QUALITY ASSURANCE FOR IMAGE-GUIDED RADIOTHERAPY

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QUALITY ASSURANCE PROGRAM

• A comprehensive QA program is mandatory at the time of commissioning and to maintain the requirements of the system

• Quality control (QC) tests should:
  - be reasonable, simple and fast to perform
  - include safety and functionalities, precision of the OBI and treatment couch movements, image quality and for CBCT or MV-CT, HU accuracy
  - involve algorithms allowing mechanical couch correction or image reconstruction and matching, etc
  - include patient dose evaluation
IMAGE GUIDED RADIONUDESY

Involves multiple imaging procedures:

- during planning process: CT images sometimes fused with PET, SPECT, ultrasound or MR imaging

- to optimise patient set-up: film or electronic imaging using a kV simulator, or use of calculated digitally reconstructed radiographs (DRRs) from the planning CT used as the simulation images

- to check patient set-up: use of EPID, diagnostic X-ray or kV or MV cone beam CT imaging

- to characterize organ or tumor motion due to the respiration or other influences: breathing correlated CT (referred as 4D CT) or linac, etc
OVERVIEW OF EXISTING COMMERCIAL TECHNOLOGIES IN IMAGE GUIDANCE

- Planar imaging, **EPID**
- **kV-CBCT**, only available on Elekta and Varian
MV-CBCT, only available on Siemens

MV-CT, only available on helical Tomotherapy

- Stereoscopic X-ray imaging, ultrasound imaging independent of linac manufacturer...

MARINELLO, AAPM, Prague 2008
Irrespective of the imaging equipment used, the following features must be verified:

- mechanical and electrical safety
- geometrical performance and reproducibility
- calibration
- image quality
- software performance, etc

The controls must be undertaken only if mechanical performances and radiation stability of the linac are correct
ANTI-COLLISION AND MECHANICAL VERIFICATIONS

After M. Djordjevic, 2007
must be made and stored ...

*Example:*

```plaintext
<table>
<thead>
<tr>
<th>Collision Interlocks</th>
<th>Position Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Arm: Left Side Panel</td>
<td>20</td>
</tr>
<tr>
<td>Upper Arm: Right Side Panel</td>
<td>20</td>
</tr>
<tr>
<td>Collision Bar</td>
<td>20</td>
</tr>
<tr>
<td>Cassette Head: All 4 Sides &amp; Top</td>
<td>20</td>
</tr>
</tbody>
</table>
```

**Daily EPIQ Quality Assurance Log**

**Dept. of Rad. Onc.**

Date: ___________  Initials: ______

**AAPM report 75 (TG58), 2001**
CHECK OF AGREEMENT BETWEEN VISUAL AND DISPLAYED SCALES

Source and detector position

<table>
<thead>
<tr>
<th>Source</th>
<th>Visual</th>
<th>Displayed</th>
<th>Source Rot</th>
<th>Visual</th>
<th>Displayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>271.7</td>
<td></td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSA</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imageur KV Vrt</td>
<td>-50.0</td>
<td></td>
<td>Imageur KV Lat</td>
<td>0.0</td>
<td>+14.8</td>
</tr>
<tr>
<td>Imageur KVLng</td>
<td>0.0</td>
<td></td>
<td>Imageur KVLng</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Imageur KVHor</td>
<td>0.0</td>
<td></td>
<td>Imageur KVHor</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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MV-aSi EPID (AS 500)
kV-aSi detector (Pax Scan 4030 CB)
kV X-ray source

VARIAN- Clinac 2100 C
**EPID GENERALLY BASED ON:**

- matrix ion chambers
- combination of camera and phosphor screen

- active matrix flat panel (*photodiode array made of amorphous silicium*, or *photoconductor array made of selenium*)...

*MARINELLO, AAPM, Prague 2008*
Compton electrons produced in copper plate:
energy released in the scintillator

=> fluorescence photons detected by photodiodes
• copper plate replaced by aluminium plate

• anti-scatter grid added to avoid scattered radiation from patient and table
Photodiodes signal read out line by line and sent to a converter 
=> digitalized images through pulses continously processed and displayed
QUALITY CONTROLS (QC)

1. ELECTRONIC PORTAL IMAGING DEVICE (EPID)
CALIBRATION OF EPID

• Purpose:
  Check that dark current, noise and homogeneity are acceptable

• Method:
  Should be carried out for all energies, dose-rates and geometrical conditions used for patients, following the recommendations made by the vendor, and using the tools provided with the system
HOMOGENEITY CHECK

RX 6MV
20 x 26 cm²
maximal field size

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Pixel defect can be detected and repaired through software interpolation
**IMAGE QUALITY : CONTRAST**

\[
C = \frac{\text{signal}}{\text{mean signal}} = \frac{\Phi_{p2} - \Phi_{p1}}{(\Phi_{p2} + \Phi_{p1} + 2\Phi_S)/2}
\]

where \(\Phi_{p1}, \Phi_{p2}, \text{and } \Phi_S\) are the primary and scatter photon fluences.

\[
\Delta = L_X |\mu_{\text{bone}} - \mu_{\text{water}}|
\]

with

\[
SF = \Phi_S \left(\Phi_S + \Phi_P\right)
\]
**IMAGE QUALITY:** SPATIAL RESOLUTION

minimum distance between 2 adjacent features, or minimum size of a feature that can be detected by EPID.
IMAGE QUALITY

AAPM TG 58, Report N° 75

Tolerances for EPID

- acceptable contrast: 1%
- spatial resolution: 2-3 mm
ALUMINIUM LAS VEGAS PHANTOM

Spatial resolution given by the visible columns and contrast deduced from the visible lines.
**EPID:** on line or off line 2D tissue and bone imaging => patient set-up and treatment verification by comparison with DRR or reference EPID image

= > softwares check mandatory
EXAMPLE OF SOFTWARE CHECKS

STEP 1

CT Scan of the phantom in "treatment" position

DDR PRODUCING using TPS

Transfert to linac through network
EPID image taken without phantom
⇓
check of the field shape using software
⇓
check of geometric reproduction of field shape
STEP 3

Anterior field

EPID Image

REFERENCE

VISUAL COMPARISON

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ANATOMY CHECK WITH CORRELATION POINTS

MARINELLO, AAPM, Prague 2008
2. MV-kV & kV-kV

QUALITY CONTROLS
Image-guidance: MV/kV Coincidence

- Treatment is orthogonal to imaging

Princess Margaret Hospital

MARINELLO, AAPM, Prague 2008

After Bissonnette, 2007
**$kV$-$kV$**

2 portal images taken at $0^\circ$ and $90^\circ$ either in radiographic or fluoroscopic modes

- safety and anticollision checks
- mechanical checks such as coincidence between rotation and beam axis, etc

*note:* no light field => need to use special tools adapted to X-ray energy and mode used.
CHECK OF CENTRAL AXIS

1. Check lasers
2. Align cube phantom with light and lasers
3. Acquire AP and lateral images
4. Check rotation axis

lead ball (Φ = 2mm) at the center of the cube

http://www.modusmed.com/igrt.htm
CHECK OF IMAGE QUALITY

Same method as for EPID but with tools adapted to diagnostic energy*...

http://www.leedstestobjects.com

* AAPM Report N°74 QA in Diagnostic Radiology, 2002
50kV – small focus spot

It is important to evaluate **contrast** and **spatial resolution** with the same parameters as those used for patients.

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CHECK OF IMAGE GEOMETRY ......
Printed Board: Set-up

Source surface distance: 1m

Printed Board: Acquisition

Source surface distance: 1m

Various surface detector distance: 20cm to 50cm
QA OF IMAGE GEOMETRY

PRINTED BOARD

To checked for both perpendicular directions

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CHECK OF TABLE DISPLACEMENT

Example of tool used to check automatic correction of table displacement by software

It can be used for:

- kV-kV
- kV- MV
- CB- CT
- MV- CT
CHECK OF TABLE DISPLACEMENT

↓

accuracy and repeatability

1. Acquire CT scan with phantom. Treatment isocenter aligned according to white crosses
2. Check lasers
3. Setup the phantom with light and lasers according to white crosses
4. Move the couch to set up the phantom according to the red or green crosses
5. Check the deviation founded by the software
6. Repeat points 3 to 4; then check and apply automatic correction of table displacement in order to check it

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3. CONE-BEAM CT (CBCT)  
QUALITY CONTROLS
**CONE BEAM CT:** 3D on line bone and soft tissue imaging => patient set-up corrections and evaluation of organ movements through comparison with **CT used for planification**

available on ELEKTA and VARIAN linacs...
CHARACTERISTICS OF VARIAN – CBCT  
(model VZW2940FH2-02)

• a kV x-ray source and an a-Si flat panel detector mounted orthogonally to the EPID (aSi500 PortalVision) on linac gantry via 2 robotically controlled arms

• source- axis distance 100 cm and axis - detector distance 50 cm

• detector area 40 x 30 cm² => maximum beam size at isocentre: 20 cm (longitudinal axis) and 26 cm (transversal axis)

• CBCT acquired by a rotation of the linac gantry over 370° (10° overlap on left side) and using x rays in radiographic or pulsed-fluoro mode (focal spots 0.4 mm or 0.8 mm)

• 2 acquisition modes depending on the size of anatomical site...
**FULL FAN MODE**

used to scan site where the size is less than 24 cm (head and neck), with detector centered

---

**HALF FAN MODE**

used for sites larger than 24 cm (mostly for body scans), with detector shifted to 1 side to cover more than the half patient volume

---

**CBCT ACQUISITION MODES**

**FULL FAN MODE**

- used to scan site where the size is less than 24 cm (head and neck), with detector centered

**HALF FAN MODE**

- used for sites larger than 24 cm (mostly for body scans), with detector shifted to 1 side to cover more than the half patient volume
TOOLS TO CHECK THE QUALITY OF THE CORRECTION

**Dark grey = scanner,**  **Clear grey = CBCT**

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TOOLS TO CHECK THE QUALITY OF THE CORRECTION

CB CT images

CT window

Reference: CT images

CB CT images

CT window

CB CT images

CT window

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Coincidence between the image of lead ball and axis < 2mm

(After Bissonnette, 2007)
EXAMPLES OF ARTEFACTS

A: Ring artefact
B: Streaking

Truncation artefact

After ZHANG, IJROBP, 2005
FLEXMAP

• ELEKTA:
  Flexes are corrected for in reconstruction algorithm

• VARIAN
  Flexes are compensated for by robotic arm motion

If artefacts remain once the calibration of the device made again => defective components or software problems
QC OF THE CBCT IMAGE

CATPHAN phantoms 500 or 600 (or equivalent) allow most of the checks at the same time using the same protocols as for patients.
Add Scatter

IEC standard 61675-1
QUALITY CONTROL OF CBCT IMAGE

CBCT Varian (half-fan- max field-125 kV- mA- 25 s)

Uniformity
Detectability & slice thickness
Resolution

Results obtained highly dependent of the equipment, software versions... and parameters of irradiation (beam hardening, scatter, energy, dose-rate...)
IMAGES OF THE HOMOGENEOUS MODULE

VARIAN- CBCT

Full fan mode

Half-fan mode

M. DJORDJEVIC
Master of sciences
Spatial Resolution

After Bissonnette, 2007
INFLUENCE OF THE SCATTERING VOLUME ON CONTRAST

5 cm (longitudinal axis) x 26 cm at the axis

20 cm* (longitudinal axis) x 26 cm

*maximal size
Figure 27. Measured HU versus expected HU for planning CT, full-fan and half-fan mode CBCT. Mean HU are used for the CBCT modes, $n = 6$. 

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M. DJORDJEVIC
IMAGES CAN BE VISUALLY OR AUTOMATICALLY ANALYSED USING SPECIAL SOFTWARES
The ARTiScan* Solution

http://www.aquilab.com

Integrated solution for **Quality Control** in **Diagnostic or Radiotherapy Imaging** including:

- **Equipment**
  independent PC connected to the PACS or network
- **Software ARTiScan**
  DICOM, Image gestion
- **Modules for automatically analysing the images**
  Specific module for each test object and imaging device

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<table>
<thead>
<tr>
<th></th>
<th>MV 2D</th>
<th>MLC</th>
<th>KV 3D</th>
<th>KV 2D</th>
<th>KV / MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPI D (PTW) – Las Vegas</td>
<td>EPI D (PTW) – Las Vegas</td>
<td>80, 120 Lames</td>
<td>CATPHAN CTP504</td>
<td>Leeds TOR 18FG</td>
<td>Plaque Test AQUILAB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 Lames, Beam Modulator</td>
<td>CATPHAN CTP503</td>
<td>Leeds TOR 18FG</td>
<td>Plaque Test AQUILAB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MV 3D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Siemens QA Phantom</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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INTEREST:

Results can automatically be compared to:

- reference data, either published in national or international recommendations (IEC...) or established by users (if possible acceptance tests of equipment) when no recommendations are existing.

- previous checks in order to point out possible changes and undertake preventive actions.
USE OF CBCT TO CHECK PATIENT SET-UP

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Automatic (version 2.0) or manual correction of couch position and angle
EVALUATION OF PATIENT DOSE
PATIENT DOSE

Benefits of IGRT are obvious => possibility to see the target and organ at risk (rectum) before the treatment

However questions are raised

• What is the dose delivered by IGRT ?
• Does daily use of IGRT for patient setup significantly increases the already high level of therapeutic radiation and the doses to the normal tissues of the patient ?
• How taking it into account?
Although different in modality and method, all radiographic techniques have in common the fact that they can deliver a significant radiation dose to the patient (especially when they are used for accurate day-to-day set-up)

REPORT OF THE AAPM TG 75

The management of imaging dose during image-guided radiotherapy

Medical Physics, Vol. 34, No10, 4041-4063

MARINELLO, AAPM, Prague 2008
EVALUATION OF IMAGING DOSE

Fundamental distinction between:

- **dose**: dose deposited locally per unit of mass by ionizing radiation (J/kg or Gy, mGy...). It depends on the **fluence** (rate and duration).

- **integral dose**: total dose integrated over the exposed mass (volume) of the anatomy (J). It depends on fluence and irradiated volume.

Absorbed dose is the meaningful quantity for estimating the biological effect of irradiation and integral dose to quantify the risk of second cancers in future.
GENERALITIES

- **Planar imaging** (portal imaging, kV-kV, MV-kV): dose to the patient/image greatest at the skin surface nearest to the source and falls off progressively as the radiation transits the body to the image detector.

- **Axial imaging** (CT, CBCT, MV-CT): dose distributed nearly uniformly throughout the image volume to produce 3D image of uniform cross-sectional quality
DOSE DELIVERED BY EPID

• The image being created with the megavoltage beam which is used to treat the patient.

• Generally source/detector distances are variable from 120 to 150 cm => cumulative dose to acquire single image using aSi panels ranges from 1 to 5 MU for most users (AAPM, 2007).

• For scenarios that involve daily or numerous portal images, it is recommended to subtract the number of MU used for imaging from the number of MU necessary to treat the patient (possibility to do it automatically with some software).
DOSE DELIVERED BY kV- kV

When used in radiographic mode to acquire AP and lateral alignment radiographs, the dose to the patient is approximately 1-3 mGy per image, depending on the technique (Perkins et al. 2006)

=> in most cases, it can be neglected.
## DOSE DELIVERED BY CBCT

### kV CBCT

<table>
<thead>
<tr>
<th>Phantom (Φ= 30 cm)</th>
<th>Dose (center)</th>
<th>Dose (lateral)</th>
<th>80Gy Daily image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synergy (120kV)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.6 cGy</td>
<td>2.3 cGy</td>
<td>64 cGy</td>
</tr>
<tr>
<td>OBI (120 kV)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>~3 cGy</td>
<td>~ 5 cGy</td>
<td>120 cGy</td>
</tr>
<tr>
<td>Siemens (Prototype)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.7 cGy</td>
<td>2.3 cGy</td>
<td>68 cGy</td>
</tr>
</tbody>
</table>


### MV CBCT

<table>
<thead>
<tr>
<th>Prostate (center)</th>
<th>6.4 cGy</th>
<th>256 cGy</th>
</tr>
</thead>
</table>

The dose delivered by kV-CBCT can be optimized by adapting the collimation aperture to the size of the volume to be explored:

- by software (Varian linacs)
- by inserting a special accessory (Elekta)
PREPARATION AND CHECK OF THE IVD METHOD

• Phantom Rando Alderson

• Irradiation conditions identical to those used for patient CBCT (prostate):
  - 125 kV
  - Half bow-tie
  - 80 mA
  - 25 ms/pulse

• Use of TLD 700H for point dose measurements…
... and use of EBT GAFCHROMIC FILM for evaluating the dose distribution

- A-P thickness 23 cm
- Table height 11.5 cm
- 15 CBCT => 100% ~ 0.7 Gy

100% = \( \frac{D_{\text{ant}} + D_{\text{post}}}{2} \)
### RESULTS - 1 CBCT (Alderson phantom)

<table>
<thead>
<tr>
<th>TH (cm)</th>
<th>$D_{\text{ant}}$</th>
<th>$D_{\text{post}}$</th>
<th>$D_{\text{left}}$</th>
<th>$D_{\text{right}}$</th>
<th>$D_{\text{mid-thickness}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>8</td>
<td>6.6</td>
<td>-</td>
<td>-</td>
<td>6.2</td>
</tr>
<tr>
<td>12.3</td>
<td>6.5</td>
<td>6.8</td>
<td>-</td>
<td>-</td>
<td>5.4</td>
</tr>
<tr>
<td>11.5*</td>
<td>5.5</td>
<td>6</td>
<td>4.9</td>
<td>4.9</td>
<td>4.7</td>
</tr>
</tbody>
</table>

*mid-thickness

- Dose heterogeneous within the irradiated volume and very dependent on the patient position/axis (TH)

- For geometrical and anatomical reasons, maximal skin doses are measured along the antero-posterior axis of the phantom (smallest thickness), and their mean is close or higher to the dose at mid-thickness of the phantom or at the rectum position (organ at risk)

$=>$ mean = REFERENCE FOR PATIENT DOSE CORRECTION
Posterior dosimeter under the table sheet (centered with light beam)
=> measured correction factor 1.24
RESULTATS

<table>
<thead>
<tr>
<th>Séquence n°</th>
<th>HT (cm)</th>
<th>Dose moyenne pour 1 CBCT (cGy):</th>
<th>Nombre de CBCT</th>
<th>DOSE TOTALE (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(D_{\text{Ant}})</td>
<td>(D_{\text{Post}})</td>
<td>(D_{\text{Droit}})</td>
</tr>
<tr>
<td>1</td>
<td>12.3</td>
<td>6,43</td>
<td>6,35</td>
<td>3,60</td>
</tr>
<tr>
<td>2</td>
<td>11.8</td>
<td>5,60</td>
<td>4,92</td>
<td>3,10</td>
</tr>
</tbody>
</table>

(2) Dose de référence 100%
(3) en supposant tous les CBCT réalisés jusqu’à l’avant dernière séance

\[\rightarrow \] Nombre de CBCT restant à réaliser le jour de l’émission de cette fiche: 3

Estimation de la dose physique totale délivrée par les CBCT: \[1,46 \text{ Gy}\] / 26 CBCT

Date: 
Signature Radiophysicien(ne):

Décision médicale: prise en compte de la dose d’imagerie par CBCT:

Oui ☐ Non ☐ Si oui, préciser comment:

Date: 
Signature Médecin référent:
CONCLUSION

• In vivo evaluation of maximal dose susceptible to be delivered to organ at risk (rectum dose for prostate irradiation) possible with TLD

• Important number of CBCT => contribution of dose to be taken into account... but how to do it and what EBR for low X-rays and high MV X-ray beams)*

*Wambersie Ph D recommends to use a correction factor of 1.13 for X-rays of 200 kV compare to $^{60}$Co but for higher doses

• Waiting for a general consensus, we have decided to subtract the physical dose delivered by CBCT from the prescribed dose (without correction for biological effects)