Small-Volume Dose Limits for SRS/SBRT of Brain/Spine Lesions

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Current SRS/SRT/SBRT Platforms

Hypofractionation Tissue Effects in Clinic (HyTEC)
Classic Whole-Organ TD5/5 - TD50/5

- Cord: 15 Gy - 20 Gy
- Peripheral Nerve: 15 Gy - 20 Gy
- Whole Brain: 15 Gy - 25 Gy
- Lens: 2 Gy - 10 Gy
- Bone Marrow: 2 Gy - 10 Gy


TG101 Dose Limits (1Fx versus 5Fx)

<table>
<thead>
<tr>
<th>Critical Vol (mL)</th>
<th>Cochlea</th>
<th>Optical Pathway</th>
<th>Cord &amp; Medulla</th>
<th>Brainstem</th>
<th>Cauda Equina</th>
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<tbody>
<tr>
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Cochlear Dose Specifications

- Maximum
- Mean
- Median
- Modiolus
Published Cochlear Dose Limits (1Fx)

- Timmer F et al (2009): point max 10.3 Gy or mean dose of 4.9 Gy
- Paek S H et al (2005): modiolus dose 6.9 Gy
- Rashid et al (2015): point max 12 Gy (~11% risk)

NS cochlear dose correlations for conventional CFRT
- Single fraction marginal dose 12-14 Gy
- Point max and mean/modiolus cochlear dose all of importance

Cochlear Dose Inter-dependence

- Dmax correlated to dose levels at all small volumes
- D(modiolus) ~ Dmean

## Max versus Small-Volume Dose Limits

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### AAPM TG101 Dose Limits (1Fx / 5Fx)

An estimated 25 Gy/1 Fx delivered to the optical nerve without any adverse radiation effect for 23 years!
• Point Max Dose recommended < 10 Gy/1Fx

• Estimated radiation-induced optic neuropathy risk ~5%

• Predominantly GKSRS experiences (e.g. voxel size 0.5 mm or less)

Dose-Volume Analysis of Radiation-Induced Optic Neuropathy After Single-Fraction Stereotactic Radiosurgery

• Risk receiving single fractional 8 Gy, 10 Gy, 12 Gy was < 2.6%; < 4.7%; < 13.9% (confidence level = 95%)

• V8 < 0.036 mL; V10 < 0.0005 mL; V12 < 0.0001 mL

• Point Max < 10 Gy is a safe dose limit

Neurosurgery 75:456–460, 2014
DOI: 10.1227/NEU.0000000000000457

No patient had vision decline or other neurological deficit

Neurosurgery 75:456–460, 2014
DOI: 10.1227/NEU.0000000000000457
Lens of the Eye

- 2 Gy to the whole lens, cataract most likely
- Dose rate dependent: 5-8 Gy for chronic exposures to induce cataract
- NCRP occupational limit: 50 mGy annually


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Evolving Spine SBRT Techniques

Fixed-beam 9-field SBRT  Overlapping Coplanar Arc-beam SBRT

* AAPM TG 101: < 2-mm or less dose grid calculations
"Reports of myelopathy from SRS to spinal lesions appear rare (<1%) when the maximum spinal cord dose is limited to the equivalent of 13 Gy in a single fraction or 20 Gy in three fractions. Long-term data are insufficient to calculate a dose–volume relationship for myelopathy when the partial cord is treated with a hypofractionated regimen."

### Risk of Myelopathy Point Max Dose Limits

<table>
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<th>Probability</th>
<th>1Fx (Gy)</th>
<th>2Fx(Gy)</th>
<th>3Fx(Gy)</th>
<th>4Fx(Gy)</th>
<th>5Fx(Gy)</th>
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<tbody>
<tr>
<td>1%</td>
<td>9.2</td>
<td>12.5</td>
<td>14.8</td>
<td>16.7</td>
<td>18.2</td>
</tr>
<tr>
<td>2%</td>
<td>10.7</td>
<td>14.6</td>
<td>17.4</td>
<td>19.6</td>
<td>21.5</td>
</tr>
<tr>
<td>3%</td>
<td>11.5</td>
<td>15.7</td>
<td>18.8</td>
<td>21.2</td>
<td>23.1</td>
</tr>
<tr>
<td>4%</td>
<td>12.0</td>
<td>16.4</td>
<td>19.6</td>
<td>22.2</td>
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*Int J Radiat Oncol Biol Phys, 2013, 85(2), 341-347*

### Logistic Curve for Radiation Myelopathy

*Int J Radiat Oncol Biol Phys, 2013, 85(2), 341-7*
Dose Grid & Dose Normalization

Point maximum interpolation leads to ~ 5% dose variability
Larger dose grid size leads to larger uncertainties (0.1 – 2.0 mm)

Dose Grid Placement Uncertainty

Summary

- Cochlea: Point Max D(< 0.01 mL): 25 Gy/5
  Mean Dose < 4.5 Gy/1Fx

- Optical: Point Max D(~0.01 mL): 25 Gy/5

- Cord: Point Max D(~0.035 mL): 25 Gy/5*

* Multi-institutional international study
Future SBRT Device Likely Refine or Re-define Small-Volume Limits

- Real time soft tissue imaging and tracking
- Adaptive planning and dose optimization on the fly
- Ultra-fast linac-based beam delivery