SRS/SBRT Case Studies: Gamma Knife for Brain (and Spine?)

David Schlesinger, Ph.D.

Lars Leksell Gamma Knife Center
University of Virginia

Education objectives

1. Understand the differences in indications and dose/fractionation strategies for intracranial SRS and spine SBRT.
2. Describe the different treatment modalities which can be used to deliver intracranial SRS and spine SBRT.
3. Cite the major differences in treatment setup and delivery principles between intracranial and spine treatments.
4. Identify key critical structures and clinical dosimetric tolerance levels for spine SBRT and intracranial SRS.
5. Understand areas of ongoing work to standardize intracranial SRS and spine SBRT procedures.

Gamma Knife Principles and Design

Gamma Knife as an Intracranial SRS Platform

Hypofractionated Gamma Knife

Gamma Knife as a Spine SRS Platform

Conclusions

Dosimetric goal of radiosurgery

6-field 3D conformal plan

Intracranial SRS treatment plan

Relies on differential biology

Relies on differential targeting

SRS radiobiology may be different

In-vitro cell survival > LQ model predicts for SRS

But clinically SRS performs better than LQ model predicts

Microvascular damage has been shown to occur at doses > 10Gy.

SRS biological effect may involve DNA damage + vascular damage

Research support: Elekta Instruments, AB

Conflicts of Interest

The Linear-Quadratic Model is Inappropriate to Model High-Dose per Fraction Effects in Radiosurgery
J. Kirkpatrick, J. Meyer, L.B. Marks
Semin Rad Onc, 18(4), 2008.

J. Kirkpatrick, J. Meyer, L.B. Marks
Semin Rad Onc, 18(4), 2008.
A single 36 Ci source yields a dose rate of ~480 mSv/hr at 1 meter! ~20 metric tons to protect you from 20 grams of $^{60}$Co

Gamma Knife Perfexion

Technical requirement to create many individual small beams led directly to the use of $^{60}$Co.

Distributing the energy over many cross-firing beams generates the steep dose gradients.

Model C: 201 beams / isocenter  Perfexion: 192 beams / isocenter
Not uncommon to have 10-20+ isocenters to create an irregular shape

Gamma Knife treatment planning process

Total dose distribution is a sum of one or more isocenters, or “shots.”
Center of each shot is a location that will dwell at isocenter of GK for calculated time
Planning is fast – a requirement when a patient is waiting with a frame
Plans are classically prescribed to the 50% isodose line to maximize gradient

What to treat and what dose?

<table>
<thead>
<tr>
<th>Disease</th>
<th>% of total cases (2007-2016)</th>
<th>relative Rx dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestibular Schwannoma</td>
<td>8%</td>
<td>11-13 Gy</td>
</tr>
<tr>
<td>AVM</td>
<td>6%</td>
<td>18-25 Gy</td>
</tr>
<tr>
<td>Meningioma</td>
<td>15%</td>
<td>15 Gy</td>
</tr>
<tr>
<td>Functional</td>
<td>1%</td>
<td>65-75 Gy</td>
</tr>
<tr>
<td>Trigeminal Neuralgia</td>
<td>11%</td>
<td>40 Gy</td>
</tr>
<tr>
<td>Pituitary Adenoma</td>
<td>12%</td>
<td>15-25 Gy</td>
</tr>
<tr>
<td>Malignant Metastases</td>
<td>38%</td>
<td>12-18 Gy</td>
</tr>
<tr>
<td>Other Tumors</td>
<td>9%</td>
<td>12-24 Gy</td>
</tr>
</tbody>
</table>

Frames for localization and immobilization

The frame defines the coordinate system and immobilizes patient
Coordinate system origin is to the right, superior, posterior of the patient’s head
All coordinates are positive - no sign mistakes
Center of the system is considered to be (100, 100, 100) (mm)
**Organs at risk and dose limits**

<table>
<thead>
<tr>
<th>Critical Structure</th>
<th>Dose Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior optic pathway</td>
<td>8 Gy (to ~0.01 cc of structure)</td>
</tr>
<tr>
<td>Brainstem</td>
<td>12 Gy to a significant volume (30% or so)</td>
</tr>
<tr>
<td>Skin</td>
<td>10-12 Gy</td>
</tr>
<tr>
<td>Lenses</td>
<td>2 Gy maximum</td>
</tr>
<tr>
<td>Cranial Nerves in Cavernous Sinus</td>
<td>TBD</td>
</tr>
<tr>
<td>Cochlea</td>
<td>TBD, maybe as low as 5 Gy</td>
</tr>
</tbody>
</table>

*Dose limit data is sparse and is based mainly on class III evidence*


**Factors involved in choosing a dose**

- Indication
  - Tumor volume (RTOG 90-05)
  - Prior RT/SRS
  - Tumor vs resection cavity
  - Location
  - Number of tumors treated

A small reduction in dose can help keep the volume of normal brain at predictive dose levels (such as 12 Gy) constant with increasing # tumors treated.

**Gamma Knife Principles and Design**

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- Hypofractionated Gamma Knife
- Gamma Knife as a Spine SRS Platform
- Conclusions

**The brain is often short on space**

- Pituitary adenoma (coronal view)
- Parasellar anatomy

**Frames have very low uncertainty**

SRS frames provide for low setup uncertainty and robust immobilization. But, practically limits treatment to single fraction. Looks more invasive than it really is.

Li, et al., IJROBP 2016.
The mechanics of the Gamma Knife have low uncertainty

Control chart: Monthly focus precision results

Site-diode tool (Focus Precision Tool) used to locate radiation isocenter

Radial difference from calibration position

Control limit (3σ) determined from first 5 measurements

Gamma Knife has small low-dose spillage

Low-dose spillage in normal brain tends to be lower with Gamma Knife SRS and other multi-isocentric techniques. But...treatments can be lengthy.

Single-isocenter VMAT is designed for speed. Tradeoff (at the moment) is low-dose spillage.

Multi-isocenter techniques: Beam-on time scales with # targets treated

Single-isocenter VMAT: Treatment time stays constant regardless of number of lesions

But remember...beam-time is not the same as total procedure time!

Sometimes cases are tricky...

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The first try: Gamma Knife Extend System

Reference measurements taken at time of CT imaging

Patient position measured at GK before each fraction. Patient repositioned to match reference measurements.
### Immobilization is the basic technical problem

*Fixation of frame at the maxilla can allow treatments lower than C2. Still need reliable methods to immobilize C-spine.*

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### A better idea for hypofractionated Gamma Knife

**Gamma Knife Perfexion** _Icon_

- CBCT image guidance
- Optical motion tracking and gating
- Compatible with G-frame, and thermoplastic mask

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### Gamma Knife Principles and Design

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### We already do Gamma Knife for spine – sort of

- C1-C2 level brain metastasis

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### Conclusions
The Gamma Knife was designed specifically around the requirements for intracranial radiosurgery. It balances high accuracy and precision with efficient workflow. As indications have changed, Gamma Knife has attempted to adapt. While upper cervical spine is within reach, immobilization remains a significant technical hurdle.

Conclusions

Thank You!

Thomas Jefferson's Rotunda at the University of Virginia