Helical Tomotherapy Quality Assurance

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Division of Medical Physics

Southwest Chapter of the AAPM, Oct 9, 2009
Objectives

• To introduce our five-year clinical experience with helical TomoTherapy
• To introduce our five-year research experience with helical TomoTherapy

There is no conflict of interest
IGRT Solution

Imaging

Ionizing
- CT
- SPECT
- Others

Non-ionizing
- Ultrasound
- MRI
- RF
- Laser
- Others
IGRT QA

- IGRT solution introduces precise targeting
- However, it may also introduce more uncertainties and increased risk to miss the target
- Therefore, comprehensive QA procedures are necessary
- Helical Tomotherapy has its own characteristics, and requires dedicated QA protocol
Helical TomoTherapy QA

QA

System

Hardware

Patient

Software

Planning

Delivery
Helical Tomotherapy Process

MVCT Guided

Helical CT Delivery

Registered image

Image registration

MVCT
Helical Tomotherapy System

Hardware
- Control Computer
- Gun Board
- Linac
- Circulator
- Magnetron
- Pulse Forming Network and Modulator
- Data Acquisition System
- High Voltage Power Supply
- Beam Stop
- Detector

Software
- Planning Station
- Data Server
- Optimization Server
- Operator Station
- Delivery Subsystem
- Status Console
- Power Control Panel
- Patient Couch
- Rotating Gantry Assembly

UT Health Science Center
Helical Tomotherapy QA Design

**Component-based:** QA each component, such as MLC, detector, couch etc.

**System-based:** QA the whole system performance

I am NOT good

I am good
# Helical Tomotherapy QA

<table>
<thead>
<tr>
<th>Daily</th>
<th>All Users Checked Treatment Output and Laser Alignment Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Alignment</td>
<td>100%</td>
</tr>
<tr>
<td>Couch Motion / Isocenter Offset</td>
<td>100%</td>
</tr>
<tr>
<td>Output Consistency</td>
<td>100%</td>
</tr>
<tr>
<td>Beam Quality Consistency</td>
<td>67%</td>
</tr>
<tr>
<td>Synchrony of Helical Delivery</td>
<td>56%</td>
</tr>
<tr>
<td>MVCT Registration</td>
<td>33%</td>
</tr>
<tr>
<td>MVCT Image Quality</td>
<td>22%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monthly (Treatment)</th>
<th>All Users Checked Treatment Output Beam Quality Monthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Treatment Beam Output</td>
<td>89%</td>
</tr>
<tr>
<td>Rotation Output Consistency</td>
<td>33%</td>
</tr>
<tr>
<td>Output Ramp Up</td>
<td>33%</td>
</tr>
<tr>
<td>Beam Quality</td>
<td>100%</td>
</tr>
<tr>
<td>In-Plane or Cross-Plane Profiles</td>
<td>67%</td>
</tr>
<tr>
<td>Laser Alignment</td>
<td>100%</td>
</tr>
<tr>
<td>MLC Alignment</td>
<td>44%</td>
</tr>
<tr>
<td>Isocenter Alignment</td>
<td>22%</td>
</tr>
<tr>
<td>Primary Jaw Divergence</td>
<td>22%</td>
</tr>
<tr>
<td>Primary Jaw Twist</td>
<td>22%</td>
</tr>
<tr>
<td>Primary Jaw Shift</td>
<td>22%</td>
</tr>
<tr>
<td>Gantry Level at IEC 0-Degrees</td>
<td>11%</td>
</tr>
<tr>
<td>Synchrony of Gantry and MLC</td>
<td>11%</td>
</tr>
<tr>
<td>Couch Y-Translation</td>
<td>22%</td>
</tr>
<tr>
<td>Couch Drive Uniformity</td>
<td>11%</td>
</tr>
<tr>
<td>Couch Drive Speed</td>
<td>11%</td>
</tr>
<tr>
<td>Couch Sag</td>
<td>11%</td>
</tr>
<tr>
<td>Procedure Interrupt and Completion</td>
<td>22%</td>
</tr>
</tbody>
</table>

Mechanical alignment testing is recommended by TomoTherapy, but is typically tested at an annual frequency instead of monthly.

Most users did not specifically test the couch, but it is unknown if frequent testing is necessary.
## Helical Tomotherapy QA

**Monthly (Imaging)**
- MVCT Dose: 33%
- MVCT Resolution: 33%
- MVCT Noise and Uniformity: 22%
- MVCT-to-Density: 22%
- MVCT Image Registration: 22%
- Centering of Imaging Plane: 22%

*Imaging was not check monthly by most users*

**Annual**
- Percent Depth Dose Measurements: 100%
- In-Plane and Cross-Plane Profiles: 100%
- MLC Tongue and Groove: 33%
- MLC Leaf Latency: 22%
- MLC Leaf Opening Synch with Gantry: 22%
- Primary Jaw Sweep: 22%
- Y-Translation per Gantry Rotation: 22%

*All Users Checked Beam Characteristics with a Scanning Water Tank*

TomoTherapy Daily QA Performance

Departure from Expected Values

-5% -4% -3% -2% -1% 0% 1% 2% 3% 4% 5%

11/4/05 3/19/07 Date 7/31/08

Output
Energy
Helical Tomotherapy Target Issue

Eroded target

Rusted on-board ion chamber
## Helical Tomotherapy Working Zones

<table>
<thead>
<tr>
<th>Dose Rate (mu/min)</th>
<th>PFN (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0</td>
</tr>
<tr>
<td>IC (volts)</td>
<td>3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0</td>
</tr>
<tr>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td></td>
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<tr>
<td>4.2</td>
<td></td>
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<tr>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>

- **Blue zone**
- **Green zone**
- **Yellow zone**
- **Red zone**
- **Black zone**
$V_{PFN}, V_{IC}$, Dose Rate Relationship

![Graph showing the relationship between % change of $V_{IC}$ and % change of dose rate for different PFN values]

- PFN 4.00
- PFN 4.02
- PFN 4.04
- PFN 4.06
- PFN 4.08
- PFN 4.10
Helical Tomotherapy MLC QA

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Author: Chengyu Shi, PhD; Lan Lin, Vikren Sarkar
Contact: cshi@ctrc.net

TomoTherapy MLC QA
Special MLC QA for Helical Tomotherapy

Seven test patterns have been designed

A. Box in Box  
B. Modified Checkerboard  
C. MLC Interleaf Leakage  
D. IEC-X gradient  
E. IEC-Y gradient  
F. Complex Field A (2 tests)  
G. Complex Field B (2 tests)
Pattern A. Box in box
Pattern A. Box in box
Pattern B. Modified checkerbox

- Can be thought as small box in box test
- Initially used for Mimic MLC test
- Modified for tomotherapy MLC test

\[
\frac{d_1}{d_2} = \frac{SAD - d}{d}
\]
Pattern B. Modified checkerbox
Pattern C. Inter leaf Leakage

Please draw a line across the open field (left click: start, right click: end).
Please draw a line across the closed field (left click: start, right click: end).
The averaged MLC percentage leakage is 0.112% +/- 0.061%.
Pass!
Pattern D. IEC-X Gradient

\[ W = M_{\text{wedge}} \bullet N_{\text{norm}} \bullet P_{\text{depth}} \]
Pattern E. IEC-Y Gradient

\[ W = M_{\text{wedge}} \cdot N_{\text{norm}} \cdot P_{\text{depth}} \]
Pattern F. Complex A
Pattern G. Complex B
MVCT QA

CT-density table consistency

3% contrast

1.6 mm resolution
Helical Tomotherapy TQA™

Test Results for Rotational Variation Module

Summary Report Trending Data

Trending

Exit Detector Flatness

Exit Detector Output Constancy

Monitor Chamber Output Constancy

Pulse By Pulse Conc Variation

Pulse By Pulse Dose 1

Pulse By Pulse Exit Detector Average
Tomotherapy Patient-Specific QA

- QA Equipment
- Generate QA procedure
- Deliver QA procedure
- Analysis QA procedure
- Evaluate QA procedure
Deliver QA procedure-Patient

- Red lasers
- Phantom
- Chamber
- EDR2 film
Deliver QA procedure - Calibration

Coronal, transverse, and sagittal green lasers

6 cm

10 cm
Analysis QA procedure-Absolute dose

Excel sheet for dose measurement

According to TG51 protocol, the dose to the calibration point is:

\[ D = M_{\text{cal}}P_{\text{ion}}P_{\text{TP}}P_{\text{elec}}P_{\text{iso}}K_{\text{Q}}N_{\text{D,0}} \]

**Dose (Gy):**

**Expected:**

**Difference:**

QA films reviewed and approved
For step valley use 6cm buildup, 10cm backscatter, film at G laser

Performed by: ____________________________

Medical Physicist: Patricia

Physician: ____________________________
What if the QA fails?

Find out why?

- Phantom resolution?
- High dose gradient?
- Small thin PTV?
- Machine output?
- ...

Repeat the QA procedure
Example-Overweight

- Patient with prostate cancer (weight 370 lb)
- Tomotherapy couch can support ~440 lb.
- Patient plan is homogeneous for PTV
- Phantom size is very different from patient size, resulting to non-homogenous dose at the point of the chamber
Example-Overweight
Example-Overweight

15.50 cm

3.88% here

6.22% here
Delta 4 Dosimeter for Tomo

- Purchased September 2008
  - TomoTherapy Option
  - RapidArc Option
- First few months
  - Research
  - SBRT QA
- Mid-January 2009
  - Fully clinical for tomotherapy DQA
- Absolute calibrate on TomoTherapy
- Phantom MVCT image for planning
Delta 4 Dosimeter Results

- 140 DQAs delivered on Delta^4
- 34 SBRT patients with gamma index > 95% (3%/3mm)
- Pass criteria
  - 3%/3mm
  - >90% gamma
- To date,
  - Mean gamma: 97.1% (85.9-100)
**MVCT Verification**

<table>
<thead>
<tr>
<th>Boni and Tissue Technique</th>
<th>Automatic Calculation</th>
<th>Manual Control</th>
<th>Translational Adjustments (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>Start Auto</td>
<td>Start Manual</td>
<td>Lateral (IEC T1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Longitudinal (IEC T2)</td>
</tr>
<tr>
<td>Incomplete Field of View</td>
<td></td>
<td></td>
<td>Vertical (IEC T3)</td>
</tr>
<tr>
<td>Translations Roll</td>
<td></td>
<td></td>
<td>Reset</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotational Adjustments (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Roll</td>
</tr>
<tr>
<td>Yaw</td>
</tr>
</tbody>
</table>

**Correlated Images**

**Reference Image**

---

**Color**

**Composition**

**Reference Image Component**

- ROLEs: 0.63
- Lesser: 0.1
- Dose: 5.0 Gy
### MVCT Verification

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Lateral</th>
<th>Longitude</th>
<th>Vertical</th>
<th>Roll</th>
<th>Re-Mark</th>
<th>Initials</th>
<th>Status</th>
<th>NOTES</th>
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<tbody>
<tr>
<td>1</td>
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<td>-0.8</td>
<td>60</td>
<td>0.0</td>
<td>AS</td>
<td>TYF</td>
<td>MF</td>
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<tr>
<td>2</td>
<td>-1.3</td>
<td>0.2</td>
<td>68</td>
<td>0.9</td>
<td>SB</td>
<td>OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>1.2</td>
<td>62</td>
<td>0.3</td>
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<td>OK</td>
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<td></td>
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<td>4</td>
<td>-1.4</td>
<td>-1.1</td>
<td>58</td>
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<td>AS</td>
<td>OK</td>
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<td></td>
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<tr>
<td>5</td>
<td>-1.0</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>-2.3</td>
<td>3.8</td>
<td>68</td>
<td>0.8</td>
<td>RB</td>
<td>OK</td>
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<td>7</td>
<td>-4.4</td>
<td>-0.2</td>
<td>68</td>
<td>1.2</td>
<td>AS</td>
<td>OK</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>4.5</td>
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<td>AS</td>
<td>OK</td>
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<tr>
<td>9</td>
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<td>83</td>
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<td></td>
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<tr>
<td>10</td>
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<td>0.7</td>
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<td>OK</td>
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<td>60</td>
<td>0.4</td>
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<td>OK</td>
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<td></td>
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<tr>
<td>23</td>
<td>-7.3</td>
<td>-3.0</td>
<td>26</td>
<td>1.4</td>
<td>AS</td>
<td>OK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Average:** | 2.7 | 1.0 | 8.8 | <--- Shift by this amount
Setup Uncertainties
Discussion

• Tomotherapy gives reliable calculation results, and it should be within 3% tolerance about dose measurement for most of cases

• EDR2 is a good tool for relative and absolute dose measurement

• Gamma factor is a good evaluation parameter

• Some QA cases need more analysis

• QA is a little hard to do in some cases such as spine and lung SBRT
Tips or Problems you may meet

• Scanning QA phantom with different resolution and extension
• Put ion chamber into homogeneity region of the PTV
• Use high resolution phantom for smaller or thinner PTV
• You can extend EDR2 film range up to 600~700 cGy, however, that is for relative dose measurement only. For absolute dose measurement using film, you can do it under 400 cGy, and it should be good for normal treatment procedure.
• Delta 4 dosimeter is a good candidate for Tomo QA
Some Research Tools Development
Design algorithm

- Hardware related
  - Target change
  - Jaw
  - MLC...

- Software related
  - Composite plan
  - DVH...

- Clinical/Research need
  - Archive patient...
Design language

- Excel VBA for clinical
- Matlab for research
- Visual c++ for fast application
- XML, html
Tools we have developed

- ToPinnacle
- TomoBin
- TomoAnnual
- TomoGkPinnacle
- Tomo-XML-DOM
- Excel sheets
ToPinnacle

**Need:** Physicians need plan comparison between Tomotherapy and Pinnacle and composite plan

**Design:** Visual c++ program to transfer dose matrix data from Tomotherapy to Pinnacle
ToPinnacle

File information:
Output file name:
plan.Trial.binary.001

Backup Data

Number of fractions:
1

Down Sampling

Max dose (cGy)/frac:
0.00

Exit

Operation:
OPEN HEADER
CONVERT DATA
TRANSFER DATA

Header information:
x dimension:
x resolution (cm/pixel):
x origin (cm):

y dimension:
y resolution (cm/pixel):
y origin (cm):

z dimension:
z resolution (cm/pixel):
z origin (cm):
Evaluation of Integral Dose in Cranio-spinal Axis (CSA) Irradiation with Conventional and Helical Delivery

José A. Peñagaríciano, M.D.
Chengyu Shi, Ph.D.
Vaneerat Ratanatharathorn, M.D.

Technology in Cancer Research & Treatment
ISSN 1533-0346
Volume 4, Number 6, December (2005)
©Adenie Press (2005)
TomoBin

Need: Tomo procedure needs sinogram and binary MLC needs QA

Design: Matlab program to design tomotherapy MLC pattern

Quality assurance of the multileaf collimator with helical tomotherapy: Design and implementation

Vikren Sarkar, Lan Lin, Chengyu Shi, a) and Niko Papanikolaou
University of Texas Health Science Center at San Antonio, San Antonio, Texas 78229
and Cancer Therapy and Research Center, San Antonio, Texas 78229

2949 Med. Phys. 34 (7), July 2007
How were the patterns designed?

- Consider dose and mechanical factors
- Seven patterns (9 tests) have been designed
- A software platform is also designed to generate and analyze the patterns
- The patterns can be transferred easily to other centers with a helical tomotherapy unit
TomoAnnual

**Need**: How to compare commission data with annual QA data? How to predict target failure?

**Design**: Matlab program to use commission data as baseline for monthly and annual profile comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td></td>
</tr>
<tr>
<td>Jaw</td>
<td>6mm (+/- 1.1mm)</td>
</tr>
<tr>
<td>Depth</td>
<td>1.5cm</td>
</tr>
</tbody>
</table>

- **Show Fig.**
- **Clear Fig.**
- **Are U Twin**
- **Report**

- **Hold on/off**
- **Shift Lt**
- **Shift Rt**
- **Fan Up**
- **Fan Dn**
- **Rot Lt**
- **Rot Rt**
- **Export image**

---

**Facility Name/Logo**
Profiles collected for the previous target a-d and after the target replacement e.
The angle difference between two profiles for d) is around 1 degree.
Need: for research use; how to transfer data from one planning station to another?

Design: Matlab program to convert dose matrix between different TPS

TomoGkPinnacle

Dosimetric comparison of Helical Tomotherapy and Gamma Knife Stereotactic Radiosurgery for single brain metastasis
José A Peñagaricano, Yulong Yan, Chengyu Shi, Mark E Linskey and Vaneerat Ratanatharathorn

Radiation Oncology
TomoGkPinnacle->APT4D

Lan Lin, Chengyu Shi, Gregory Swanson, Nikos Papanikolaou, "Development of a Novel Post-processing Treatment Planning Platform for 4D Radiotherapy," Technology in Cancer Research and Treatment (April 2008)
Tomo-XML-DOM

Need: how to extract necessary information from tomotherapy plan to perform a 2nd check?

Design: XML language to extract archived patient information

<table>
<thead>
<tr>
<th>Struct. No.</th>
<th>Name</th>
<th>Vol.(cc)</th>
<th>Max. dose (cGy)</th>
<th>Min. dose (cGy)</th>
<th>Med. dose (cGy)</th>
<th>Avg. dose (cGy)</th>
<th>Std. (cGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>gtv</td>
<td>719.225</td>
<td>42.071</td>
<td>34.016</td>
<td>40.637</td>
<td>40.613</td>
<td>0.348</td>
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<tr>
<td>3</td>
<td>spinal_cord</td>
<td>36.051</td>
<td>6.518</td>
<td>0.533</td>
<td>3.111</td>
<td>3.024</td>
<td>1.574</td>
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<tr>
<td>4</td>
<td>heart</td>
<td>1353.433</td>
<td>41.278</td>
<td>1.212</td>
<td>10.166</td>
<td>12.923</td>
<td>10.182</td>
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Tomo Patient QA 2nd Check

Tomo 2nd Check (SAD=85)

Control Panel:
- Point of Meas(cm): -1.56, -1.52, -2.54
- Plan Point Dose(cGy): 205.54
- Mode: Patient_DQA

Summary Panel:
- Patient Name: [Patient Name]
- Patient ID: 000001
- Fiducial (mm): 2.0
- Pitch: 0.287
- Gantry Period(s): 19
- Calc Dose(cGy): 202.7157
- Dose Diff(%): -1.5176
- 2nd Check Signature: [Signature]

Sinogram map

Accumulated Dose (cGy)
Excel sheets

Need: daily, monthly, annual QA, patient setup, QA...

Design: excel VBA
Excel sheets - Annual QA

Annual Calibration Report
Institution: Cancer Therapy and Research Center
7979 Wurzbach Rd, San Antonio, TX 78229

Linear Accelerator: Tomotherapy-Vault 4

Safety Aspects
- Patient Viewing/Communication: Pass
- Emergency-Offs: Pass
- Radiation Warning Lights: Pass
- Radiation Warning Signs: Pass
- Beam Off (Dedicated Keyboard): Pass
- Console Key Interlock: Pass

Room Survey
Survey Meter: Model 3
Serial #: 171816

<table>
<thead>
<tr>
<th>Room</th>
<th>Survey Meter</th>
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<th>Baseline</th>
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<tr>
<td>Console Area</td>
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Mechanical Checks
- Gantry Position: Pass
- Collimator Size: Pass
- Couch Position Indicators: Pass
- Couch Level: Pass
- Couch Top Sag: Pass
- Radiation Isocenter Check: Pass
- Laser overlap: Pass
- Sagittal Laser Alignment: Pass
- Ceiling Laser Alignment: Pass
- Couch laser alignment: Pass
- Barometer Comparison: Pass
- Thermometer Comparison: Pass
- Source/primary collimator alignment: Pass
- Central axis/y-axis deliverance: Pass
- Jaw/Gantry rotation alignment: Pass
- Field center vs. jaw setting: Pass
- MLC T&G: Pass
- MLC axis/gantry rotation alignment: Pass
- MLC center/gantry isocenter alignment: Pass
- Couch y-translation and gantry synchrony: Pass
- Couch speed uniform: Pass
- MLC and gantry synchrony: Pass

Date: 3/4/2008

UT Health Science Center
San Antonio
QA for Helical Tomotherapy: Report of the AAPM Task Group 148

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Chester R. Ramsey
Thompson Cancer Survival Center, Knoxville, TN 3791

John Balog
Rome, NY
Where do we go?

- System-based QA vs. component-based QA
- Internet QA with intra/inter institution comparison
- Risk estimation for failure rate and prediction
- System self QA vs. third-part QA
Summary

• Current Helical Tomotherapy QA Status is component-based QA and varies from center to center

• Future implementation of Helical Tomotherapy QA maybe system-based, internet-based, risk-estimation, and system-self QA

• AAPM TG 148 will provide recommendations for QA tests and frequency of testing
Acknowledgements

- Dr. Papanikolaou
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Thank You

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