

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

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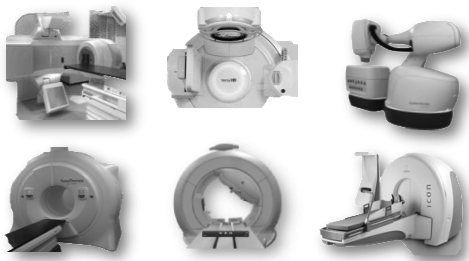
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## Current SRS/SRT/SBRT Platforms



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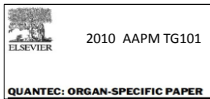
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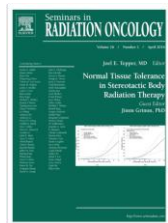
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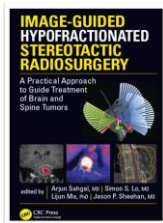


**Hypofractionation  
Tissue Effects in  
Clinic (HyTEC)**

2016



2016



2016

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### Classic Whole-Organ TD5/5 - TD50/5

- Cord 15 Gy - 20 Gy
- Peripheral Nerve 15 Gy - 20 Gy
- Whole Brain 15 Gy - 25 Gy

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- Lens 2 Gy - 10 Gy
- Bone Marrow 2 Gy - 10 Gy

Phil Rubin (1989) Radiation Tolerance Dose of Normal Tissues, Vol 23, Karger

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### TG101 Dose Limits (1Fx versus 5Fx)

Critical Vol (mL)	Cochlea	Optical Pathway	Cord & Medulla	Brainstem (-)Medulla	Cauda Equina	Sacral
0.035*	9 vs 25	10 vs 25	14 vs 30	15 vs 31	16 vs 32	16 vs 32
0.2		8 vs 23				
0.35			10 vs 23			
0.5				10 vs 23		
1.2			7 vs 14.5			
5.0					14 vs 30	14.4 vs 30

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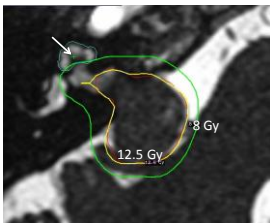
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### Cochlear Dose Specifications



- Maximum
- Mean
- Median
- Modiolus

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**Published Cochlear Dose Limits (1Fx)**

- Timmer F et al (2009): point max 10.3 Gy or mean dose of 4.9 Gy
- Brown M. et al (2011): mean dose 5.3 Gy
- Paek S H et al (2005): modiolus dose 6.9 Gy
- Kano H et al (2009): modiolus dose >4.2 Gy
- Rashid et al (2015): point max 12 Gy (~11% risk)

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Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 3, Supplement, pp. S26-S27, 2010  
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 Printed in the USA. All rights reserved.  
 0360-3015/10/\$ - see front matter  
 doi:10.1016/j.ijrobp.2009.04.096

**QUANTEC: ORGAN-SPECIFIC PAPER** **Central Nervous System: Ear**  
**RADIATION THERAPY AND HEARING LOSS**

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

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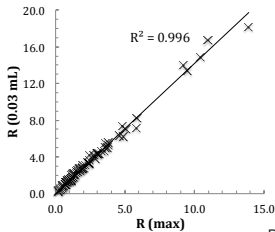
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**Cochlear Dose Inter-dependence**



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

Pract Radiat Oncol. 2017. Vol 7(1):e1-e7. doi: 10.1016/j.prr.2016.08.005.

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### Max versus Small-Volume Dose Limits

Point Max (0.0 mL) (Gy)	Dose (0.01 mL) (Gy)	Dose (0.03 mL) (Gy)	Mean Dose (Gy)	Modiolus Dose (Gy)
9	6	4.8	4.5	4.9
12	8	6.0	5.5	6.0
14	9	6.7	6.2	6.7

Pract Radiat Oncol. 2017. Vol 7(1):e1-e7. doi: 10.1016/j.prro.2016.08.005.

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

Critical Vol (mL)	Cochlea	Optical Pathway	Cord (+)Medulla	Brainstem (-)Medulla	Cauda Equina	Sacral Plexus
0.035	9/25	10/25	14/30	15/31	16/32	16/32
0.2		8/23				
0.35			10/23			
0.5				10/23		
1.2			7/14.5			
5.0					14/30	14.4/30

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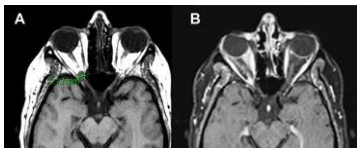
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CASE REPORT PEER-REVIEWED

### Extreme Tolerance of the Optic Nerve to Ionizing Radiation: A Case Report Revealing the Role of the Dose-Volume Effect

John R. Adler<sup>1</sup>, Judith Murovic, Yaping Joyce Liao, Lawrence M. Shuer



An estimated 25 Gy/1 Fx delivered to the optic nerve without any adverse radiation effect for 23 years !

DOI: 10.7759/cureus.187 (2014)

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**QUANTEC: ORGAN-SPECIFIC PAPER**      **Central Nervous System: Optic Nerve/Chiasm**

**RADIATION DOSE-VOLUME EFFECTS OF OPTIC NERVES AND CHIASM**

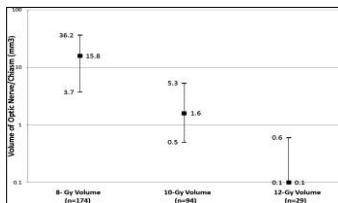
- Point Max Dose recommended < 10 Gy/1Fx
- Estimated radiation-induced optic neuropathy risk ~5%
- Predominantly GKSRS experiences (e.g. voxel size 0.5 mm or less )

**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

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



**No patient had vision decline or other neurological deficit**

Neurosurgery  
75:456-460, 2014  
DOI:  
10.1227/NEU.000000  
0000000457

## 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

Int J Radiat Biol. 2017 Apr 3:1-9. doi: 10.1080/09553002.2017.1304669.

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

Critical Vol (mL)	Cochlea	Optical Pathway	Cord (+)Medulla	Brainstem (-)Medulla	Cauda Equina	Sacral Plexus
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0.2		8/23				
0.35			10/23			
0.5				10/23		
1.2			7/14.5			
5.0					14/30	14.4/30

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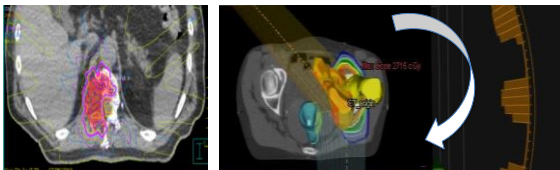
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## Evolving Spine SBRT Techniques



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

\* AAPM TG 101: < 2-mm or less dose grid calculations

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Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 3, Supplement, pp. S42-S49, 2010  
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0360-3016/10/\$ - see front matter

doi:10.1016/j.ijrobp.2009.04.095

QUANTEC: ORGAN SPECIFIC PAPER

Central Nervous System: Spinal Cord

RADIATION DOSE-VOLUME EFFECTS IN THE SPINAL CORD

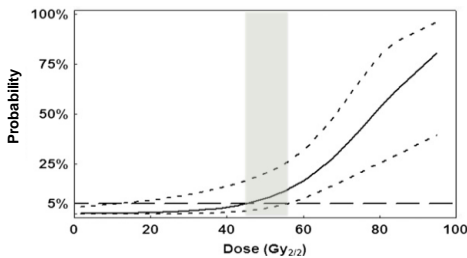
“Reports of myelopathy from SRS to spinal lesions appear rare (<1%) when the maximum spinal cord dose is limited to the equivalent of **13 Gy in a single fraction or 20 Gy in three fractions**. Long-term data are insufficient to calculate a dose-volume relationship for myelopathy when the partial cord is treated with a hypofractionated regimen.”

Risk of Myelopathy Point Max Dose Limits

Probability	1Fx (Gy)	2Fx(Gy)	3Fx(Gy)	4Fx(Gy)	5Fx(Gy)
1%	9.2	12.5	14.8	16.7	18.2
2%	10.7	14.6	17.4	19.6	21.5
3%	11.5	15.7	18.8	21.2	23.1
4%	12.0	16.4	19.6	22.2	24.4
5%	12.4	17.0	20.3*	23.0	25.3

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

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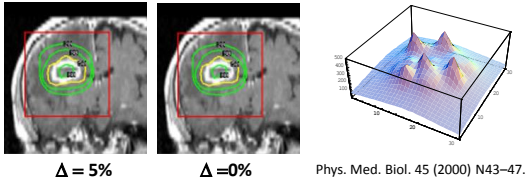
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### Dose Grid & Dose Normalization

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




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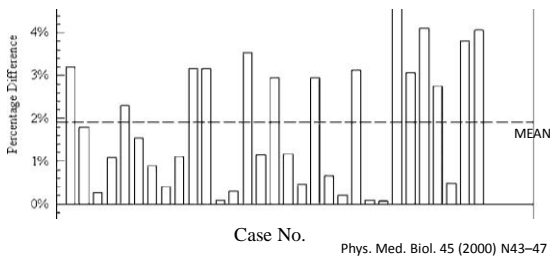
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### Dose Grid Placement Uncertainty




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### 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




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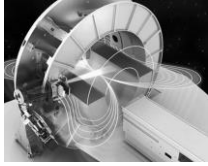
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## Future SBRT Device Likely Refine or Re-define Small-Volume Limits



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

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