QA for Helical Tomotherapy: Report of the AAPM Task Group 148

Members:
Katja Langen (Co-chair) Chengyu Shi
Niko Papanikolaou (Co-chair) David Followill
Walter Grant Chester Ramsey
Richard Crilly John Balog
Murty Goddu Gustavo Olivera

TG-148 overview
- Introductory chapters. Define TomoTherapy specific terminology. Cover unique aspects of technology and clinical implementation.
- Provide QA guidelines for treatment delivery, imaging, and treatment planning system. Recommendations on what to test. Provide examples of how to test.
- Provide summary of QA aspects according to frequency.

Conflict of Interest:
Dr. John Balog owns TomoTherapy stock.
Dr. Katja Langen holds a research agreement with TomoTherapy, Inc.
Dr. Gustavo Olivera is an employee of TomoTherapy Inc. and has a financial interest in TomoTherapy, Inc.

System Overview
- Front view
- Lateral view

System Overview- MLC

System Overview- Operation
- Relative opening time
- MLC leaf
Three QA chapters

- Treatment Delivery
- Imaging
- Treatment planning system

Three QA chapters

- Treatment Delivery
- Imaging
- Treatment planning system

Treatment Delivery QA

- Mechanical alignments
- Beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Calibration

Treatment Delivery QA

- Mechanical alignments
- Beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Annual
- Calibration

Treatment Delivery QA

- Alignment of Linac
  - in x-direction against MLC
    - Look for symmetry
    - against Y-jaw
    - Look for center
  - in y-direction

- beam divergence is perpendicular to axis of rotation
**Mechanical alignment QA**

- Y-Jaw is parallel to plane of rotation
- Treatment field centering: test that all fields have common center
- MLC centering and twist: test that MLC is centered and parallel to plane of rotation

**Film**

**Treatment Delivery QA**

- Mechanical alignments
- Beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Calibration

**Fan Beam**

- 400 mm
- 10, 25, or 50 mm
- no flattening filter

**Beam parameter QA**

- X-direction beam profile:
  - Monthly: consistency
  - Annual: agreement with model
  - TG-142 tolerance: 1% (av. difference within 80% of field)

- Longitudinal beam profile:
  - Monthly: consistency
  - Annual: agreement with model
  - 1% FWHM tolerance
Beam parameter QA

Percentage Depth Dose:

Monthly: consistency
Annual: agreement with model
TG-142 tolerance: 1% PDD$_{10}$ or TMR$_{10}^{20}$

Beam parameter QA

Monitor output using static and/or rotational procedures (if static daily, rot. weekly, or vice versa)

Daily (within 3%)
Monthly (with calibrated IC) within 2%

Fixed gantry
No MLC action
Rotating gantry
MLC action
e.g. phantom-based treatment plan

Beam parameter QA

Monitor rotational output variation monthly

Tolerance ± 2%

Treatment Delivery QA

- Mechanical alignments
- Beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Calibration

Synchronicity (quarterly)

Gantry angle: Consistency and accuracy during tx (1°) tolerance
Couch speed: Uniformity (2% tolerance)
Couch translation per gantry rotation: Synchronicity

Example tests are detailed in Fenwick et al. (PMB, 49, 2933-2953)
**Miscellaneous (monthly)**

Interrupted procedure = Uninterrupted procedure
(tolerance 3% in delivered dose)

Couch travel: actual distance = digital readout
(tolerance 1 mm)

Misc. couch aspects (level, sag, travel perpendicular
to treatment plane)

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**Miscellaneous**

Lasers:
- **Stationary (green)**
- **Movable (red)**

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**Treatment Delivery QA**

- QA of mechanical alignments
- QA of beam parameters
- Synchronicity tests
- Miscellaneous Aspects
  - **Calibration**

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**Calibration**

**TG-51 equivalent static beam calibration:**

Problem: \( k_Q \) values in TG-51 are a function of PDD
@ 100 cm SSD for 10 by 10 cm field

>> not achievable on Tomo (85 cm SSD, max field
length 5 cm)

>> IAEA/AAPM joint committee proposed non-compliant beam calibration formalism

(Alfonso et al., Med Phys, 35, 5179-86, 2008)
Calibration-machine specific reference field (msr)
Tomo-msr: 5 cm by 10 cm @85 cm SSD

\[ D_{w, Q_{\text{msr}}}^{f_{\text{msr}}} = M_{Q_{\text{msr}}}^{f_{\text{msr}}} \cdot N_{D, w, Q_{\text{msr}}} \cdot k_{Q_{\text{msr}}} \cdot k_{Q_{\text{msr}}, f_{\text{ref}}} \]

Corrected reading in msr-field

Chamber calibration factor

\[ k_{Q_{\text{msr}}} \text{ under standard conditions} \]

Correction for IC response from standard to msr-field
Calibration-machine specific reference field (msr)

Tomo-msr: 5 cm by 10 cm @85 cm SSD

\[ D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} \cdot N_{D,w,Q_{0}} \cdot k_{Q_{0}} \cdot k_{Q_{msr, Q_{0}}} \]

Thomas et al. technique

Thomas et al.
Med. Phys. 32, 1346, 2005

Calibration-plan-class specific reference field (pcsr)

(Alfonso et al) pcsr: “as close as possible to a final clinical delivery scheme, but delivers a homogeneous absorbed dose to an extended geometrically simple target volume”

Tomo: generate treatment plan using helical tomotherapy delivery mode

Calibration-plan-class specific reference field (pcsr)

\[ D^{f_{pscr}}_{w,Q_{pscr}} = M^{f_{pscr}}_{Q_{pscr}} \cdot N_{D,w,Q_{0}} \cdot k_{Q_{0}} \cdot k_{Q_{pscr, Q_{0}}} \cdot k_{Q_{msr, Q_{pscr}}} \]

For 2.5 and 5 cm field

* Derived from work by Duane (MP, 33, 2003) and Jerai (MP, 32, 57)
Calibration

Of the two calibration routes, the calibration via pcsr-field (rotational delivery) is the relevant route for tomotherapy.

(Alfonso et al., Med Phys, 35, 5179-86, 2008)

Three QA chapters

- Treatment Delivery
- Imaging
- Treatment planning system

Imaging QA

- Geometry Tests
- Image Quality Tests
- MVCT Dosimetry

Geometry Tests

- Image registration and alignment (Daily)
  Image misaligned phantom, check registration and automatic alignment
- MVCT Image Distortions (Monthly)
  Image phantom, check dimensions and orientation
- imaging/treatment coordinate coincidence (Annual)
  Phantom based end-to-end test

Example daily imaging test

- Test imaging, registration, alignment chain

1) Scan
2) Register - compare to known offsets
3) Align - test automatic couch setup

Tolerance: Consistency within 1 mm

Image Quality (monthly)

- Noise
- Uniformity
- Spatial resolution
- CT-number
Image Quality (monthly)
- Noise (SD of HU unit in uniform phantom)
- Uniformity (HU of central vs. peripheral ROI)
- Spatial resolution
- CT-number

Spatial resolution
Resolution of high contrast object:
Tolerance: 1.6 mm object should be resolved

CT number
Important if MVCT is used for dose calculations
Monitor HU for water, lung, bone equivalent material

MVCT Dosimetry
Measure multiple slice average dose (MSAD) in Phantom during MVCT scan, IC based

Three QA chapters
- Treatment Delivery
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Treatment Planning QA
Geometric validation tests
Dosimetric validation test
Annual phantom-based end-to-end test
Plan specific QA
TPS- Geometric test (Annual)

Test CT data import: dimensions, orientation, text

Test integrity of imported structure set: volume and dimension

TPS- Dosimetric tests (Annual)

Generate phantom-based plans test with IC measurements

Generate plans for on- and off-axis targets

Generate plans for each commissioned field size

Tolerance: 3%/3 mm

TPS- Patient Plan QA (DQA)

Recalculate plan in phantom geometry:

Expectation: 90% of measurements pass 3%/3mm test

Example: “Cheese” phantom, IC and Film

Summary Chapter:

Reorganize QA test by frequency

Provide daily, monthly, quarterly and annual QA tables

Provide tables for what to do after major component replacement

Summary Chapter: Daily

<table>
<thead>
<tr>
<th>Task</th>
<th>Purpose</th>
<th>Tolerance</th>
<th>Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>Radiation or Stats</td>
<td>Accuracy: within ±2%</td>
<td>Within ±2%</td>
</tr>
<tr>
<td>Image registration and alignment</td>
<td>Accuracy</td>
<td>Accuracy: ±1 mm</td>
<td>Within ±1 mm</td>
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<tr>
<td>Head/neck re-orientation</td>
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Month

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<tr>
<th>Task</th>
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<td>Within ±1 mm</td>
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<tr>
<td>X-ray machine</td>
<td>Performance</td>
<td>Consistency: ±2%</td>
<td>±2%</td>
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<tr>
<td>Treatment planning</td>
<td>Consistency</td>
<td>Consistency: ±2%</td>
<td>±2%</td>
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<tr>
<td>Equipment</td>
<td>Consistency</td>
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<tr>
<td>Software</td>
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## Quarterly

<table>
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<th>Component repl.</th>
<th>Magnetron/SSM</th>
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</table>

## Annual

<table>
<thead>
<tr>
<th>Component repl.</th>
<th>After Major Component Replacement</th>
</tr>
</thead>
</table>

### Material
- **Magnetron/SSM**: Required for both quarterly and annual replacements.
Component repl.

Where is TG-148 now?

- Accepted for publication in Med Phys (June 2010)
- Scheduled for August 2010 issue