Quality Assurance in Stereotactic Radiosurgery and Fractionated Stereotactic Radiotherapy

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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

Quality Assurance in Linac SRS/SBRT

LOTS of variation in Linac SRS technologies ...


... and in radiation delivery

Isocentric Accuracy: The Winston-Lutz Test

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Is the projection of the ball centered within the field?

Good results: $\bar{x} \leq 0.5$ mm

What can you expect and what can you do about it?

Before

After

Localization Accuracy of Stereotactic Frames

End-to-End Localization Accuracy

For SRT, it is essential to ensure daily reproducibility of frames

σ = 0.4 mm (n=2000), but "The frame is not appropriate for single fraction radiosurgery, as a large setup error (> 2 mm) for a single treatment cannot be excluded."
End-to-End Localization Accuracy
(with verification of MLC shapes, orientation, etc.)

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

Beam Data Acquisition and Dose Computation

Traditional radiosurgery dose algorithms are quite simple, with dose specified by the product of measured beam parameters:

\[ \text{Dose} = \text{TMR} \times \text{OAR} \times \text{Output} \times \text{MU} \]

Corrections for tissue heterogeneities, surface irregularities, etc. are generally neglected.

But accurate measurement of beam data is difficult.

Dosimetry Equipment

Diode / Ion Chamber

DIODE WARNING: Diodes exhibit enough energy dependence that ratios between large and small field measurements are inaccurate at the level required for radiosurgery.

What to do?

Measure output factors ≤ 2x2 cm² using diode
≥ 2x2 and ≤ 4x4 cm² using diode & chamber
≥ 4x4 cm² using chamber

Beam Data

Beam characterization is best performed in water. Diodes are well suited to small field dosimetry though other dosimeters can certainly be used.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth Dose (PDD or TMR)</td>
<td>Diode / Ion Chamber</td>
</tr>
<tr>
<td>Off Axis Ratios</td>
<td>Diode / Ion Chamber</td>
</tr>
<tr>
<td>Relative Output</td>
<td>Diode / Ion Chamber</td>
</tr>
<tr>
<td>Absolute Dose</td>
<td>Ion Chamber</td>
</tr>
</tbody>
</table>

Specific Mechanical Component/Software Incompatibility Resulted in 1.25 mm Shift in Target Area Alignment in Radiosurgery Treatment

The staff in target area alignment for the specific configuration of mechanical component and software used in radiosurgery was determined by a BrainLAB support engineer and a customer during an on-site calibration period. A custom error test, performed in software, identified errors in the target area alignment due to the specific configuration of mechanical component and software used in radiosurgery. The error was not discovered earlier during commissioning tests and customer commissioning procedures.

Dosimetry has shown this error for a mechanical component/software configuration for the specific BrainLAB configuration. The custom error test procedure was performed during the commissioning phase and was identified in this specific configuration.
Radiosurgery beams exhibit a sharp decrease in output with decreasing field size.

This means that with small collimators, treatment times can be long.
Surveyed beam data from 40 identical Linac SRS Units:
- Percent Depth Dose
- Relative Scatter Factors
- Absolute Dose-to-Monitor Unit CF

Reference Condition
Applied statistical methods to compare data
Relative Output Factor: 6 mm x 6 mm MLC

Relative Output Factor: 42 mm x 42 mm MLC

Commissioning your system: Does calculation agree with measurement?

- Directly verify the delivered distribution

Relative Dosimetry for individual fields

Relative Dosimetry for composite plan

80, 50, 20% isodose lines of calculation and measurement

80, 50, 20% isodose lines of calculation and measurement

~45%

~6%

~80, 50, 20% isodose lines of calculation and measurement

~80, 50, 20% isodose lines of calculation and measurement

Calculation arc-step = 10°

Calculation arc-step = 2°
Use an appropriate phantom

Absolute dosimetry

Segmental and dynamic intensity-modulated radiotherapy delivery techniques for micro-multileaf collimator

Michael Anger, Christine S. Schaefer

Difference between calculation and measurement:
the first 160 IMRT patients

$\bar{x} = 0.26, \sigma = 1.75$

System Commissioning
End-to-end dosimetry is essential

Directly verify the delivered dose

What about independent verification of monitor units?

- Circular Collimators
- Micro-MLC
- Dynamic Conformal Arc
Why do we need CT?

- 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?

1.8 ± 0.5 mm shift of MR images relative to CT and delivered dose

Shifts occur in the frequency encoding direction
Due to susceptibility artifacts between the phantom and fiducial markers of the Leksell localization box


Automatic Image Fusion for Extracranial Anatomy

Image Fusion

DOESN'T WORK!
**Image Fusion for Extracranial Anatomy**

**TABLE II. Achievable Uncertainties in SRS**

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

Stereotactic Radiosurgery, AAPM Report No. 54, 1995

Other sources not evaluated: MRI, relocatable frames, ...

Can we do better?

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

*Optical Photogrammetry*  
**Stereophotogrammetry in Radiotherapy**

*Active* Infrared Photogrammetry

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**Frameless Radiosurgery an UNMC**

*Infrared patient positioning for extracranial radiosurgery of extracranial tumors*
How do we know the system is targeting properly?
End-to-end evaluation that mimics a patient procedure

Embed a hidden target
Perform a CT scan
Fix the phantom in a frame
Create a treatment plan

Results of Phantom Data

<table>
<thead>
<tr>
<th></th>
<th>Lat.</th>
<th>Long.</th>
<th>Vert.</th>
<th>3D vector</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>
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- Sample size = 50 trials (justified to 95% confidence level, +/- 0.12mm)

Comparison in 45 SRS patients and 565 SRT fractions

### Single Fraction

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<td>Average</td>
<td>-0.02</td>
<td>0.04</td>
<td>0.25</td>
<td>1.00</td>
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<tr>
<td>Standard Deviation</td>
<td>0.66</td>
<td>0.55</td>
<td>0.72</td>
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### Multiple Fractions

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<td>0.17</td>
<td>0.47</td>
<td>0.17</td>
<td>2.36</td>
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<tr>
<td>Standard Deviation</td>
<td>1.24</td>
<td>2.11</td>
<td>1.03</td>
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Frameless SRS on a conventional linac

Lots of redundancy
- Patient is marked
- Immobilization device is marked
- Location of IR markers is recorded
- Table heights and shifts are provided

Comparative Patient Shift Data for Cranial Cases

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End-to-end evaluation: Extracranial

Extracranial Applications - Spine
Extracranial Applications - Spine

Extracranial Applications - Lung

Radiosurgery Guidelines

ASTRO/AANS Consensus Statement on stereotactic radiosurgery quality improvement, 1993
RTOG Radiosurgery QA Guidelines, 1993
AAPM Task Group Report 54, 1995
European Quality Assurance Program on Stereotactic Radiosurgery, 1995
DIN 6875-1 (Germany) Quality Assurance in Stereotactic Radiosurgery/Radiotherapy, 2004
AAPM Task Group 68 on Intracranial stereotactic positioning systems, 2005
ACR Practice Guidelines for the Performance of Stereotactic Radiosurgery, 2006
ACR Practice Guidelines for the Performance of Stereotactic Body Radiation Therapy, 2006