RESULTS

CURRENT STATUS OF QUALITY ASSURANCE OF TREATMENT PLANNING SYSTEMS

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Abstract

A review is given of the current status of quality assurance of treatment planning systems. At this moment only one comprehensive report is available. In order to review national activities a questionnaire has been distributed amongst national societies of medical physicists. From the 23 responding countries, 8 indicated that only limited efforts are underway, 8 answered that a working group is evaluating their specific national requirements while in 5 countries a document is drafted. The highlights of these reports have been summarized.

1. INTRODUCTION

In contrast with the information available on quality assurance, QA, programmes of treatment machines, there is relatively little guidance related tot QA of a Treatment Planning System, TPS. Acceptance testing, commissioning and quality control of accelerators are well developed procedures and many documents exist giving recommended procedures. For treatment planning systems these recommendations are scarce or still have to be developed. Although the need for QA of a TPS is generally recognized and each physicist is performing a set of (routine) tests of his/her planning system, different approaches are possible. It is the purpose of this presentation to review the current status of QA of TPS, mainly for external photon beams.

In order to start a QA programme of a TPS, accuracy requirements have to be formulated. As an example for good clinical practice, the following data, given as one standard deviation, have been proposed [1, 2]:

- absorbed dose at the dose specification point (average dose) : 3.5%
- absorbed dose at other points in the target volume : 5 %
- position of field edge : 4 mm

Knowledge of the dose delivered to a point in a patient is usually the result of three distinct steps:
(1) determination of the absolute dose at the reference point in a water phantom under reference circumstances;
(2) calculation of the dose at points in the patient relative to the dose at the reference point in the water phantom;
(3) deviations between actual and intended set-up and treatment of the patient.

The uncertainty in step (1) is about 2.5% and in step (3) may be estimated to be 1.5% along the central axis of the beam and about 3% at other places in the field. This leaves an uncertainty in the determination of the relative dose distribution varying between about 2% and 3% (excluding the effect of heterogeneities). This is in agreement with the requirement given in some documents as summarized in Table I.

TABLE I. CRITERIA OF ACCEPTABILITY IN COMPARING CALCULATED TO MEASURED RELATIVE ABSORBED DOSE DISTRIBUTIONS OF EXTERNAL PHOTON BEAMS.

Reference		Small dose gradient (%) (mm)	Large dose gradient
McCullough and Krueger	[3]	3	4
Dahlin et al.	[4]	3	3
ICRU Report 42	[5]	2	2
Brahme et al.	[6]	3	3
Van Dyk et al.	[7]	2-3*	4
Kutcher et al.	[8]	2	2

* The lower value is valid for central-ray data; the higher one for the high-dose region

The actual position of the field edges with respect to the target volume is also the result of several steps, including the uncertainty introduced by the treatment planning system. Compared with the other uncertainties, e.g. patient movement, the geometric uncertainty resulting from the planning system can be made quite small, e.g. of the order of 2 mm or less. Although this requirement can generally be achieved for 2D-treatment planning systems, the increased number of possibilities of 3D-planning systems requires a much more extensive QA programme to check if such a requirement is achieved in all directions, as will be discussed in section 5.

2. TESTING TREATMENT PLANNING SYSTEMS

The main error sources in computerized treatment planning are related to:

(1) hardware components;
(2) beam data acquisition and reconstruction;
(3) patient data acquisition and representation;
(4) algorithms used for the dose computation and representation.

In principle the manufacturer of a TPS should provide the user with detailed information about the performance of the system. It is, however, extremely difficult, both for the vendor and the user, to assure the quality of the system under all clinical conditions. For that reason only recently guidelines have been formulated for acceptance testing, commissioning and QA of a TPS.

Before placing a computer planning system into clinical use, it must be carefully checked with respect to its diverse functions and accuracy. Basically there are two different approaches of testing computer planning systems:
(1) a comprehensive test using a *standard set of beam data* [9, 10, 11];
(2) a user oriented test based on *local beam data* and local computer facilities [12, 13].

Method (1) is more general and avoids the necessity of making measurements by the user of the test programmes. It does require, however, the introduction by the physicist of basic beam data in the system which are generally not directly of relevance for his own clinic. The second method has the advantage that the results are directly applicable to his own situation. A comparison with other institutions is, however, more difficult because the treatment planning system and/or the treatment beam will differ.

Most of these systematic tests or intercomparisons of treatment planning systems concerned comparisons of measured and predicted dose distributions. Differences could generally be attributed to limitations in the accuracy of dose calculations algorithms, particularly in the scattered component of the dose. Some intercomparisons also revealed discrepancies between the actual beam data and those applied in the TPS [9, 13]. Although most information deals with external beam treatment planning, systematic tests of treatment planning systems for brachytherapy have also been performed [e.g., 14].

It should be noted that these tests are not specifically addressing the problem of program correctness. For this purpose a number of techniques for preventing, discovering and repairing programming errors have been discussed by Jacky and Kalet [15].

It is important that the manufacturer provides a description of the dose calculation models and their limitations to the users. The manufacturer should, in addition, make available documentation of the use of the system, for instance of the beam weighting procedures and of wedge factors. Finally the manufacturer should make available to all users information concerning software "bugs" and other relevant information, for instance during users' meetings and in release notes.

3. REPORTS ON QA OF TREATMENT PLANNING SYSTEMS

The first report that describes systematically a series of tests to be performed by a TPS user in order to evaluate the accuracy of dose calculations, has been presented by McCullough and Krueger [3]. Their publication does not, however, provide information on a routine QA programme. At this moment the only comprehensive report that deals with commissioning and QA of a TPS, is the report by a group of physicists from Ontario, Canada [7]. The contents of that report is given in Table II.

TABLE II. CONTENTS OF THE ONTARIO REPORT ON THE COMMISSIONING AND QA OF TREATMENT PLANNING COMPUTERS [7]

1. Computer programs and system documentation and user training
2. Sources of uncertainties and suggested tolerances
3. Initial system checks
4. Reported system checks
5. Quality assurance through manual procedures and in vivo dosimetry.
6. Additional considerations, including administration and manpower requirements

Detailed information, including a large number of examples of initial and reproducibility tests can be found in this report.

QA of TPSs is also part of a more general report on QA for radiation oncology as published by the AAPM Radiation Therapy Committee Task Group 40 [8]. This report does not provide detailed tests, as given in the Van Dyk et al. manuscript, but gives recommendations on the frequency and tolerance limits of these tests.

4. QUESTIONNAIRE ON NATIONAL ACTIVITIES IN THE FIELD OF QA OF TREATMENT PLANNING SYSTEMS

In order to review national activities in the field of QA of TPS, a questionnaire was sent to representatives of national societies of medical physicists active in this field. The questions were: "Do national recommendations on QA of TPS exist in your country? If not yet available, is there a group working on a such a national report and are there other activities going on in your country such as users' meetings of a particular TPS?".

TABLE III. CONTENTS OF THE DRAFT IPSM REPORT ON QA OF TREATMENT PLANNING SYSTEMS

1. Introduction
2. Description of the computerized planning system
3. Testing of general hardware
4. CT interface
5. External photon beam algorithms
6. Evaluation of electron beam algorithm
7. External beam-patient planning checks
8. Brachytherapy algorithms

TABLE IV. CONTENTS OF THE PROPOSED NORWEGIAN PROTOCOL ON QA OF TREATMENT PLANNING SYSTEMS

1. Introduction
2. Competence levels
3. Acceptance tests for system
4. Acceptance tests for treatment unit data
5. Constancy tests for system
6. Constancy tests for treatment unit data

App. A. Test geometries
App. B. Forms

TABLE V. SUGGESTED AUSTRALIAN PROTOCOL FOR COMMISSIONING AND QA OF TREATMENT PLANNING SYSTEMS AND MONITOR UNIT CALCULATIONS [16]

Frequency	Test	Tolerance
Commissioning and following software update	Identify algorithms used and their limitations	Appropriate for application
	Single field or source isodose distribution	2% or 2 mm
	MU calculations	2%
	Test cases	2% or 2 mm
	I/O system	1 mm
Weekly	I/O devices	1 mm
Monthly	Checksum	No change
	Subset of reference QA test (when checksums not available)	No change
	I/O system	1 mm
Annual	MU calculations	2%
	Reference QA test set	2% or 2 mm
	I/O system	1 mm

TABLE VI. OUTLINE OF THE REPORT ON QA OF TREATMENT PLANNING SYSTEMS IN THE CZECH REPUBLIC / SLOVAK REPUBLIC.

1. Recommendation for documentation
   a) Documentation provided by the producer
   b) Documentation of basic beam data of TPS
   c) Log-book of TPS (for recording all modifications of data, software, hardware and all failures and repairs of TPS)
   d) Documentation of the information obtained from TPS
   e) Documentation of patient treatment
2. User training
3. Sources of uncertainties in treatment
4. Suggested tests and checks of TPS (with tolerance and action levels and frequency of tests)
   a) Commissioning tests
   b) Tests after repair or new software release or modification of data
   c) Regular tests of TPS

Appendices:

I. Short description of algorithms for photon beam calculation
II. Short description of algorithms for electron beam calculation
III. Short description of inhomogeneity corrections and corrections for patient outline.

TABLE VII. NATIONAL REPORTS IN PREPARATION ON QA OF TREATMENT PLANNING SYSTEMS.

Country	Contact person
Great Britain	Dr Jim Shaw, Clatterbridge Centre for Oncology, Clatterbridge Hospital, Bebington Wirral L63 4JY, Great Britain
Australia	Dr Jim Cramb, Peter MacCallum Cancer Institute, Locked Bag 1, A' Beckett Street, Victoria, Australia, 3000
Norway	Dr Sverre Leverness, Dept. of Medical Physics, The Norwegian Radium Hospital, N-0310 Oslo, Norway
Czech Republic/ Slovak Republic	Dr Anna Kindlova, Dept. of Radiotherapy and Oncology, Faculty Hospital Královské Vinohrady, Šrobárova 50, 100 34 Prague, 10, Czech Republic.

From the 23 responding countries, 8 indicated that only limited efforts are underway, 8 answered that a working group is evaluating their specific national requirements while in 5 countries a document is drafted or tested in various clinics (Table VII). The outline of the British, Norwegian, Australian, Czech Republic and Slovak Republic protocols are presented in Tables III - VI, respectively. The Norwegian protocol is currently tested in some radiotherapy centres in Norway. The Australian protocol is part of a more extensive QA document [16]. The activities in Great Britain are described in a report of the Institute of Physical Sciences in Medicine, IPSM [17]. A special feature of this report is the extensive testing of hardware. These tests concern the functioning of individual system elements and comparisons with existing information. In the Czech Republic and the Slovak Republic a common set of recommendations for QA in radiotherapy is under preparation. It will include an extensive list of tests, as well as tolerance limits, action limits and frequencies of these tests.

A number of replies to the questionnaire mentioned that participation in users' meetings of a particular TPS and having close contacts with the manufacturer is an important aspect of a QA programme of a TPS. In some countries national or regional TPS users' meetings have been reported (Table VIII). In Finland all 9 radiotherapy centres nowadays have the same TPS (Varian - Dosetek CADPLAN). The QA in radiotherapy in Finland is performed by the Finnish Centre for Radiation and Nuclear Safety (STUK). Besides quality audits of equipment STUK is starting now also a programme of QA of TPS. For this purpose a special phantom [18] will be used.

5. QA OF 3-D TREATMENT PLANNING SYSTEMS

QA of a 3-D TPS is a time consuming process, particularly if wedges, blocks and asymmetric collimators are involved. The problems related to gathering the optimum amount of data, designing models to describe the 3-D dose distribution and to verify the results of these calculations, are still under investigation. At this moment it is recommended to apply a pragmatic approach instead of an extensive QA programme, i.e., to test only those geometries in 3-dimensions that are applied clinically. For instance, a comparison of measured and calculated dose values at relevant points for specific treatment techniques (e.g., breast treatment [13]) is a good approach. These tests provide, however, an overall result and do not discriminate between errors in beam data, dose calculation algorithm or other sources. A more fundamental approach of testing special aspects of a 3-D TPS can be performed in some institutions. Their experience should then be reported to the vendor and other users of the system.

Use of image information is extremely important in 3-D treatment planning. Not only CT information but also MR images, digitized radiographs and digitally reconstructed radiographs are currently incorporated in the planning process. All these imaging tools should be checked using specific geometrical tests. Also other geometrical locations of, for instance, Beam's-Eye-View and Region-of-Interest (ROI) should be tested. The use of dose volume histograms (DVHs) is one of the advantages of 3-D treatment planning systems over conventional systems. The proper functioning of the integration over specific ROIs should be checked. This is of particular importance if the DVH is sensitive to grid size and contour directions (e.g., if the DVH of the rectum wall is calculated for pelvic treatments [19]).

Most of the tests described in QA protocols concerns 2-D planning systems, i.e. mainly checks of treatment plans in the central plane. In principle these tests can also be extended to other planes if target volume, normal tissue contours and beam configuration are indicated in these planes as well. In addition 3-D image information concerning anatomy, beam set-up and dose distribution should be verified. Finally tools for analysis of dose distributions should be tested. This subject is still in its early stage of development and has been discussed by McShan [20].

TABLE VIII. REPORTED USERS' MEETING

Country	Treatment planning system
Finland	Varian - Dosetek - CADPLAN
Nordic countries	HELAX TMS
Poland	Alfard*
The Netherlands, Australia	Nucletron - PLATO

* 2D PC-based Polish system

6. CONCLUSIONS

At this moment there is only one comprehensive report available that deals with QA of treatment planning systems while no national or international recommendations are currently available. In a number of countries, however, working groups are drafting documents with sets of recommendations. It can be expected that in the near future a more uniform approach of QA of treatment planning systems will be adopted in radiotherapy institutions. For 3-D treatment planning systems systematic checks are still under development. Close cooperation between manufacturers and users of treatment planning systems remains an important aspect of the quality of the use of these systems.

REFERENCES

[1] MIJNHEER, B.J., BATTERMANN, J.J., WAMBERSIE, A., What degree of accuracy is required and can be achieved in photon and neutron therapy?, Radiother. Oncol. **8** (1987) 237-253.

[2] WAMBERSIE, A., VAN DAM, J., HANKS, G., MIJNHEER, B.J., BATTERMANN, J.J., "What accuracy is needed in dosimetry", IAEA-TECDOC-734, IAEA, Vienna (1994) 11-35.

[3] MCCULLOUGH, E.C., KRUEGER, A.M., Performance evaluation of computerized treatment planning systems for radiotherapy: External photon beams, Int. J. Radiat. Oncol. Biol. Phys. **6** (1980) 1599-1605.

[4] DAHLIN, H., LAMM, I.-L., LANDBERG, T., LEVERNES, S., ULSØ, N., User requirements on CT-based computed dose planning systems in radiation therapy, Acta Radiol. Oncol. **22** (1983) 397-415.

[5] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photon and Electrons, Report 42, ICRU, Bethesda, MD, (1987).

[6] BRAHME, A. (Ed), Accuracy requirements and quality assurance of external beam therapy with photons and electrons, Acta Oncol., suppl. 1 (1988) 76 pp.

[7] VAN DYK, J., BARNETT, R.B., CYGLER, J.E., SHRAGGE, P.C., Commissioning and quality assurance of treatment planning computers, Int. J. Radiat. Oncol. Biol. Phys. **26** (1993) 261-273.

[8] KUTCHER, G.J., COIA, L., GILLIN, M, HANSON, W.F., LEIBEL, S., et al., Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40, Med. Phys. **21** (1994) 581-618.

[9] ROSENOW, U.F., DANNHAUSEN, H.-W., LÜBBERT, K., NÜSSLIN, F., RICHTER, J, et al, Quality assurance in treatment planning. Report from the Germany Task group. (Proc. 9th Int. Conf. on the Use of Computers in Radiotherapy, 1987), 45-48.

[10] SOCIÉTÉ FRANÇAISE DES PHYSICIENS D'HOPITAL. Choix et évaluation des systèmes informatiques en radiothérapie, SFPH, Siège Institut Curie, 26 Rue d'Ulm, 75231 Paris (1989) 361 pp.
[11] KOSUNEN, A, JÄRVINEN, H., VATNITSKIJ, S., ERMAKOV, I., CHERVJAKOV, A., et al. Intercomparison of radiotherapy treatment planning systems for external photon and electron beam dose calculations, Radiother. Oncol. **29** (1993) 327-335.
[12] WITTKÄMPER, F.W., MIJNHEER, B.J., VAN KLEFFENS, H.J., Dose intercomparison at the radiotherapy centers in The Netherlands. 2. Accuracy of locally applied computer planning systems for external photon beams, Radiother. Oncol. **11** (1988) 405-414.
[13] VAN BREE N.A.M., VAN BATTUM, L.J., HUIZENGA, H., MIJNHEER, B.J. Three-dimensional dose distribution of tangential breast treatment: a national dosimetry intercomparison. Radiother. Oncol. **22** (1991), 252-260.
[14] FEROLDI, P., GALELLI, M., BELLETTI, S. A comparison of the accuracy of computer treatment planning systems in brachytherapy, Radiother. Oncol. **24** (1992) 147-154.
[15] JACKY, J., KALET, I., Assuring the quality of critical software. (Proc. 9th Int. Conf. on the Use of Computers in Radiotherapy, 1987), 49-52.
[16] AUSTRALASIAN COLLEGE OF PHYSICAL SCIENTISTS AND ENGINEERS IN MEDICINE AND BIOLOGY. A Code of Safe Practice for External Beam and Sealed Brachytherapy Sources Used in Radiation Oncology (in press).
[17] INSTITUTE OF PHYSICAL SCIENCES IN MEDICINE. Quality Assurance in Treatment Planning Systems (in press).
[18] SIPILÄ, P., "Quality assurance of treatment planning systems", Radiation Dose in Radiotherapy from Prescription to Delivery, IAEA-TECDOC-734, IAEA, Vienna (1994) 341-344.
[19] VAN 'T VELD, A.A. AND BRUINVIS, I.A.D. Accuracy in grid-based volume calculations. (Proc. 10th Int. Conf. on the Use of Computers in Radiotherapy, 1994), 76-77.
[20] MCSHAN, D.L., Comments on: Commissioning and quality assurance of treatment planning computers, Int. J. Radiat. Oncol. Biol. Phys. **26** (1993) 371-372.