Monte Carlo Investigation into Effect of Setup and Motion Uncertainties on Dosimetry of Trigeminal Neuralgia Treatments with Virtual Cone SRS

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ABSTRACT

Purpose: Estimate impact of setup and motion uncertainties on dosimetry of SRS with Virtual Cone (VC) and evaluate a simple method to account for such uncertainties in clinical dose calculations.
Methods: SRS treatment of trigeminal neuralgia using Virtual Cone (proposed by University of Alabama, UAB) involves multiple noncoplanar arcs and collimator rotations using HD MLCs with two leaf pairs opened during the treatment to create a fixed gap. The gap sizes of 1.4 – 2.6 millimeters were reported. Vancouver Island Monte Carlo (MC) system was used to model such treatments. Voxel size of 1mm was used as most common dose resolution for such calculations, and 0.5% statistical uncertainty was used. MC calculations were also re-run with 1.25, 1.5 and 2mm voxels. Fluence convolution method was used to model setup uncertainties.
Results: For the treatments with 1.4mm leaf gap, setup uncertainties with 0.5 and 1mm standard deviations (SD) reduced the values of maximum dose (Dmax) by 10.5% and 26% respectively. For the treatments with leaf gap of 2.1mm, Dmax reduction was 8% and 24%, and for the leaf gap of 2.6mm Dmax reduced by 7% and 22%. MC calculations using 1.5mm voxel size (no setup uncertainty) agreed with the dose from modeling 0.5% SD setup uncertainty, reducing Dmax differences to less than 1.5% for all studied leaf gaps. The dose profiles also agreed within less than 0.2mm below 90% isodose. Similarly, using calculations with 2mm voxel size (no setup uncertainty) reproduced the Dmax from calculations that included 1mm setup uncertainty within 3%.
Conclusions: Setup uncertainties can have considerable effect on dosimetry of VC SRS. Larger voxels sizes such as 1.5mm and 2mm may better reproduce dosimetry for uncertainties of 0.5% and 1% SD than commonly used 1 mm voxels.

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INTRODUCTION

Using Virtual Cone[1] (VC) for treatment of trigeminal neuralgia was proposed by University of Alabama, (UAB) group. This method involves multiple non-coplanar arcs, each with different collimator rotations and using static HD MLCs where only two central leaf pairs are opened during the treatment to create a fixed 5mm long gap. The gap width sizes of 1.4 – 2.6 millimeters were reported in the literature. Such beam delivery was shown to produce very small, near spherical dose distributions with steep dose gradients. Despite small size of the gap width, in-phantom dosimetry of this technique was reported to be accurate within 5% compared to planned dose[1,2].

Investigations of impact of uncertainties on this treatment so far have been however rather limited[3,4], focusing mostly on the possible systematic leaf misplacements or motion.

Most dose calculations reported in the literature used 1mm dose grid size with some[5] using the grid size as small as 0.1mm. However, no reports were found investigating dose grid size accounting for expected setup/motion uncertainties in treatment delivery.

This study evaluates potential impact of random setup/motion uncertainties on dosimetry of VC SRS treatments as well as appropriate dose grid (voxel) sizes for such dose calculations.

METHODS AND MATERIALS

VC SRS plans with 1.4, 2.1- and 2.6-mm gaps were created in Eclipse 18.0 on 20 cm cube water phantom. These plans were re-calculated using Monte Carlo (MC) modeling with Vancouver Island MC system[6,7] that has been previously well benchmarked and demonstrates very good agreement with Eclipse AAA even for such challenging small field calculations.

Mechanical tolerances in modern linacs on gantry, collimator and couch motions allow 0.5mm variation of these rotations from the isocenter. In addition, despite rigid patient immobilization and intrafraction monitoring, patient head motion still occurs during the treatment. Therefore, combined geometrical uncertainty of 0.5mm standard deviation (SD) and up to 1mm SD can be considered as realistic values for this multi-arc non-coplanar treatments.

We modeled random geometric uncertainties using fluence convolution method[8]. Implementation and validation of this method to MC calculations was previously described by Stapleton et al[9].

It is well known that random setup/motion errors lead to smearing of the dose distribution profiles. Qualitatively the same effect is produced by volume averaging when larger voxels are used in dose calculations. We therefore investigated if volume averaging could mimic the dose smearing effect from setup uncertainties in VC SRS treatment configuration.

All VC SRS plans were modeled using MC with 1 mm voxel size, 0.5% statistical uncertainty. All plans were then modeled with MC again using voxel sizes of 1.25mm, 1.5mm and 2mm.

All VC SRS plans were also modeled using MC with incorporated random setup/motion uncertainties of 0.5mm and 1mm SD.

RESULTS

Agreement of MC modeling against Eclipse 18.0 AAA dose calculations exceeded 90% pass rate with 3%/1mm thresholds and 50% low dose threshold (Figure 1).

For the treatments with 1.4mm leaf gap, setup/motion uncertainties with 0.5mm and 1mm standard deviations (SD) reduced the values of maximum dose (Dmax) by 10.5% and 26% respectively. For the treatments with leaf gap of 2.1mm, Dmax reduction was 8% and 24%, and for the leaf gap of 2.6mm Dmax reduced by 7% and 22%.

MC calculations using 1.5mm voxel size (no setup uncertainty) agreed with the dose from modeling 0.5% SD setup uncertainty, reducing Dmax differences to less than 1.5% for all studied leaf gaps. The dose profiles also agreed within less than 0.2mm below 90% isodose. Similarly, using calculations with 2mm voxel size (no setup uncertainty) reproduced the Dmax from calculations that included 1mm setup uncertainty within 3% (Figures 2-3).

Table 1. Reduction of the maximum dose Dmax due to random setup/motion uncertainties with 0.5mm and 1mm SD for VC SRS with 1.4-2.6mm leaf gaps.

Leaf gap	Uncertainty, SD	
	0.5 mm	1 mm
1.4 mm	10.5%	26%
2.1 mm	8%	24%
2.6 mm	7%	22%

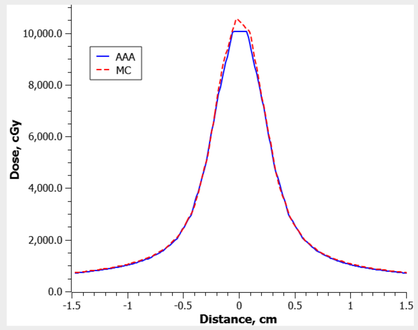

Figure 1. Comparison of Eclipse AAA 18.0 (Blue) vs MC calculated dose (Red, dashed) profiles for VC SRS plan with 2.6 mm leaf gap.

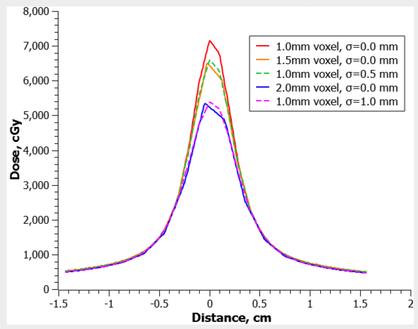

Figure 2. Demonstrates MC dose distributions calculated for VC SRS plan with 1.4mm leaf gap. Red - 1mm voxel size (no setup uncertainty), Orange – 1.5mm voxel size (no setup uncertainty), Green – 1.0mm voxel size (0.5 mm SD setup/motion uncertainty), Blue – 2.0mm voxel size (no setup uncertainty), Pink – 1.0mm voxel size (1.0 mm SD setup/motion uncertainty).

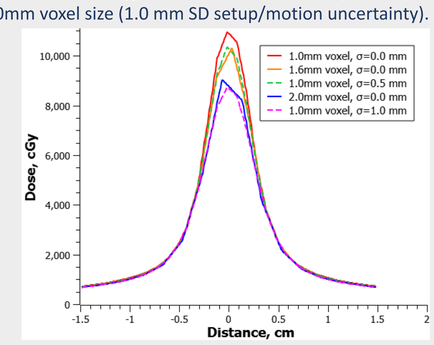

Figure 3. Demonstrates MC dose distributions calculated for VC SRS plan with 2.6mm leaf gap. Red - 1mm voxel size (no setup uncertainty), Orange – 1.6mm voxel size (no setup uncertainty), Green – 1.0mm voxel size (0.5 mm SD setup/motion uncertainty), Blue – 2.0mm voxel size (no setup uncertainty), Pink – 1.0mm voxel size (1.0 mm SD setup/motion uncertainty).

DISCUSSION

Using high resolution dose grid is indeed required for characterization of beam profiles in small field dosimetry as well as beam model in TPS calculations. However, in clinical treatment plan calculations the situation is different as intension is to reproduce delivered dose, ideally, including geometric uncertainties.

Our study produced counter-intuitive results demonstrating that dose calculations for VC SRS treatments may better reproduce delivered dose when voxel size increased, rather than decreased, compared to commonly used 1mm. Increasing the voxel size also has practical impact in clinical settings where dose calculations would be much faster and producing smaller, more robust data sets.

This result can be explained by the fact that both phenomena – volume averaging and dose smearing due to random uncertainties, can be considered as convolution of the dose distribution with appropriate probability density function. In case of volume averaging this is a uniform function. In case of random geometrical uncertainties this is Gaussian function with a given SD. With the dose distribution so peaked and gradients steep due small leaf gap, volume averaging across appropriate voxel size can approximate convolution of the dose with the Gaussian of given SD.

CONCLUSIONS

Setup uncertainties can have considerable effect on dosimetry of VC SRS. This study suggests that in clinical dose calculations that aim to reproduce dose distributions in VC SRS treatment, larger voxel sizes such as 1.5mm and 2mm may provide better dosimetry for uncertainties of 0.5% and 1% SD than commonly used 1 mm voxels.

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