Dosimetry of the Gamma Knife™

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Outline

- Introduction to stereotactic radiosurgery
- Elekta Gamma Knife
- In-air dose calibration protocol
- Future directions
Introduction to Stereotactic Radiosurgery

- Stereotactic radiosurgery (SRS) has been in use since 1951
- Benefits over traditional surgery
  - Non-invasive
  - Little or no anesthesia
  - Outpatient procedure
- Ultimate goal is the destruction of abnormal tissues while sparing healthy tissues and critical structures
- No chance to modify later treatments
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Elekta Gamma Knife

- Leksell Gamma Knife (GK)
  - Dedicated to intercranial SRS
  - Multiple simultaneously exposed $^{60}$Co sources
- The GK has been used to treat 500,000 patients
- Trigeminal Neuralgia
  - 70-90 Gy to the root entry area of the trigeminal nerve
GK: Physical Characteristics

- GK treatment system consists of the treatment unit, patient table, and four collimator helmets
GK: Model B and C

- Each source is individually collimated twice
- Collimation may be 18, 14, 8, or 4 mm, or plugged
GK: Perfexion

- Model B and C GK units have identical beam configurations – the Perfexion uses 8 quadrants
- The Perfexion is the next generation of GK units
  - Helmetless
  - Change collimation by sector
  - 16, 8, and 4 mm collimation
GK: Perfexion
GK: Perfexion
GK: Dose Distribution
GK Fields: Model B and C

18 mm field  
scale: 400 x 400 pixels

14 mm field  
scale: 400 x 400 pixels

8 mm field  
scale: 200 x 200 pixels

4 mm field  
scale: 200 x 200 pixels
GK Fields: Perfexion

16 mm field
scale: 400 x 400 pixels

8 mm field
scale: 400 x 400 pixels

4 mm field
scale: 400 x 400 pixels
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In-Air Protocol: Modify TG-21

- TG-21 has a good physics in it and is more appropriate
- The $^{60}$Co in-air calibration allows a direct measurement at the isocenter of a $^{60}$Co unit
  - Assuming a small enough chamber
- Can be performed with minor modifications
  - Geometry
  - Irradiation scheme
  - Monte Carlo can be used to calculate TG-21 factors for the specific geometry of the GK unit
- TG-21 also provides a way to verify the in-air measurement with an in-phantom measurement
New Protocol: Tissue-Air Ratio

- Tissue-air ratio (TAR) value is the ratio of the dose at $X$ to the dose at $X'$
  - $X'$ is the dose to water in free space
  - $X$ is the dose in tissue (or sometimes water)

- Function of:
  - Depth below surface
  - Size of field at depth
  - Quality of the radiation
New Protocol: Material-Air Ratio

- Material-air ratio (MAR) value is still the ratio of the dose at X to the dose at X'
  - X' is the dose to water in free space
  - X is the dose in the specific material in question
- Specific with respect to:
  - Depth below surface
  - Size of field at depth
  - Quality of the radiation
  - Material composition
  - Spherical phantom
New Protocol: In-Air Measurement
New Protocol: In-Phantom Measurement
# New Protocol: Results

<table>
<thead>
<tr>
<th>Location</th>
<th>Media</th>
<th>Measured ( \dot{D}_{\text{water}} ) Gy/min</th>
<th>% difference In-Air to PMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit A</td>
<td>In-Air</td>
<td>3.918</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
<td>3.904</td>
<td>-0.18</td>
</tr>
<tr>
<td>Unit B</td>
<td>In-Air</td>
<td>2.636</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
<td>2.641</td>
<td>0.26</td>
</tr>
<tr>
<td>Unit C</td>
<td>In-Air</td>
<td>3.105</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
<td>3.097</td>
<td>-0.06</td>
</tr>
<tr>
<td>Unit D</td>
<td>In-Air</td>
<td>1.334</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
<td>1.334</td>
<td>-0.06</td>
</tr>
</tbody>
</table>

**In-air uncertainty:** ~0.8%

**In-phantom uncertainty:** ~1.2%
New Protocol: Results

- In-air measurements made at seven separate GK units

<table>
<thead>
<tr>
<th>Location</th>
<th>Measured $\dot{D}_{\text{water}}$ $\frac{\text{Gy}}{\text{min}}$</th>
<th>TPS $\dot{D}_{\text{water}}$ $\frac{\text{Gy}}{\text{min}}$</th>
<th>% difference Measured to TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit A</td>
<td>3.918</td>
<td>3.828</td>
<td>2.3</td>
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<tr>
<td>Unit B</td>
<td>2.636</td>
<td>2.587</td>
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<tr>
<td>Unit C</td>
<td>3.105</td>
<td>3.059</td>
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<tr>
<td>Unit D</td>
<td>1.334</td>
<td>1.303</td>
<td>2.3</td>
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<tr>
<td>Unit E</td>
<td>2.224</td>
<td>2.159</td>
<td>2.9</td>
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<td>Unit F</td>
<td>3.068</td>
<td>2.992</td>
<td>2.5</td>
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<tr>
<td>Unit G</td>
<td>2.853</td>
<td>2.796</td>
<td>2.0</td>
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</table>
## Perfexion dose rates

<table>
<thead>
<tr>
<th>Location</th>
<th>Media</th>
<th>$\dot{D}_{\text{water}}^{\text{Gy/min}}$</th>
<th>% difference In-Air to PMMA</th>
<th>% difference In-Air to TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit A</td>
<td>In-Air</td>
<td>3.279</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
<td>3.261</td>
<td>0.54</td>
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<tr>
<td></td>
<td>TPS</td>
<td>3.199</td>
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<td>2.4</td>
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<tr>
<td>Unit B</td>
<td>In-Air</td>
<td>3.677</td>
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<td>2.4</td>
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<tr>
<td></td>
<td>PMMA</td>
<td>3.649</td>
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<td></td>
<td>TPS</td>
<td>3.531</td>
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<td>4.0</td>
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<tr>
<td>Unit C</td>
<td>In-Air</td>
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<td>5.0</td>
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<tr>
<td></td>
<td>PMMA</td>
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<tr>
<td></td>
<td>TPS</td>
<td>3.302</td>
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</tr>
</tbody>
</table>
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TG 178

- Gamma Stereotactic Radiosurgery Dosimetry and Quality Assurance

1. Review calibration phantoms versus in-air calibration for GSR devices
2. Work with Working Group on Dosimetry Calibration Protocol for Beams that are Not Compliant with TG-51 (WGDCPB)
3. Suggest a protocol for calibration with ionization chambers calibrated appropriately at an Accredited Dosimetry Calibration Laboratory that can be successfully utilized with all GSR devices
4. Update Quality Assurance protocols for all static GSR devices
5. Create new Quality Assurance protocols for new GSR devices with rotating or moving sources
Considerations

- **Disadvantages**
  - Increasing treatment times
  - Periodic reloading
  - Regulatory concerns
  - Stereotactic frame

- **Advantages**
  - General reliability
  - Precision
  - Cobalt-60
  - Perfexion