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


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## Conflict of Interest:

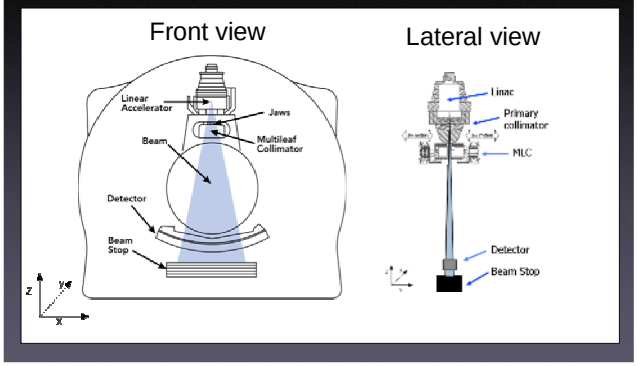
Dr. John Balog owns TomoTherapy stock.

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

## TG-148 overview

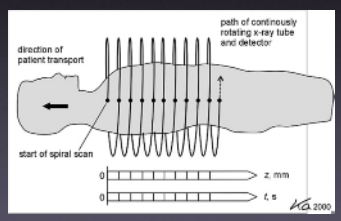
- Introductory chapters. Define TomoTherapy specific terminology. Cover unique aspects of technology and clinical implementation.
- Provide QA guidelines for treatment delivery, imaging, and treatment planning system. Recommendations on what to test. Provide examples of how to test.
- Provide summary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

## System Overview



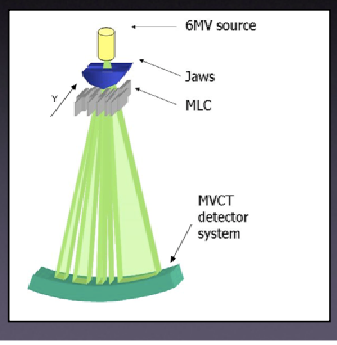
# System Overview

Gantry continuously rotates while patient is translated through beam plane




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

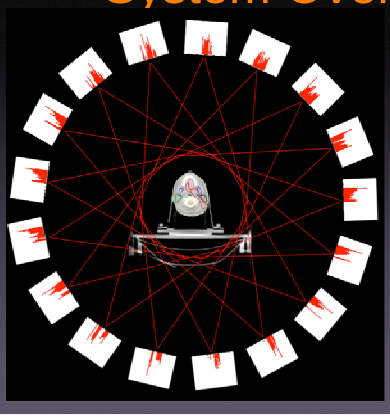
# System Overview
## Collimation

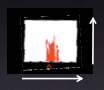



Y-jaw: Collimates beam in y-direction to 1, 2.5 or 5 cm

MLC: 64 leafs, open or closed temporal modulation

# System Overview





Relative opening time

MLC leaf

# Treatment Delivery QA

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

## Treatment Delivery QA

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

## 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

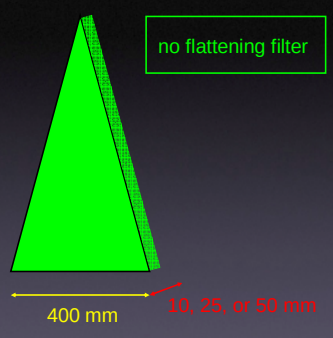
MLC centering and twist: test that MLC is centered and parallel to plane of rotation

## Treatment Delivery QA

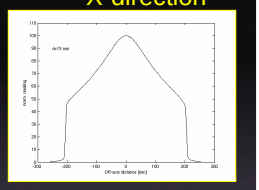
- QA of mechanical alignments
- QA of beam parameters
- Synchronicity tests
- Miscellaneous Aspects
- Calibration

Fan Beam

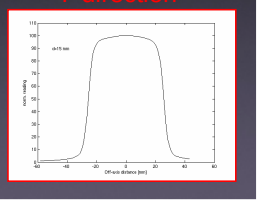
no flattening filter




X-direction

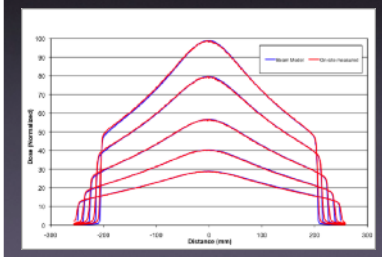


Y-direction



# Beam parameter QA

X-direction beam profile:



Monthly: consistency

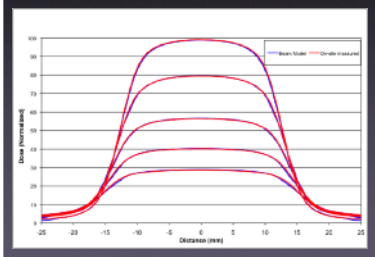
Annual: agreement with model

TG-142 tolerance

# Beam parameter QA

Longitudinal beam profile:

Monthly: consistency

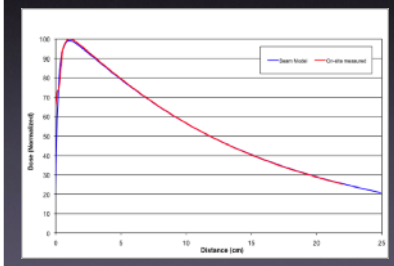


Annual: agreement with model

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 %

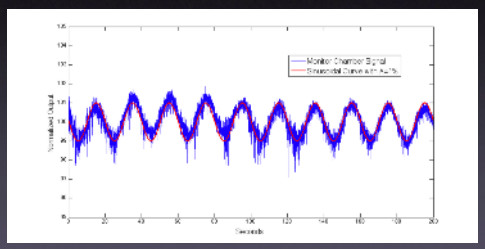
Fixed gantry
No MLC action

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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- 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)

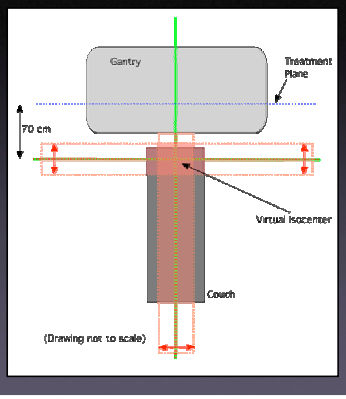
Misc. couch aspects (level, sag, travel perpendicular to treatment plane)

# Miscellaneous

Lasers:

Stationary (green)

Movable (red)




# Miscellaneous

Lasers:

<u>Daily</u>: Red=Green at initialization

<u>Monthly:</u> Red laser movement=planned movement

<u>Annual (green):</u>
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

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

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

## Calibration-machine specific reference field (msr)

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

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

Corrected reading in msr-field

## Calibration-machine specific reference field (msr)

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

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

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

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

$k_Q$ under standard conditions

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

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

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

## Calibration-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)

(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”

## Calibration-plan-class specific reference field (pcsr)

Tomo: generate treatment plan using helical tomotherapy delivery mode

## Calibration-plan-class specific reference field (pcsr)

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

## Calibration-plan-class specific reference field (pcsr)

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

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

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

## 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

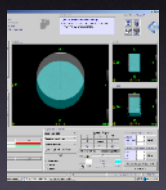
- Geometry Tests
- Image Quality Tests

# Geometry Tests

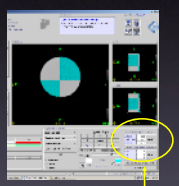
- MVCT Image Reconstruction Accuracy (Monthly)
- Image Registration tests (Annual)
- Dosimetric end-to-end test of registration accuracy (Annual)

# 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)

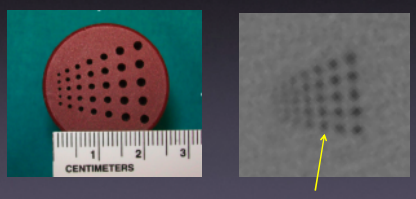
- Noise
- Uniformity
- Spatial resolution
- CT-number

# 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

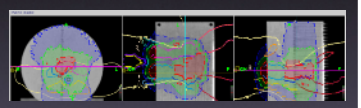
Tolerance: 3%/3 mm

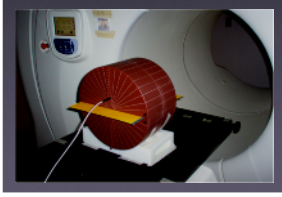
# TPS- Patient Plan QA (DQA)

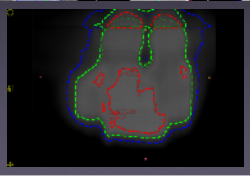
Recalculate plan in phantom geometry:

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

Example:
"Cheese" phantom,
IC and Film







# Frequency: Daily

| 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. |

# Frequency: Monthly

| MONTHLY Test | Purpose | Tolerance Limit |
|---|---|---|
| ***Beam parameters*** | | |
| Output Static (IC) | Consistency | 2% |
| Output Rotational (IC) | Consistency with TPS | 2% |
| Rotation output variation | Amplitude of variation | 2% |
| | | |
| Energy | Consistency with baseline | 1% $PDD_{10}$ or $TMR^{10}_{20}$ |
| Transverse Profile | Consistency with baseline | 1% average difference |
| Longitudinal Profiles (each Field) | Consistency with baseline | 1% of slice width @ FWHM |
| | | |
| ***Alignment and Misc.*** | | |
| Interrupted Procedure | Agreement with uninterrupted Proc. | 3% |
| Red laser movement | Correct movement | 2 mm |
| Couch | Digital movement vs actual movement | 1 mm |
| Couch | Level | 0.5 degrees |
| Couch | Longitudinal motion alignment | 1 mm |
| Couch | Sag | 5mm |
| | | |
| ***MVCT*** | | |
| Image reconstruction | Dimension, location, orientation | 1 MVCT voxel |
| | | |
| Noise | Monitor image quality | 70 HU in center, 35 HU in periphery |
| Uniformity | Monitor image quality | 25 HU |
| Spatial Resolution | Monitor image quality | 1.6 mm object |
| Dose | Monitor image dose | within 30% of baseline |
| | | |
| *(if MVCT is used for dose calc.)* | | |
| HU (water test plug) | Consistency with baseline | within +/-HU 30 of baseline |
| HU (lung/water/bone test plug) | Consistency with baseline | within +/-HU 50 of baseline |

# Frequency: Quarterly

| QUATERLY | Purpose | Tolerance |
|---|---|---|
| **Test** | | **Limit** |
| **Synchronicity** | | |
| Gantry angle | Correct and consitent | 1 degree |
| Couch speed uniformity | Uniform | 2% dose non-uniformity |
| Couch translation per gantry rotation | Synchrony | 1 mm per 5 cm |

# Frequency: Annual

| ANNUAL | Purpose | Tolerance |
|---|---|---|
| **Test** | | **Limit** |
| ***Mechanical alignments*** | | |
| Y-jaw Centering | Source to y-jaw alignment | 0.3 mm @ source |
| X-alignment of source | Source to MLC alignment | 0.24 mm @ source |
| Y-jaw Divergence/Beam Centering | Source alignment with axis of rotation | 0.5 mm @ iso |
| Y-jaw/Gantry rotation plane alignment | Y-jaw alignment with axis of rotation | 0.5 degrees |
| Treatment beam field centering | Common center | 0.5 mm @ iso |
| MLC lateral offset | MLC alignment with center of rotation | 1.5 mm @ iso |
| MLC twist | Alignment with beam plane | 0.5 degrees |
| | | |
| ***Beam parameters*** | | |
| PDD (each Field) | Agreement with Model | 1% $PDD_{10}$ or $TMR^{10}_{20}$ |
| Transverse Profile (each Field) | Agreement with Model | 1% average difference |
| Longitudinal Profiles (each Field) | Agreement with Model | 1% of slice width @ FWHM |
| | | |
| TG-51 calibration | Calibration | 1% |
| | | |
| ***Misc.*** | | |
| Axial green laser (distance and twist) | Nominal distance to iso | 1 mm/0.3degree |
| Sagittal/coronal green laser | Alignment with axis of rotation | 1 MVCT voxel |
| | | |
| ***MVCT*** | | |
| Image registration | accurate with respect to laser | size of of larger voxel |
| Dosimetry test of registration accuracy | accurate location of dose | dep. on dose calc. and image matrix |
| | | |
| ***Treatment Planning System*** | | |
| *CT data import* | | |
| Dimension of object in TPS | Agreement with physical dimension | 1 kVCT voxel |
| CT voxel dimensions | Correct transfer | pass/fail |
| CT orientation | Correct transfer | pass/fail |
| CT gray scale values | Correct transfer | pass/fail |
| Associated test info | Correct transfer | pass/fail |
| | | |
| *Structure set import* | | |
| Dimension of structure | Agreement with contouring software | 1 kVCT voxel |
| Location of structure | Agreement with contouring software | pass/fail |
| Orientation of structure | Agreement with contouring software | pass/fail |
| | | |
| *Dosimetric verification* | | |
| Point dose in low gradient area | Agreement with TPS | within 3% |
| Point dose in high gradient | Agreement with TPS | 3%/3mm |

# Where is TG-148 now ?

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