Sub-Arc Gating Tolerances for Single Target Cranial VMAT

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INTRODUCTION

Intrafraction patient motion contributes uncertainty to plan level radiation therapy dose distributions. There is limited research concerning the consequence of patient motion at the level of volumetric arc therapy (VMAT) control points. Therefore, we explored plan deliverability robustness by identifying and gating motion-sensitive regions within single-target cranial plans. Planning target volume (PTV) dose volume histograms (DVH) were analyzed to define a control point motion sensitivity indicator using an area under the curve (AUC) method [1,2]. Simulated intrafraction patient motion traces were then applied to motion-sensitive regions of the plan to simulate sub-arc gating.

METHODS

An in-house MATLAB application reconstructed thirty single-target cranial VMAT plans into static-field plans to provide access to control point dose volumes. Plan dose from simulated intrafraction motion with one hundred realistic 3D motion traces were derived from a previous study [3]; these are herein referred to as ungated. These simulations also allowed the dose-informed quantification of control point sensitivity to motion.

Control point motion sensitivity was quantified using the Euclidean distance (EucD) from the origin of a standard deviation-versus-mean plot of differences in AUC of control point PTV DVHs.

A nine-control-point sliding-window-sum (SWS) algorithm was applied to the EucD profile to identify regions of elevated motion sensitivity. Sub-arc gating windows were defined using thresholds (60th, 70th, 80th, and 90th percentiles) of SWS. Intrafraction motion simulations were then conducted for the four percentile-based sub-arc gating conditions, and full-plan gating (all control points gated) using a 1 mm motion tolerance. Variance in PTV D99% (dose received by 99% of the PTV) was compared between full-plan gating and each comparison condition using the Brown–Forsythe test (α = 0.05).

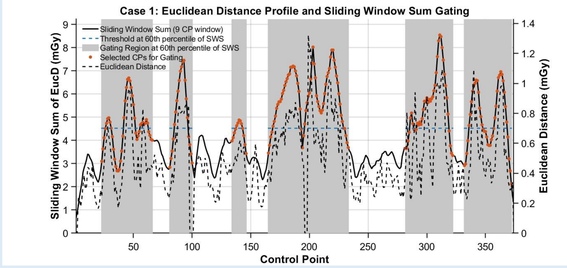

Figure 1: Using Case 1 as an example, a nine-control-point SWS algorithm generated gating windows from the EucD motion sensitivity profile. Percentile thresholding of the SWS profile identified regions of elevated motion sensitivity for simulated sub-arc gating. A 1 mm motion tolerance was applied to control points in the gating windows.

RESULTS

Sub-arc gating windows were algorithmically identified using SWS percentile thresholding from dose-informed EucD motion sensitivity profiles. As the SWS percentile threshold increased, smaller and fewer gating windows were identified, and consequently, fewer control points were selected for gating. In the 30-plan pooled cohort, an average of 237 control points were gated at the 60th percentile condition while an average of 415 control points were gated in the full-plan condition (Table 1). Nevertheless, prescription dose coverage remained comparable between the 60th percentile and full-plan gating conditions (Figure 1). The minimum of PTV D99% coverage distribution differed by 0.16% between the 60th percentile SWS condition and the full-plan gating condition.

The within-plan Brown-Forsythe variance testing showed that the PTV D99% variance at the 60th percentile threshold was statistically different from full-plan gating in only 4 of 30 cases (Table 2). In contrast, variance differed in 28 of 30 cases between the ungated and full-plan gating conditions. When examining the PTV D99% within each of the 30 patient plans, some cases displayed a degree of motion resistance (Case 1 shown in Figure 3).

Table 1. Number of control points gated and PTV D99% minimum differences from Full-Plan Gating for the full cohort. As the SWS percentile threshold increased, fewer control points were gated resulting in an increase in the observed PTV D99% distribution (Figure 2). The minimum differences in D99% variance were nearly equivalent at the 70th percentile relative to full-plan gating.

Gating Condition	Control Points Gated mean and sd	Min. Difference in D99%* %
Full-Plan	415 ± 67	N/A
60th %	237 ± 42	0.16
70th %	190 ± 35	0.28
80th %	137 ± 30	0.85
90th %	80 ± 17	1.45
ungated	0	2.11

*Relative to Full-Plan Gating Condition

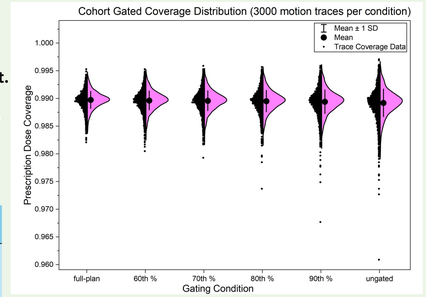

Figure 2: Prescription dose coverage is presented for the 100 simulated motion traces applied to each of the 30-plan cohort gating conditions. Coverage distributions narrowed toward the full-plan gating condition with a 2.1% difference in minimum PTV D99% coverage. The minimum of the 60th percentile gating condition differed from full-plan gating by only 0.16%.

Gating Condition	# of Cases Statistically Different from Full-Plan Gating	Variance Ratio median	Brown-Forsythe p-value median
60th %	4	1.2	0.439
70th %	6	1.3	0.256
80th %	15	1.5	0.051
90th %	21	1.8	0.010
ungated	28	2.3	<0.001

Table 2. Variance Ratios and Brown – Forsythe analysis of PTV D99% variance relative to full-plan gating. Higher variance ratios indicate greater variability in PTV D99% relative to the full-plan gating. PTV D99% variance was compared with full-plan gating within each of the 30 case plans using the Brown–Forsythe test (α = 0.05). At the 70th percentile, 6 of 30 cases showed a significant difference in PTV D99% variance relative to full-plan gating, while 24 of 30 cases did not produce a significant difference.

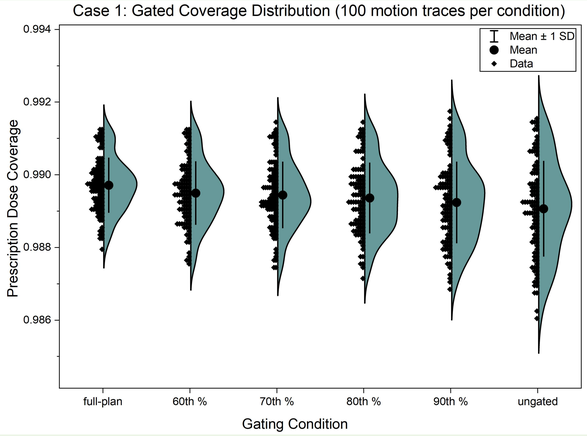

Figure 3: For case 1, the distribution of prescription dose coverage is presented for the 100 motion traces applied to each gating condition. For comparison, the 60th, 70th, 80th, and 90th percentile conditions gated 228, 173, 136, and 99 control points out of 374, respectively. The minimum PTV D99% decreased from 0.988 in full-plan gating and reached 0.986 without gating. This patient case was relatively resistant to motion [2].

DISCUSSION

Prescription dose coverage from the most control point inclusive sub-arc gating conditions (60th and 70th percentiles of SWS) were comparable to the full-plan condition for most of the examined single target cranial cases. The 60th percentile SWS threshold condition resulted in 26 of 30 cases showing no statistically significant difference in PTV D99% variance relative to full-plan gating. In the full cohort PTV D99% coverage distributions, the 60th percentile condition was also comparable to full-plan gating.

The findings suggest that the EucD motion sensitivity profile and the SWS-based gating method can identify regions of plans where selective sub-arc gating may produce comparable benefits to that of full-plan gating. Full-plan gating may introduce more treatment interruptions and increase treatment time. However, treatment interruption burden may be reduced by sub-arc gating as only the most motion sensitive regions were selected for gating.

CONCLUSION

In 24 patient cases, gating at 70% of control points resulted in the same PTV coverage protection as full plan gating. Reducing the number gated control points may reduce interruption burden and minimize treatment time. The next steps are to apply this method to another anatomical area and investigate directional sensitivity of individual control points. Further investigations are needed to determine whether these simulation-based results can be incorporated into clinical workflows.

REFERENCES

[1] Li H, Liu W, Park P, Matney J, Liao Z, Chang J, Zhang X, Li Y, Zhu RX. Evaluation of the systematic error in using 3D dose calculation in scanning beam proton therapy for lung cancer. J Appl Clin Med Phys. 2014 Sep 8;15(5):4810.

[2] Crawford D, Church C, MacDonald RL. J Appl Clin Med Phys. 2026;27(1):e70447. doi:10.1002/acm2.70447.

[3] MacDonald RL, Lee Y, Soliman H *et al*., *Med Phys*. 2021; 48(12): 8045 – 51.

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