IMPACT OF GRID SIZE ON DOSE CALCULATIONS FOR CRANIAL TUMORS

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ABSTRACT

This study assessed how Monte Carlo grid size (1%/1mm vs. 2%/2mm) affects dose accuracy in 110 cranial SRS plans using Elements TPS. Grid size had minimal impact on dose calculations for large tumors like GBM and MGM. However, in small or irregular targets such as BM, PA, and VS, the coarser 2%/2mm grid led to significant dose reductions and increased CI and GI values. These results highlight the importance of using finer grids for accurate dose modeling in small-volume or anatomically complex lesions, reinforcing the need for individualized grid optimization in treatment planning.

INTRODUCTION

Stereotactic radiosurgery (SRS) is a non-invasive, highly precise radiation therapy used to treat surgically challenging tumors, vascular malformations, and certain functional brain disorders[1]. It delivers a high dose to the target while sparing healthy tissue, thanks to a steep dose fall-off[2]. Treatment planning systems (TPS) use algorithms like Pencil Beam (PB) and Monte Carlo (MC). PB has limitations in heterogeneous tissues and small fields, while MC is the gold standard due to its accuracy in modeling complex scenarios[3]. However, MC's performance is influenced by grid resolution[4]. Grid size can notably impact dose estimates, especially for small targets[5]. This study investigates how different grid sizes affect MC dose accuracy in SRS planning for various cranial pathologies using the Elements TPS, offering practical guidance for optimization.

METHODS AND MATERIALS

Study Design

This observational study followed the STROBE guidelines and included 110 VMAT plans: 10 for AVM, and 20 each for GBM, meningioma (MGM), brain metastases (BM), pituitary adenoma (PA), and vestibular schwannoma (VS). All plans were created using the Monte Carlo (MC) algorithm in the Elements TPS (v4.0), while Pencil Beam (PB) plans were used for comparison without protocol modification. Only the MC plans varied in grid size (1%/1mm and 2%/2mm); PB used a fixed 1 mm grid.

Plan Quality Metrics

Analyzed metrics included GTV and PTV volumes, PTV margins, intersection with bone, total MUs, conformity index (CI), gradient index (GI), dose coverage at D98%, D95%, D2%, and mean dose. Organs at risk (OARs) like the cochlea, brainstem, chiasm, optic nerves, and tracts were also evaluated. All plans were normalized to deliver 95% of the prescribed dose to the GTV.

Treatment Protocols

Protocols varied by pathology: AVM and BM used single-fraction SRS at 21 Gy; GBM received 10 fractions (CTV: 52 Gy, PTV: 43 Gy); MGM and PA were treated over five fractions (30 Gy for MGM, 27 Gy for PA); VS received 12 Gy in a single fraction. PTV margins ranged from 0–3 mm depending on the diagnosis.

Statistical Analysis

Data normality was tested using Shapiro-Wilk. Median, range, and 95% CI were reported. The Mann-Whitney test compared grid configurations at D98%, D95%, and D2%. ANCOVA assessed the effect of grid size on dose metrics, adjusting for PTV volume and bone intersection. Interactions were also tested. Significance was set at $p<0.05$. Analyses were done in SPSS v24, and graphs in GraphPad Prism 8.0.1.

RESULTS

A total of 110 treatment plans were analyzed using Elements Cranial TPS with MC algorithms. GBM had the largest volumes, while VS had the smallest targets and the highest intersection with bone. AVM and BM showed minimal bone intersection (Table 1).

Table 1. Summary of PTV and GTV Volumes, and PTV-Bone Intersection.

	Volume PTV	Volume GTV	Intersection PTV and Bone	
	[cc]	[cc]	[cc]	%
AVM	2.1(1.9–7.1)	1.26(1.0–4.6)	0.00(0.0–2.2)	0.0(0.0–31.7)
BM	2.0(0.4–4.7)	1.2(0.3–3.1)	0.0(0.0–0.1)	0.2(0.0–8.8)
BM	137.1(60.2–253.5)	24.7(7.3–68.5)	1.4(0.0–29.5)	0.8(0.0–11.6)
MGM	8.5(1.5–29.4)	6.1(0.7–24.0)	0.3(0.0–5.7)	3.43(0.0–22.8)
PA	4.4(2.1–45.3)	2.9 (1.0–37.8)	0.4(0.0–2.2)	8.5(1.0–19.6)
VS	0.5(0.2–1.9)	0.5(0.2–1.9)	0.2(0.1–0.3)	46.7(10.6–68.0)

MC dose calculations using 1%/1mm and 2%/2mm grids produced similar overall trends, with higher GTV doses in GBM and lower in VS, reflecting target size differences. Plans for AVM and BM, delivered in a single fraction, required more MUs. Coarser MC grids (2%/2mm) tended to increase CI and GI, especially in small, irregular targets like VS and PA.

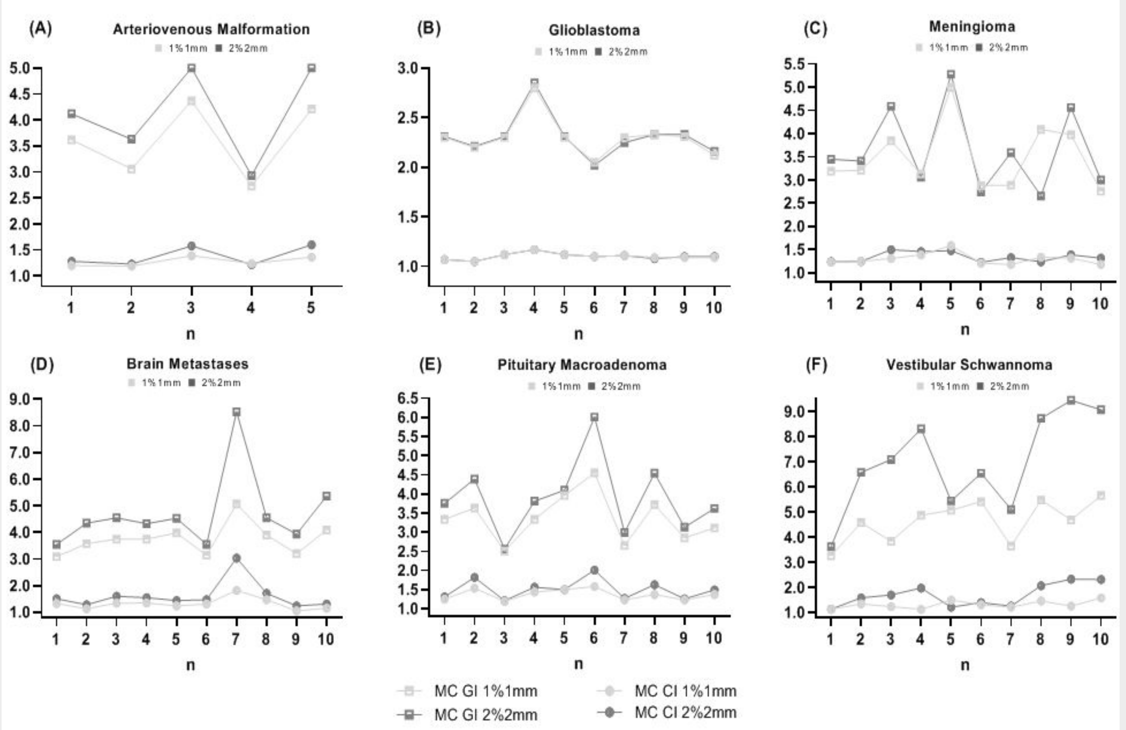

Figure 1. Descriptive distribution of CI and GI values comparing the 1%/1mm and 2%/2mm grid configurations.

No differences were found in PB dose metrics between grid sizes. For MC, grid size (1%/1mm vs. 2%/2mm) did not significantly affect D98%, D95%, or D2% in AVM, GBM, or MGM. However, significant differences were observed in BM, PA, and VS, where coarser grids led to lower doses (Figure 2).

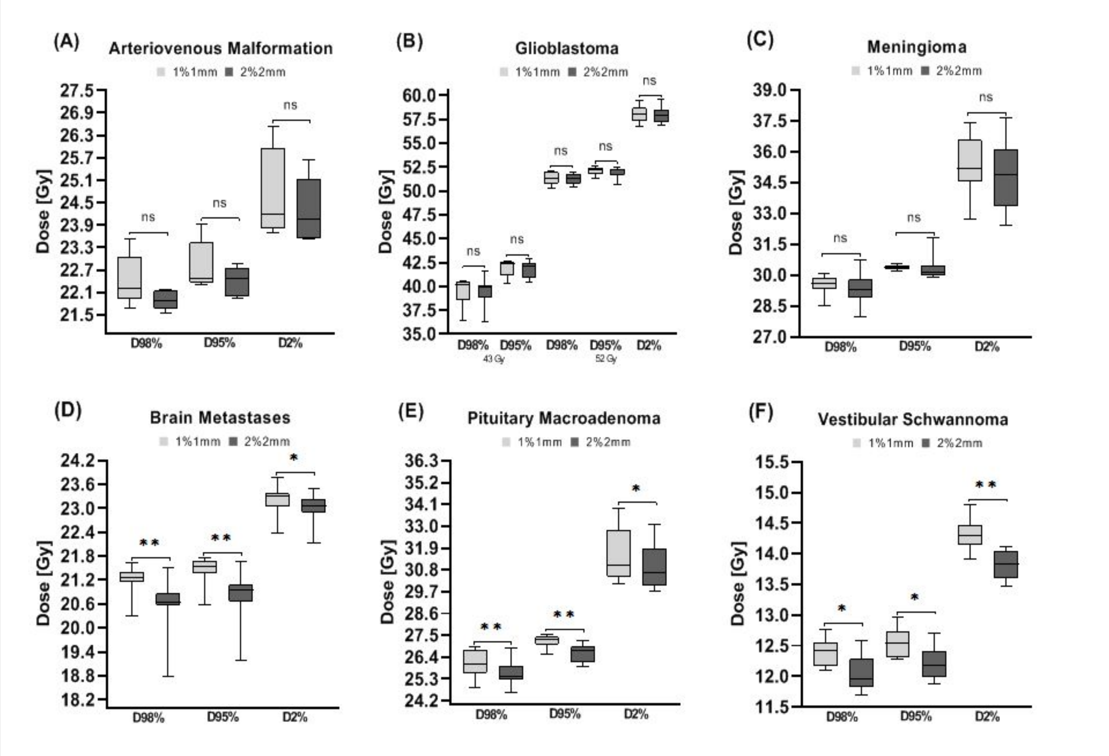

Figure 2. Comparison between MC algorithm methods with different grid configurations for dose calculations for cranial tumors.

After adjusting for PTV volume and bone intersection, the 2%/2mm grid consistently resulted in lower dose metrics ($p<0.001$). These covariates, along with their interaction, significantly influenced dose estimates, highlighting the importance of anatomical and volumetric context in grid selection (Table 2).

Table 2. Dose values according to grid size, adjusted for volume (cc) and bone intersection (%) (n = 110).

Dose Gy	Grid		*p-value*	*Adjusted p-value*
	1%1mm	2%2mm		
D98%	25.59±0.85	25.25±0.85	0.711	<0.001
D95%	26.23±0.86	25.88±0.86	0.717	<0.001
D2%	29.69±1.01	29.35±1.01	0.735	<0.001

DISCUSSION

This study examined the impact of dose calculation grid size (1%/1mm vs. 2%/2mm) using the MC algorithm in SRS across various cranial pathologies. Grid size had little impact on large-volume targets like GBM and MGM, but significantly affected dose metrics in small lesions such as BM, PA, and VS. Coarser grids (2%/2mm) led to underestimation of GTV dose coverage in these cases, consistent with prior simulation-based studies highlighting voxel size as a critical factor in dose accuracy, especially for small targets and steep gradients[5,6].

ANCOVA showed that both PTV volume and intersection with bone significantly influenced the effect of grid resolution. VS lesions, with small volumes and high bone involvement, were especially sensitive, emphasizing the need for finer grids in anatomically complex regions, particularly at skull base where MC calculations outperform analytical algorithms[7]. Both conformity index (CI) and gradient index (GI) increased with the coarser grid, especially in small targets. This indicates reduced accuracy in dose shaping and fall-off, reinforcing the importance of fine grid resolution for precise SRS planning[8]. CI was notably higher in lesions smaller than 1 cm^3, supporting the role of high-resolution grids in accurate conformity assessment[9].

CONCLUSIONS

Grid size had minimal impact on dose calculations for large tumors like GBM and MGM. However, in small or irregular targets such as BM, PA, and VS, the coarser 2%/2mm grid led to significant dose reductions and increased CI and GI values. These results highlight the importance of using finer grids for accurate dose modeling in small-volume or anatomically complex lesions, reinforcing the need for individualized grid optimization in treatment planning.

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