TomoTherapy for Cranial Radiosurgery: The Saint Mary’s Experience

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The combined 3D imaging from CT, with the delivery of radiation from a binary collimator, from 360° of rotation.
Helical CT: TomoTherapy Process
**General Requirements for Successful Cranial Radiosurgery**

- **Good Immobilization**
  - Patient should not be able to move significantly.

- **Localization**
  - Must be able to place patient back into treatment position.

- **Excellent Dose Conformality**
  - To shape dose cloud around optic chiasm, brain stem, etc.

- **Q.A. Verifiable**
  - Is that dose distribution really deliverable?
Questions for an Early TomoTherapy Adopter

- Immobilization
  - Can a mask-based system be used without invasive fixation?

- Localization
  - Is image-guidance in TomoTherapy sensitive enough for cranial radiosurgery (single fraction and fractionated)?

- Conformality
  - How conformal is dose distribution?

- Q.A.
  - How good are the Q.A. tools?

- How important is daily imaging-IGRT?
If you can’t see what you are doing clearly, you may not get the desired outcome!
Carbon Fiber “S-Frame” Immobilizer
Typical Immobilization
Gold Fiducial Imaging

Axial “Fine”

Axial “Ultra Fine”
**Imaging Collimator Size**

Fine, Normal and Coarse

- 0.4 cm slit (0.6 cm)

Ultra Fine

- 0.1 cm slit (0.3 cm)
SAGITTAL LINE PAIR

PHANTOM TEST

COARSE
6 mm

NORMAL
4 mm

FINE
2 mm

ULTRA-FINE
1 mm

FINE AXIAL STANDARD
Protocols Available

**Slice Spacing**
- Fine (2 mm)
- Normal (4 mm)
- Coarse (6 mm)

**Ultra Fine (1 mm)**

Note: Current maximum is 80 slices per imaging session. Finest modality is chosen to allow coverage of region of interest.

6 MV used for all imaging
No flattening filter

<4 MV
Expect Something More

Standard Collimator
0.69 cm

Ultra fine Collimator
0.39 cm

Average Imaging Dose per Procedure

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Ultra fine</th>
<th>Fine</th>
<th>Normal</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.87</td>
<td>2.83</td>
<td>1.56</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Pitch
0.26 0.29 0.58 0.87
## Summary of Cranial Cases

**March 2005-March 2007**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th># Patients</th>
<th>Fractions</th>
<th>Dose (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GBM</td>
<td>18</td>
<td>5-33</td>
<td>35.0-59.4</td>
</tr>
<tr>
<td>Metastases</td>
<td>14</td>
<td>1</td>
<td>14.0-18.0</td>
</tr>
<tr>
<td>Meningioma</td>
<td>14</td>
<td>30-33</td>
<td>52.7-59.4</td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>6</td>
<td>30-33</td>
<td>54.0-59.4</td>
</tr>
<tr>
<td>Acoustic Neuroma</td>
<td>2</td>
<td>1-28</td>
<td>18.0-50.4</td>
</tr>
<tr>
<td>Others</td>
<td>8</td>
<td>28-33</td>
<td>50.4-59.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Coordinate System For Measurements

Linear one dimensional shifts do not represent total three-dimensional shift.
The Need for IGRT: Daily Shifts from initial Setup Position

Mean = 4.1 mm
n = 116

2.35 mm
Fusion Improvement with Rotational Shifts

- **Right Marker**
- **Center Marker**
- **Left Marker**

Legend:
- No IGRT
- Linear Only
- Linear + Rotational
## Auto Fusion Accuracy

<table>
<thead>
<tr>
<th>Patient</th>
<th>Fusion</th>
<th>RT</th>
<th>Center</th>
<th>LT</th>
<th>Gold Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Linear+Rot</td>
<td>0.71</td>
<td>0.79</td>
<td>0.13</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>2</td>
<td>Linear+Rot</td>
<td>1.73</td>
<td>2.06</td>
<td>1.95</td>
<td>1.1 mm</td>
</tr>
<tr>
<td>3</td>
<td>Linear+Rot</td>
<td>0.55</td>
<td>0.52</td>
<td>0.67</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>4</td>
<td>Linear+Rot</td>
<td>1.75</td>
<td>3.08</td>
<td>1.78</td>
<td>1.4 mm</td>
</tr>
<tr>
<td>5</td>
<td>Linear+Rot</td>
<td>0.07</td>
<td>0.99</td>
<td>0.13</td>
<td>0.2 mm</td>
</tr>
</tbody>
</table>

(n=116)
**Typical Protocol for SRS/SRT**

- 2 days 512x512 MRI, 2 mm slices T1/T2
- -1 days 3D reconstruction of MRI, head pitch determined
- Day 0 immobilization using double layer aquaplast mask and 2 mm slices KV-CT with IV contrast
- +1 day fusion (MRI + CT) and contouring
- +2 days plan generated/approved
- +3 days QA completed
- +4 days imaging only day. A minimum of two datasets collected (fine/ultra fine mode). This confirms patient’s stability over a short period of time.
- +5 days, imaging and treatment
“Single Fraction” Radiosurgery

- **Typical** table minimum velocity is 0.05 mm/sec
  - Theoretical minimum is 0.012 mm/sec

- Minimum gantry rotation is ~1 rpm
  - Typical Dose max is ~10 Gy per pass

- Dose greater than 10 Gy requires multiple passes
  - 18 Gy single fraction = 9 Gy/ff x 2 ff
Single Fraction Radiosurgery: Treatment Time

- Typical 18.0 Gy fraction for a 2 cm lesion, using 1 cm collimator
  - Imaging time is 5 min (fine mode)
  - Treatment time (9 Gy) is 20 min
  - 20 min x 2 passes = 40 min treatment time
    - Add a second imaging session of 5 min
    - Add overhead of 10 min
- Total time is 10+40+10 = 60 min
“Single Fraction” Radiosurgery: Is There a Radiobiological Concern?

• Two “mini” fractions delivered over a 1-hour period.

• This is comparable to typical radiosurgery where a single fraction may take 1 hour or more to deliver.
Sample Case: One Sensitive Structure
Sample Case: One Sensitive Structure
Sample Case: Two Sensitive Structures
Sample Case: Two Sensitive Structures
Sample Case: Two Sensitive Structures
Sample Case: Two Sensitive Structures
Sample Case: Two Sensitive Structures
Metastasis - Melanoma
Acoustic Neuroma
Glioblastoma Multiforme
Trigeminal Neuralgia
Summary

• Immobilization
  - Typical setup error with mask-based system without bone registration is a vector of ~4.1 mm.

• Localization
  - TomoTherapy IGRT/fusion process reduces uncertainty to ~1.15 mm (0.1-3.1mm).
  - When position is critical, additional gain can be achieved by implanted objective markers.
  - Daily imaging necessary.

• Conformality
  - Conformality acceptable even for small lesions adjacent to sensitive structures.

• Q.A.
  - Q.A. tools adequate for delivery evaluation.
If We Stand Still, We Fall Behind