A Comparison of Radiosurgical Planning Techniques for the Treatment of Trigeminal Neuralgia

K Doxsee[1,2], I Paddick[3], W Friedman[1], J Li[1], A De Leo[1], M Koch[1], F Bova[1]
[1]University of Florida, Gainesville, FL, [2]Prisma Health, Greenville, SC, [3]Queen Square Radiosurgery Centre, London, UK

UF College of Medicine UNIVERSITY of FLORIDA

PRISMA HEALTH SM

Introduction

In modern Radiation Oncology, Stereotactic Radiosurgery has played an ever-increasing role as a therapeutic modality since the late 1980s. This steady increase, for treatment of both malignant and benign conditions, can be attributed to careful documentation by clinicians, particularly in peer-reviewed literature, reporting such data as prescription details, target and symptom control effectiveness, and normal tissue complications, leading to the development of effective and safe clinical protocols. [1] [2] [3]

This study focuses on the radiosurgical treatment planning for Trigeminal Neuralgia (TN). Stereotactic radiosurgery (SRS) is an ablative technique often used in patients who are not good candidates for more invasive surgical procedures, such as elderly patients with concurrent medical illnesses, that require a minimally invasive approach.

Rationale and Objectives

The radiosurgical treatment of TN requires a very high treatment dose to a small volume of the trigeminal nerve near the pons, and so has warranted the publication of many reports, clinical guidelines, and protocols. For these treatments, the prescription has historically been to a point dose within the trigeminal nerve as visualized on MRI imaging data, such that an actual target volume is rarely defined. Consequently, the minimum and maximum doses to the cross section of the nerve are seldom determined, and even the total volume of the prescribed dose coverage and actual dose profiles are usually not documented. Furthermore, treatments are diversely delivered via modalities such as Gamma Knife and static-MLC, dynamic-MLC, or cone-based linear accelerator (LINAC) collimated plans.

Today, LINAC-based radiosurgery has several variables that can be altered, such as couch rotation, gantry arc length, dose rate modulation and more, that can shape the dose delivered to the trigeminal nerve via MLC- or cone-based collimation. However, along with this increased treatment flexibility, it becomes increasingly difficult to decipher exactly how radiation doses and anatomic target location affect patient outcomes. Recent Gamma Knife studies have suggested that both biological equivalent dose (BED) [4] and prescription dose are predictive of pain relief [5] [6] but there has not been work to repeat these findings for LINAC-based radiosurgery.

This study provides an analysis of commonly used treatment approaches to help define a set of variables that should be reported with all future clinical outcome studies.

Method

Various stereotactic radiosurgery treatment plan approaches used for TN were recreated based on the same set MRI scans using Fast Imaging Employing Steady-state Acquisition (FIESTA). All plans were calculated on the same CT and MRI data sets to reduce anatomical variations that could effect dose calculation and distribution. The treatment planning ensemble included a Gamma Knife Radiosurgery plan, cone-based multiple-arc LINAC plans with common arc arrangements and cone sizes, and a static MLC-based multi-arc technique commonly referred to as "Virtual Cone" [7], comprising a total of eight distinct treatment plans.

The Gamma Knife (Leksell GammaPlan 11.4, Elekta Instrument AB, Stockholm, Sweden) plan for this study used a 4-mm conical collimator. The plan was calculated with a 0.5 mm dose grid.

For LINAC-based treatment planning, several iterations of commonly cited treatment techniques were produced. In all LINAC plans, a flattening filter free beam of 6 MV nominal energy was employed.

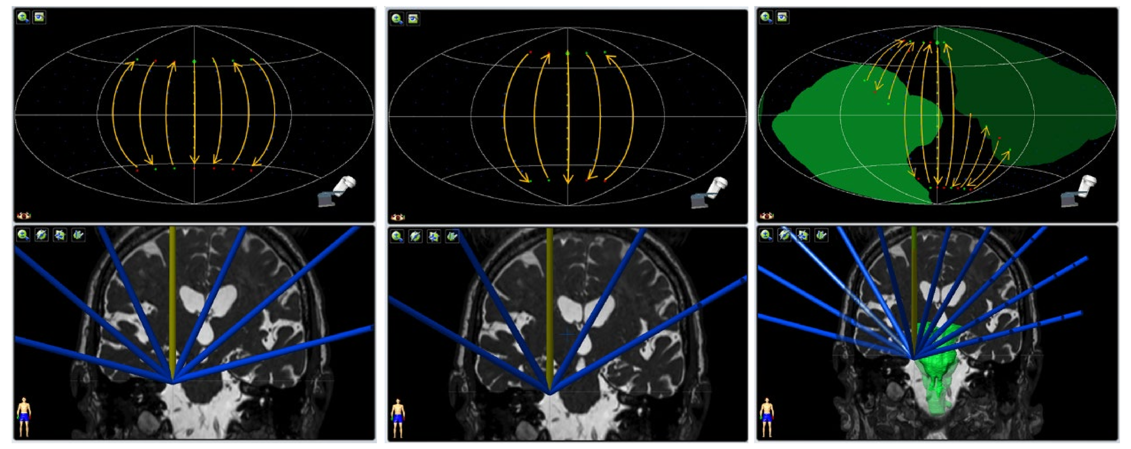

Figure 1. Arc arrangements for cone-based LINAC treatment plans.

For the cone-based LINAC treatment plans, three plan templates were employed (see Figure 1), one with 5 non-coplanar arcs, one with 7 non-coplanar arcs, and one with 11 non-coplanar arcs. The 5-arc plans comprise 5 equally spaced arcs, covering 120 degrees at table angles of 30, 60, 90, 300 and 330 degrees. The 7-arc plans comprise 7 equally spaced arcs, each covering 100 degrees at table angles 15, 40, 65, 90, 295, 320, and 345 degrees. The 11-arc plans contain 11 arcs with variable lengths selectively chosen to minimize dose to the brainstem. Each of the three cone-based linear accelerator templates were planned with (separately) a 4-mm and 5-mm conical collimator. Cone-based plans were created with iPlan Dose 4.5.5 treatment planning system (Brainlab AG, Munich, Germany) using 0.5 mm dose grid and the RT Dose Monte Carlo dose calculation algorithm.

Finally, the MLC-based Virtual Cone plan was created in Eclipse 16.1 (Varian Medical Systems, Palo Alto, CA) using the AAA dose calculation algorithm with heterogeneity correction and a 1 mm dose grid.

All treatment plans were prescribed to deliver 85Gy to the maximum point dose.

Results

There are significant differences in the dose profiles and gradients between plans.

Variations in isodose shape are observed across techniques, as shown in Figure 2. Focusing specifically on the 80% isodose lines (yellow) in Figure 2b, the placement of isocenter may affect the nerve coverage significantly, especially with the 4 mm physical cone plans and the virtual cone plan.

Figures 3, 4 and 5 demonstrate dose line profiles across isocenter in two orthogonal planes, created to similarly visualize and compare each planning technique in terms of dose coverage and fall off. From these dose profiles, it is apparent that collimator size selection results in the largest variation between the different planning strategies. The (4 mm) Gamma Knife technique has broadest coverage, falling to approximately 50% and 30% of maximum dose at 3 mm and 4 mm from isocenter, respectively. Contrastingly, the narrowest coverage is provided by the 4 mm physical cone LINAC plans, falling to approximately 60% and 30% of maximum dose at 2 mm and 3 mm from isocenter, respectively.

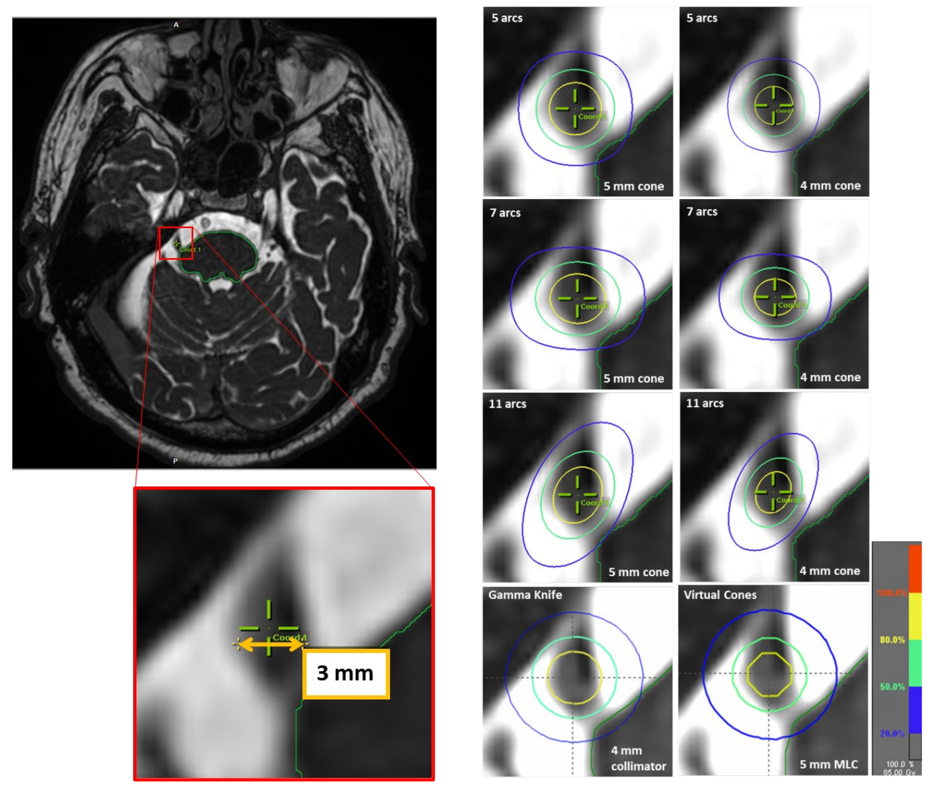

Figure 2. Cross-section dose distributions (Figure 2b) across the trigeminal nerve with each of the eight planning techniques, visualizing the same slice of the singular MRI dataset (amplified in Figure 2a).

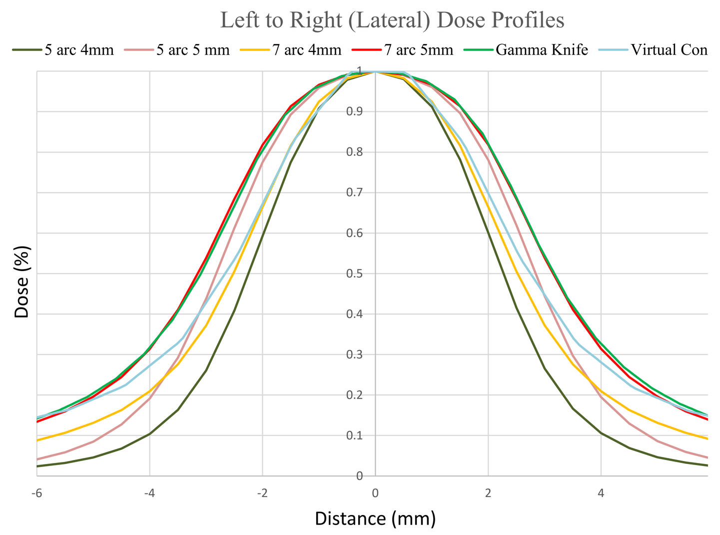

Figure 3. Lateral dose profiles

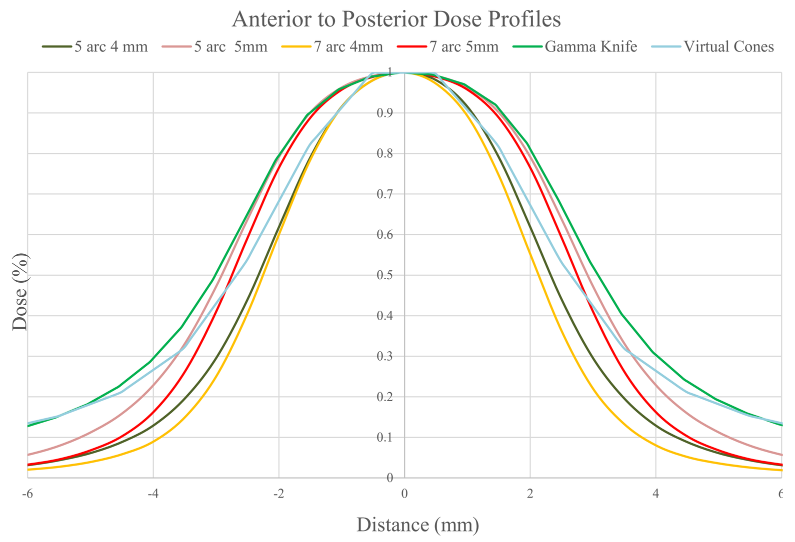

Figure 4. Anterior to posterior dose profiles

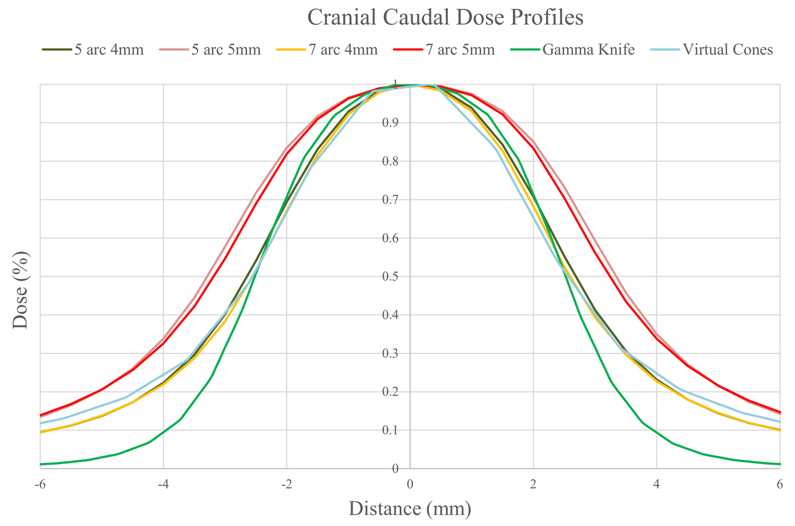

Figure 5. Cranial caudal dose profiles

TABLE 1	
Calculated GI for each plan type	
Plan Type	**GI**
Gamma Knife	3.29
5 arc 4mm	4.19
7 arc 4mm	4.18
11 arc 4 mm	4.13
5 arc 5 mm	3.39
7 arc 5mm	3.47
11 arc 5 mm	3.36
Virtual Cones	4.87

A common quantitative measure for comparing dose gradients between plans is the Gradient Index (GI) [8], defined in the equation below.

GI= (50% Isodose Volume)/(Prescription Isodose Volume)

For this calculation, a prescription isodose volume is required – a complication for this study since the prescription is to the isocenter. As a result, for the GI calculation, the 80% isodose volume was selected as a representative prescription isodose volume. The GI was calculated for each plan type and presented in Table 1.

The lengths in the three orthogonal axes as well as the volumes encompassed by the 80% and 50% isodose lines are displayed in Tables 2 and 3, respectively. The brainstem maximum dose to 0.1 cc volume was compared and results in Table 4, using a prescription dose of 85 Gy. The minimum dose at 1.5 mm and 2 mm away from isocenter was compared for each planning technique. These two distances were chosen to simulate what the minimum edge dose to a hypothetical 3 mm or 4 mm trigeminal nerve would receive, since the true nerve volumes were not created. Results for this comparison are displayed in Table 5.

TABLE 2				
Lengths along three orthogonal axes and volume covered by 80% isodose line				
Plan Type	Lateral (mm)	Ant-Post (mm)	Foot-Head(mm)	Volume (mm3)
Gamma Knife	4.0	4.0	3.4	28.5
5 arc 4 mm	2.8	2.9	3.2	13.9
5 arc 5 mm	3.8	3.9	4.3	33.4
7 arc 4 mm	3.1	2.9	3.1	14.6
7 arc 5 mm	4.1	3.7	4.1	33.3
11 arc 4 mm	2.8	3.3	3.0	14.4
11 arc 5 mm	3.8	4.3	4.0	34.5
Virtual Cones	3.2	3.1	3.0	15.6

TABLE 3				
Lengths along three orthogonal axes and volume covered by 50% isodose line				
Plan Type	Lateral (mm)	Ant-Post (mm)	Foot-Head(mm)	Volume (mm3)
Gamma Knife	6.0	6.2	5.1	97.5
5 arc 4mm	4.5	4.7	5.3	58.2
5 arc 5 mm	5.6	5.8	6.6	113.4
7 arc 4mm	5.0	4.5	5.1	60.9
7 arc 5mm	6.3	5.5	6.4	115.8
11 arc 4 mm	4.4	5.3	4.8	59.4
11 arc 5 mm	5.5	6.6	6.0	115.8
Virtual Cones	5.4	5.3	5.1	77.2

Results (continued)

TABLE 4	
Brainstem Dose (Gy)	
Plan Type	0.1 cc Dose
Gamma Knife	8.5
5 arc 4mm	5.0
7 arc 4mm	7.0
11 arc 4 mm	2.5
5 arc 5 mm	8.1
7 arc 5mm	9.5
11 arc 5 mm	3.5
Virtual Cones	9.7

TABLE 5		
Minimum dose to hypothetical nerve (Gy)		
Plan Type	Nerve Width	
	3 mm	4 mm
Gamma Knife	73	60
5 arc 4mm	66	50
7 arc 4mm	67	51
11 arc 4 mm	65	48
5 arc 5 mm	77	66
7 arc 5mm	75	65
11 arc 5 mm	75	64
Virtual Cones	68	55

Conclusion

- The selection of radiosurgery for treatment of TN should be considered in context of the differences in dose distribution between available delivery techniques
- There are distinct differences between even this sample of eight treatment plan types.
- Comprehensive and uniform planning information and dose characteristic reporting is needed to objectively compare studies and outcome data for TN radiosurgery.
- It is a recommendation of this study to contour the entire cross section of the trigeminal nerve that is to be targeted to accurately determine the integral dose and minimum dose to that section of the nerve.
- It is also recommended to document and report volume-based dose and maximum dose received by the brainstem.

References

[1] Russell, Dylan et al. "Stereotactic radiosurgery alone or combined with embolization for brain arteriovenous malformations: a systematic review and meta-analysis." *Journal of neurosurgery* vol. 128,5 (2018): 1338-1348. doi:10.3171/2016.11.JNS162382

[2] Weil, R S et al. "Optimal dose of stereotactic radiosurgery for acoustic neuromas: A systematic review." *British journal of neurosurgery* vol. 20,4 (2006): 195-202. doi:10.1080/02688690600886108

[3] Pinzi, Valentina et al. "Radiosurgery for intracranial meningiomas: A systematic review and meta-analysis." *Critical reviews in oncology/hematology* vol. 113 (2017): 122-134. doi:10.1016/j.critrevonc.2017.03.005

[4] Régis, Jean et al. "The Very Long-Term Outcome of Radiosurgery for Classical Trigeminal Neuralgia." *Stereotactic and functional neurosurgery* vol. 94,1 (2016): 24-32. doi:10.1159/000443529

[5] Warnick, Ronald E et al. "The relevance of biologically effective dose for pain relief and sensory dysfunction after Gamma Knife radiosurgery for trigeminal neuralgia: an 871-patient multicenter study." *Journal of neurosurgery*, 1-13. 16 Feb. 2024, doi:10.3171/2023.12.JNS231569

[6] Shrivastava, Adesh et al. "Impact of Integral Dose on the Maintenance of Pain Relief in Patients with Idiopathic Trigeminal Neuralgia Treated with Upfront Gamma Knife Radiosurgery." *World neurosurgery* vol. 129 (2019): e375-e380. doi:10.1016/j.wneu.2019.05.155

[7] Popple, Richard A et al. "The virtual cone: A novel technique to generate spherical dose distributions using a multileaf collimator and standardized control-point sequence for small target radiation surgery." *Advances in radiation oncology* vol. 3,3 421-430. 2 Mar. 2018, doi:10.1016/j.adro.2018.02.011

[8] Paddick, Ian, and Bodo Lippitz. "A simple dose gradient measurement tool to complement the conformity index." *Journal of neurosurgery* vol. 105 Suppl (2006): 194-201. doi:10.3171/sup.2006.105.7.194