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

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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.

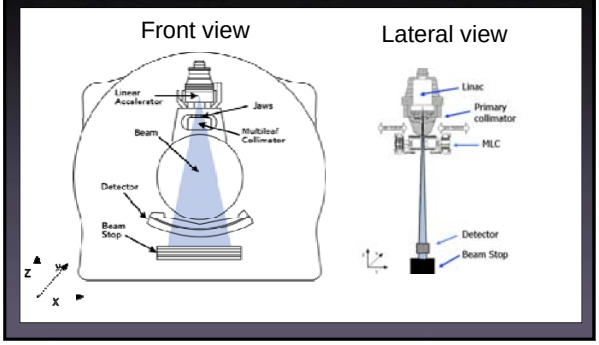
Introduction

- TG-148 provides QA guidelines specific for helical tomotherapy.
- Adapt guidelines from current TG reports where appropriate (e.g. output constancy test).
- Generate technology specific guidelines for QA aspects that are not covered elsewhere (e.g. specific mechanical alignment tests).

TG-148 overview

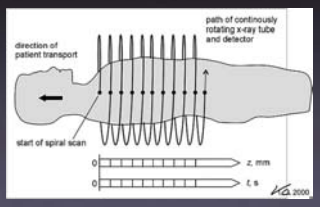
- Introductory chapters. Define TomoTherapy specific terminology. Cover unique aspects of technology and clinical implementation.
- Provide QA guidelines for treatment delivery, imaging, and treatment planning system. Recommendations on what to test. Provide examples of how to test.
- Provide summary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

System Overview



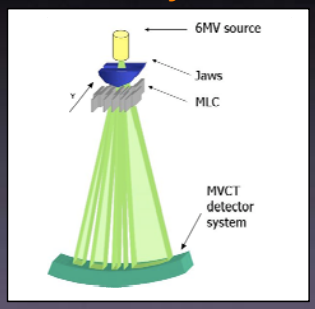
System Overview

Gantry continuously rotates while patient is translated through beam plane

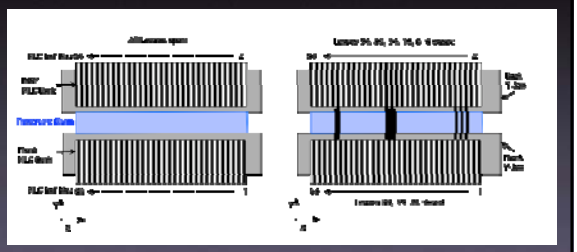


from: W. Kalender, Computed Tomography: Fundamentals, System Technology, Image Quality, Applications

System Overview binary MLC



System Overview binary MLC



System Overview

Treatment Delivery QA

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

Treatment Delivery QA

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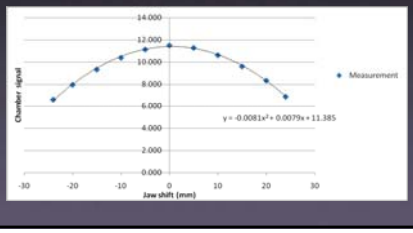
Treatment Delivery QA

- Alignment of Linac

in y-direction ⟶ against y-jaw

sweep y-jaw in y-direction, measure output



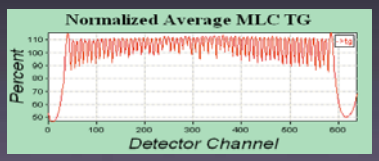
Treatment Delivery QA

- Alignment of Linac

in x-direction ⟶ against MLC

measure Tongue & Groove profile,

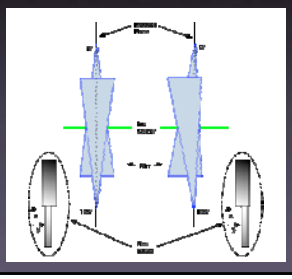
look for symmetry



Treatment Delivery QA

- Alignment of Linac

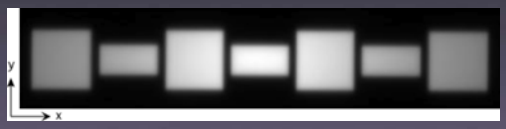
beam divergence ⟶ perpendicular to plane of rotation



Mechanical alignment QA

For treatment - 3 commissioned
field sizes in y-direction: 1, 2.5, and 5 cm

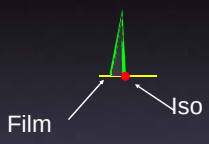
Treatment field centering: test that all fields have common center



Mechanical alignment QA

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

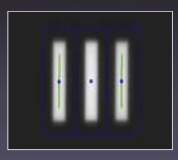
Gantry @ 0 °
Irradiate film positioned at iso



Swing gantry to 180 °
Close central leafs

Mechanical alignment QA

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



Two outer areas should be parallel- no twist

Central area should be centered between outer areas-no offset

Treatment Delivery QA

- QA of mechanical alignments
- QA of beam parameters
- Synchronicity tests
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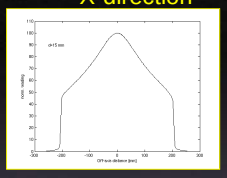
Fan Beam

no flattening filter

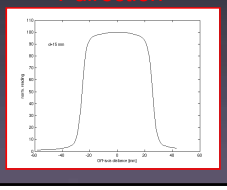
400 mm

10, 25, or 50 mm

X-direction

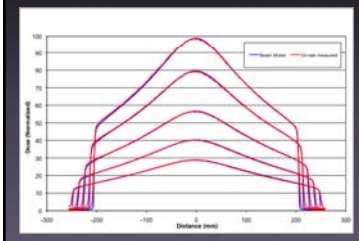


Y-direction



Beam parameter QA

X-direction beam profile:



Monthly: consistency

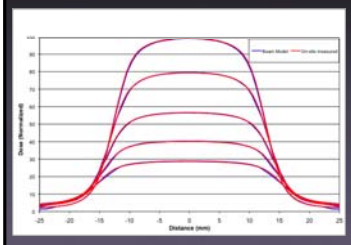
Annual: agreement with model

TG-142 tolerance

Beam parameter QA

Longitudinal beam profile:

Monthly: consistency

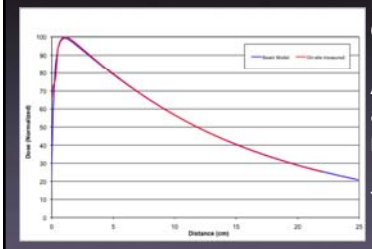


Annual: agreement with model

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 %

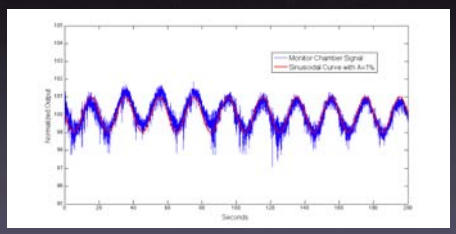
Fixed gantry
No MLC action

Rotating gantry
MLC action

e.g. phantom-based treatment plan

Beam parameter QA

Monitor rotational output variation monthly



Tolerance 2%

Treatment Delivery QA

- QA of mechanical alignments
- QA of beam parameters
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- 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
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Miscellaneous (monthly)

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

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

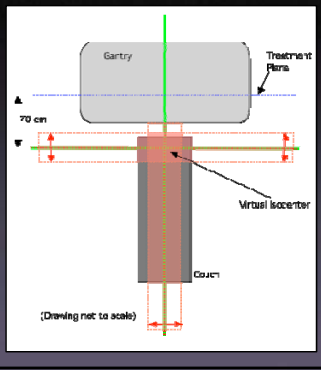
Misc. couch aspects (level, sag, travel perpendicular to treatment plane)

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
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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

Allow two calibration routes:

Machine-specific reference field: msr (static delivery)

Plan class specific reference field: pcsr (rotational delivery)

(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

$$D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k^{f_{msr},f_{ref}}_{Q_{msr},Q}$$

Calibration-machine specific reference field (msr)

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

$$D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k^{f_{msr},f_{ref}}_{Q_{msr},Q}$$

Corrected reading in msr-field

Calibration-machine specific reference field (msr)

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

$$D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k^{f_{msr},f_{ref}}_{Q_{msr},Q}$$

Chamber calibration factor

Calibration-machine specific reference field (msr)

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

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$

k_Q under standard conditions

Calibration-machine specific reference field (msr)

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

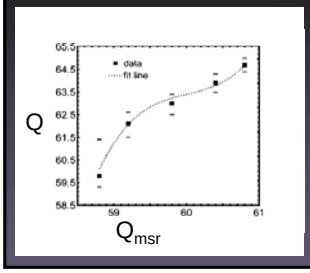
$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$

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

Calibration-determine k_{Q,Q_0}

Measure Q_{msr} in msr field, convert to Q

$Q = 1.35805 \bullet Q_{msr}^{3} - 244.493 \bullet Q_{msr}^{2} + 14672.98 \bullet Q_{msr} - 293479.4$



Example:

Q_{msr}= 58.74

Q= 59.66

Thomas et al., Med Phys, 32, 1346-53, 2005

Calibration-determine k_{Q,Q_0}

Ion Chamber	k_{Q,Q_0} Beam quality Q 58	63	66
Capintec PR-05/PR-05P	0.999	0.997	0.995
Exradin A1 Shonka[a]	0.999	0.998	0.996
Exradin A12 Farmer	1	0.999	0.996
Exradin A1SL miniature Shonka	0.999	0.998	0.996
NE2505/3,3A 0.6 cc Farmer	1	0.998	0.995
NE2571 0.6cc Farmer	1	0.998	0.995
NE2577 0.2cc	1	0.998	0.995
PTW N30001 0.6cc Farmer[b]	1	0.996	0.992
PTW N30002 0.6cc all Graphite	1	0.997	0.994
PTW N30004 0.6cc Graphite	1	0.998	0.995
PTW 31003 0.3cc waterproof[c]	1	0.996	0.992
Wellhofer IC-10/IC-5	1	0.99	0.996

Example:

Q_{msr}= 58.74

Q= 59.66

Small correction

Calibration-machine specific reference field (msr)

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

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \bullet N_{D,w,Q_0} \bullet k_{Q,Q_0} \bullet k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$

Monte Carlo Calculations by Jerai = 0.997

(Jerai et al., Med Phys, 32, 570-7, 2005)

Calibration-plan-class specific reference field (pcsr)

pcsr: "as close as possible to a final clinical delivery scheme, but delivers a homogeneous absorbed dose to an extended geometrically simple target volume"

$$D_{w,Q_{pcsr}}^{f_{pcsr}} = M_{Q_{pcsr}}^{f_{pcsr}} \bullet N_{D,W,Q_o} \bullet k_{Q,Q_o} \bullet k_{Q_{msr},Q}^{f_{msr},f_{ref}} \bullet k_{Q_{pcsr},Q_{msr}}^{f_{pcsr},f_{msr}}$$

(Duane et al., Med Phys, 33, 2093, 2006)

Duane (experimental) = 1.003 For 2.5 and 5 cm field

Calibration-plan-class specific reference field (pcsr)

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

$$D^{f_{pscr}}_{w,Q_{pscr}} = M^{f_{pcsr}}_{Q_{pcsr}} \bullet N_{D,W,Q_o} \bullet k_{Q,Q_o} \bullet k^{f_{msr},f_{ref}}_{Q_{msr},Q} \bullet k^{f_{pcsr},f_{msr}}_{Q_{pcsr},Q_{msr}}$$

= 1
For 2.5 and 5 cm fields

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

- Spatial/Geometry Tests
- Image Quality Tests
- MVCT Dosimetry

Spatial/Geometry Tests

- MVCT Image Reconstruction Accuracy (Annual)

Image known object, check dimension, orientation, and location

Tolerance: within 1 MVCT pixel

Spatial/Geometry Tests

- Image Registration tests (Annual)

Use phantom with high contrast object:

position with respect to external lasers

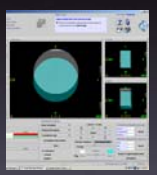
or

use known offset

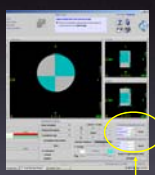
Tolerance: within 1 MV/kV pixel (larger pixel is limiting)

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

Phantom-based end-to-end test

- Dosimetric end-to-end test of registration accuracy (Annual)

  Phantom based end-to-end test, image, register, treat

  Analyze spatial accuracy of dose distribution in phantom using film dosimetry

  Accounts for registration, dose calculation, and delivery accuracy

Image Quality (monthly)

- Noise
- Uniformity
- Spatial resolution
- CT-number
- MVCT Dose

Noise

Standard deviation of HU in uniform phantom

Typical noise level:

50-70 HU central region

25-35 HU in peripheral region

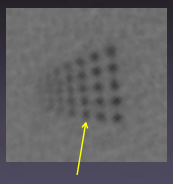
Uniformity

In uniform phantom, central and peripheral ROI:

Tolerance: less than 25 HU difference

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

MVCT dosimetry

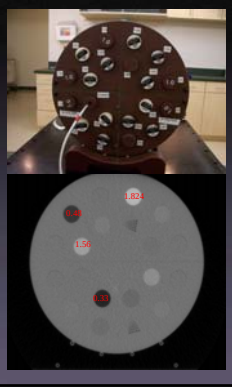
Multiple slice average dose (MSAD) measurement:

Scan phantom with IC inserted

In cheese phantom: 1-3 cGy for “Normal” scan

On monthly basis: less than 30 % variation

Monthly MVCT QA



Test Consistency

HU
Noise
Uniformity
Spatial resolution
Dose

- can be done with 1 MVCT scan

Treatment Planning QA

Geometric validation tests

Dosimetric validation test

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

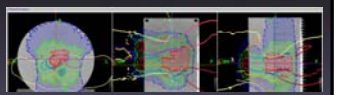
Tolerance: 3%/3 mm

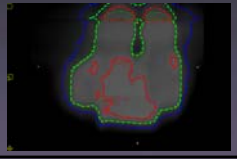
TPS- Patient Plan QA (DQA)

Recalculate plan in phantom geometry:

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

Example:
“Cheese” phantom,
IC and Film





Frequency:
Daily, monthly, quarterly, annual

Example:

DAILY Test	Purpose	Tolerance Limit	Report Section
Output Rotational or Static	Consistency	3%	V.B.2.d.
MVCT artifact	Consistency with ATP	pass/fail	VI.B.1.c.
Image registration	Consistency	2 mm	VI.B.1.c.
Laser and couch movement post registration	Consistency	1 mm	VI.B.1.c.
Red laser initalization	red=green laser	1 mm	V.B.4.b.

System Maintenance

Provide guidance of what to test after work on:

Magnetron/SSM
Linac/Target
Y-Jaw
MCL

Where is TG-148 now ?

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