Quality Assurance in Stereotactic Radiosurgery and Fractionated Stereotactic Radiotherapy

David Shepard, Ph.D.
Swedish Cancer Institute
Seattle, WA

Timothy D. Solberg, Ph.D.
University of Texas Southwestern Medical Center
Dallas, TX

Outline

• Mechanical aspects
• Linac
• Frames
• Beam data acquisition
• Commissioning of TP system
• End-to-end evaluation
• Imaging and Image Fusion
• Frameless Radiosurgery
• References and Guidelines

Can we hit the target?
Can we put the dose where we want it?

How accurate is radiosurgery?

TABLE II. Achievable Uncertainties in SRS

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereotactic Frame</td>
<td>1.0</td>
</tr>
<tr>
<td>Isocentric Alignment</td>
<td>1.0</td>
</tr>
<tr>
<td>CT Image Resolution</td>
<td>1.7</td>
</tr>
<tr>
<td>Tissue Motion</td>
<td>1.0</td>
</tr>
<tr>
<td>Angio (Point Identification)</td>
<td>0.3</td>
</tr>
<tr>
<td>Standard Deviation of Position Uncertainty (by Quadrature)</td>
<td>2.4 mm 3.7 mm</td>
</tr>
</tbody>
</table>

Other sources: MRI Distortion
Image Fusion
Relocatable frames
Dosimetric

Frames & CT

Isocentric Accuracy: The Winston-Lutz Test
Mechanical Uncertainties

Is the projection of the ball centered within the field?

Isocentric Accuracy: The Winston-Lutz Test

Is the projection of the ball centered within the field?

Good results \( \leq 0.5 \) mm

A daily Lutz test is extremely important because:

- The mechanical isocenter can shift over time
- The AMC board in Varian couches can fail
- The cone or MLC may not be repositioned perfectly after service

Before (right) and After (left) relatively simple couch adjustment

A Lutz test with the MLC is also important because:

- The Cone-based Lutz test does not tell you anything about the mechanical isocenter of the MLC
- The MLC may not be repositioned perfectly after service

Lutz test with 12 x 12 mm MLC field

End-to-End Localization Accuracy

End-to-End Localization Accuracy (Surely my vendor has checked this)
End-to-end localization evaluation

<table>
<thead>
<tr>
<th>Phantom Specifications</th>
<th>Stereotactic Coordinates</th>
<th>Structure AP LAT VERT AP LAT VERT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder</td>
<td></td>
<td>0.0 0.0 30.0 1.0 0.4 30.8</td>
</tr>
<tr>
<td>Cube</td>
<td></td>
<td>20.0 -17.0 40.0 20.8 -17.1 42.4</td>
</tr>
<tr>
<td>Cone</td>
<td></td>
<td>-35.0 -20.0 40.0 -34.6 -19.7 40.8</td>
</tr>
<tr>
<td>Sphere</td>
<td></td>
<td>25.0 20.0 32.7 25.5 20.2 33.5</td>
</tr>
</tbody>
</table>

Verification of MLC shapes and isocenter

System Accuracy
Simulate the entire procedures: Scan, target, plan, deliver

Phantom with film holder
Pin denotes isocenter

Resulting film provides measure of targeting accuracy ...

Offset from intended target
... as well as falloff for a multiple arc delivery

Imaging Uncertainties

- Use CT for geometric accuracy
- Use MR for target delineation

“MRI contains distortions which impede direct correlation with CT data at the level required for SRS”

Stereotactic Radiosurgery – AAPM Report No. 54

Other References


What do we do about MR spatial distortion?

Use Image Fusion

Fusion Verification

Beam Data Acquisition and Dosimetry
Small field measurements can be challenging; Diodes and small ion chambers are well suited to SRS dosimetry, but their characteristics / response must be well understood.

PTW Detectors
- PinPoint
  - 0.015 cc
  - Cylindrical or Spherical
  - Liquid-filled
  - 800 V
- Diode
  - 1 mm x 2.5 µm
- Diamond
  - 1-6 mm x 0.3 mm
  - 100 V

Exradin Detectors
- A14
  - 0.016 cc
- A16
  - 0.007 cc
- A14SL
  - 0.016 cc

Wellhofer Detectors
- CC04
  - 0.04 cc
- CC01
  - 0.01 cc

MR Fusion

Standard Diode

Pinpoint Chamber 0.015 cc

Stereotactic Diode
Diode Warnings!!!

1) Diode response will drift over time
   Re-measure reference between each change in field size

2) Diodes exhibit enough energy dependence that ratios between large and small field measurements are inaccurate at the level required for radiosurgery
   Use an intermediate reference field appropriate for both diodes and ion chambers

Reference diode output to an intermediate field size

\[
\text{Output Factor} = \frac{\text{Reading (FS)_{diode}}}{\text{Reading (Ref')_{diode}}} \times \frac{\text{Reading (Ref')_{IC}}}{\text{Reading (Ref)_{IC}}}
\]

Options:

NO! \[
\frac{\text{Reading (6 mm)_{diode}}}{\text{Reading (100 mm)_{diode}}} \times \frac{\text{Reading (24 mm)_{IC}}}{\text{Reading (100 mm)_{IC}}}
\]

YES! \[
\frac{\text{Reading (6 mm)_{diode}}}{\text{Reading (24 mm)_{diode}}} \times \frac{\text{Reading (24 mm)_{IC}}}{\text{Reading (100 mm)_{IC}}}
\]

Radiosurgery beams exhibit a sharp decrease in output with decreasing field size

This means that with small collimators, treatment times can be long

6X Output Factors – Circular Cones

Small field depth dose show familiar trends

Novalis Tx
Off Axis Profiles – Cones

Penumbra: Cones versus MMLC

Need proof that beam data acquisition for small fields is difficult?

Surveyed Beam Data from 40 identical treatment units:
Percent Depth Dose
Relative Scatter Factors
Absolute Dose-to-Monitor Unit CF
Reference Condition
Applied statistical methods to compare data

Even people in the U.S have problems

<table>
<thead>
<tr>
<th>Cone size (mm)</th>
<th>Original Output Factor</th>
<th>Re-measured Output Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>0.312</td>
<td>0.699</td>
</tr>
<tr>
<td>7.5</td>
<td>0.610</td>
<td>0.797</td>
</tr>
<tr>
<td>10.0</td>
<td>0.741</td>
<td>0.835</td>
</tr>
<tr>
<td>12.5</td>
<td>0.833</td>
<td>0.871</td>
</tr>
<tr>
<td>15.0</td>
<td>0.862</td>
<td>0.890</td>
</tr>
<tr>
<td>17.5</td>
<td>0.888</td>
<td>0.904</td>
</tr>
<tr>
<td>20.0</td>
<td>0.903</td>
<td>0.913</td>
</tr>
<tr>
<td>25.0</td>
<td>0.920</td>
<td>0.930</td>
</tr>
<tr>
<td>30.0</td>
<td>0.928</td>
<td>0.940</td>
</tr>
</tbody>
</table>

A different institution in the U.S
And still another institution in the U.S

Phantom Plans

Start simple, and increase complexity

Commissioning your system: Does calculation agree with measurement?

End-to-end testing
Dosimetric uncertainty

Relative Dosimetry

Absolute Dosimetry
Independent MU Calculations

End-to-end dosimetric evaluation

Lucy Phantom
What about “Frameless Systems?”

A “frameless” stereotactic system provides localization accuracy consistent with the safe delivery of a therapeutic dose of radiation given in one or few fractions, without the aid of an external reference frame, and in a manner that is non-invasive.

Frameless stereotaxis is inherently image guided

Also required:

- Immobilization – need not be linked to localization
- Ability to periodically monitor / verify

(Stereo)photogrammetry - the principle behind frameless technologies

Stereophotogrammetry in Radiotherapy

Spatial Resolution: 0.05 mm
Temporal Resolution: 0.03 s
Localization Accuracy: 0.2 mm

Optical Photogrammetry

Stereophotogrammetry in Radiotherapy

How do we know the system is targeting properly?

End-to-end evaluation that mimics a patient procedure
Results of Phantom Data

<table>
<thead>
<tr>
<th></th>
<th>Lat. (mm)</th>
<th>Long. (mm)</th>
<th>Vert. (mm)</th>
<th>3D vector (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>-0.06</td>
<td>-0.01</td>
<td>0.05</td>
<td>1.11</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.56</td>
<td>0.32</td>
<td>0.82</td>
<td>0.42</td>
</tr>
</tbody>
</table>

* Sample size = 50 trials (justified to 95% confidence level, +/- 0.12mm)

Difference Between conventional and frameless localization

- Frameless localization is equivalent to frame-based rigid fixation
- Frameless localization improves accuracy of relocatable frames

End-to-end evaluation: CyberKnife

Chang et al, Neurosurgery 2003

3D error 1.1 ± 0.3 mm

End-to-end evaluation: Extracranial

3D error 1.2 ± 0.4 mm

Localization using implanted fiducials

Courtesy Sam Hancock, PhD, Southeast Missouri Hospital
Localization using implanted fiducials

Radiosurgery Guidelines

• ACR / ASTRO Practice Guidelines
  PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC RADIOSURGERY
  PRACTICE GUIDELINE FOR THE PERFORMANCE OF STEREOTACTIC BODY RADIATION THERAPY

• What do they cover?
  Personnel Qualifications / Responsibilities
  Procedure Specifications
  Quality Control / Verification / Validation
  Follow-up

Radiosurgery Guidelines

• Task Group Reports
  AAPM Report #54 – Stereotactic Radiosurgery
  AAPM Report #91 – The Management of Motion in Radiation Oncology (TG 76)
  TG 68 – Intracranial Stereotactic Positioning Systems
  TG 101 – Stereotactic Body Radiotherapy
  TG 104 – kV Localization in Therapy
  TG 117 – Use of MRI in Treatment Planning and Stereotactic Procedures
  TG 132 – Use of Image Registration and Data Fusion Algorithms and Techniques in Radiotherapy Treatment Planning
  TG 135 – QA for Robotic Radiosurgery
  TG 147 – QA for Non-Radiographic Radiotherapy Localization and Positioning Systems
  TG 155 – Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry
  TG 176 – Task Group on Dosimetric Effects of Immobilization Devices
  TG 178 – Gamma Stereotactic Radiosurgery Dosimetry and QA
  TG 179 – QA for Image-Guided Radiation Therapy Utilizing CT-Based Technologies

• RTOG Protocols
  RTOG 9005 – Single Dose Radiosurgical Treatment of Recurrent Previously Irradiated Primary Brain Tumors and Brain Metastases
  RTOG 9305 – Randomized Prospective Comparison Of Stereotactic Radiosurgery (SRS) Followed By Conventional Radiotherapy (RT) With BCNU To RT With BCNU Alone For Selected Patients With Supratentorial Glioblastoma Multiforme (GBM)
  RTOG 9508 – A Phase III Trial Comparing Whole Brain Irradiation Alone Versus Whole Brain Irradiation Plus Stereotactic Radiosurgery for Patients with Two or Three Unresected Brain Metastases
  RTOG 0236 – A phase II trial of SBRT in the treatment of patients with medically inoperable stage I/II non-small cell lung cancer
  RTOG 0618 – A phase II trial of SBRT in the treatment of patients with operable stage I/II non-small cell lung cancer
  RTOG 0813 – Seamless phase I/II study of SBRT for early stage, centrally located, non-small cell lung cancer in medically operable patients

Other Documents

ASTRO/AANS Consensus Statement on stereotactic radiosurgery quality improvement, 1993
RTOG Radiosurgery QA Guidelines, 1993
European Quality Assurance Program on Stereotactic Radiosurgery, 1995
DIN 6875-1 (Germany) Quality Assurance in Stereotactic Radiosurgery/Radiotherapy, 2004

... and read the literature
... and talk with your colleagues