC programme provided us with important practical insight that allowed us to improve its efficiency. In particular, a detailed QC manual for clinical NM departments has been created, file naming, data organization and transfer to PACS have been improved, and the NMQC analysis programme itself has undergone several modifications which have improved its performance, allowed us to extract more information from the data, and made its operation simpler and more user friendly.

**Conclusions.** A comprehensive QC programme covering five NM departments at the VCH has been created. In order to facilitate analysis of the data strictly according to NEMA standards as well as compare the results originating from different cameras the NMQC, software application has been developed. The software performs all of the basic quality control tests necessary for planar and SPECT scintillation cameras. Our application is easy to use, can be run on different platforms, and serves as an independent complement to gamma camera manufacturers’ proprietary quality control software.

**REFERENCES**

