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

Conflict of Interest:

Dr. John Balog owns TomoTherapy stock.

Dr. Gustavo Olivera is an employee of TomoTherapy Inc. and has a financial interest in TomoTherapy, Inc.

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.

System Overview

Front view  Lateral view
**System Overview**

Gantry continuously rotates while patient is translated through beam plane

*from: W. Kalender, Computed Tomography: Fundamentals, System Technology, Image Quality, Applications*

**System Overview**

Collimation

- **Y-jaw**: Collimates beam in y-direction to 1, 2.5 or 5 cm

- **MLC**: 64 leaves, open or closed temporal modulation

**System Overview**

Relative opening time

**Treatment Delivery QA**

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

Annual

Treatment Delivery QA
- Alignment of Linac
  - in x-direction against MLC
  - in y-direction against Y-jaw
  - beam divergence is perpendicular to axis of rotation

Mechanical alignment QA
Treatment field centering: test that all fields have common center

Y-Jaw is parallel to plane of rotation

MLC centering and twist: test that MLC is centered and parallel to plane of rotation
Fan Beam

X-direction

Y-direction

no flattening filter

Beam parameter QA

X-direction beam profile:

Monthly: consistency
Annual: agreement with model
TG-142 tolerance

Beam parameter QA

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
Beam parameter QA

Monitor output using static and/or rotational procedures:

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

Fixed gantry
No MLC action

Rotating gantry
MLC action
e.g. phantom-based treatment plan

Tolerance 2%

Treatment Delivery QA

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

Synchronicity (quarterly)

- **Gantry angle**: Consistency and accuracy during tx
- **Couch speed**: Uniformity
- **Couch translation per gantry rotation**: Synchronicity

Example tests are detailed in Fenwick et al. (PMB, 49, 2933-2953)
Treatment Delivery QA

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

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)

Miscellaneous

Lasers:

Stationary (green)

Movable (red)

Miscellaneous

Lasers:

Daily: Red=Green at initialization

Monthly: Red laser movement=planned movement

Annual (green):
Virtual iso to treatment plane = 70 cm
x and z location cross in center of imaging plane
Treatment Delivery QA
- QA of mechanical alignments
- QA of beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Calibration

Calibration
TG-51 equivalent static beam calibration:
Problem: $k_Q$ values in TG-51 are a function of PDD at 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
Allow two calibration routes:

Machine-specific reference field: msr

Plan class specific reference field: pcsr

(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

\[
D_{w, Q_{msr}}^{f_{msr}} = M_{Q_{msr}} \cdot N_{D, w, Q_{0}} \cdot k_{Q_0} \cdot k_{Q_{msr}, Q}
\]

**Corrected reading in msr-field**

Calibration-machine specific reference field (msr)

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

\[
D_{w, Q_{msr}}^{f_{msr}} = M_{Q_{msr}} \cdot N_{D, w, Q_{0}} \cdot k_{Q_0} \cdot k_{Q_{msr}, Q}
\]

**Chamber calibration factor**

**Measure** \( Q_{msr} \) field => get \( Q \) via Thomas technique (Thomas et al., Med Phys, 32, 1346, 2005)
Calibration-machine specific reference field (msr)
Tomo-msr: 5 cm by 10 cm @85 cm SSD

\[ D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}} \cdot N_{D_{w,Q_{0}}} \cdot k_{Q_{0}} \cdot k_{f_{msr,ref}} \]

Correction for IC response from (hypothetical) standard to msr field

Monte Carlo Calculations by Jerai
(Jerai et al., Med Phys, 32, 570-7, 2005) = 0.997

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 (pcs-r)

\[ D_{\phi, \theta}^{f_{\text{pcsr}}} = M_{\phi, \theta}^{f_{\text{pcsr}}} \cdot N_{\phi, \theta}^{f_{\text{pcsr}}} \cdot k_{\phi, \theta}^{f_{\text{pcsr}}} \cdot k_{\phi, \theta}^{f_{\text{pcsr}}} \cdot k_{\phi, \theta}^{f_{\text{pcsr}}} \]

Duane (experimental) = 1.00
For 2.5 and 5 cm field

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)

Imaging QA

- Geometry Tests
- Image Quality Tests
Geometry Tests
- MVCT Image Reconstruction Accuracy (Monthly)
- Image Registration tests (Annual)
- Dosimetric end-to-end test of registration accuracy (Annual)

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 2 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

Tolerance: less than 30 HU for water
less than 50 HU for lung/bone

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

**Frequency:**
- Daily
- Monthly
Where is TG-148 now?

- Initial submission to TPC in March
- Received TPC reviews in late April
- Re-submission to TPC in July