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Optimizing Sharpness: Impact of Control Ring Geometry on Dose Gradients In Varian Ethos 2.0 High-Fidelity Mode for Small Fields

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ABSTRACT

Purpose: Varian HyperArc (HA) is the non-coplanar gold standard for intracranial SRS, but the coplanar Varian Ethos platform offers daily online adaptation—a critical advantage for unstable resection cavities or fast-growing lesions. This study optimizes the Ethos High Fidelity (HF) engine and establishes a target volume threshold where adaptive coplanar SRS achieves dosimetric parity.

Methods: Fourteeen HA SRS patients were replanned on Ethos across five configurations to identify the optimal tuning ring geometry. Ethos plans were compared to clinical HA plans using the Wilcoxon Signed-Rank test. Scale-dependent convergence was evaluated using a Spearman rank correlation of relative normal tissue spillage.

Results: The Ethos HF Offset (5mm ring gap) minimized healthy brain exposure by 35.4% over standard controls, proving optimal. Matched-pair analysis showed HA maintained statistical superiority in conformity and fall-off. However, relative spillage differences tightly correlated with target volume . Below 3 cc, Ethos exhibited a pronounced low-dose halo. Above 3 cc, the relative spillage curves converged, rendering the normal tissue sparing difference clinically negligible.

Conclusion: The HF 5mm Offset ring optimizes Ethos SRS planning. While HA remains mandatory for lesions <3 cc to restrict single-fraction healthy brain V_12Gy, this volume represents a clear clinical pivot threshold. At this volume—where fractionated SRS is standard—the minor physical gradient penalty of Ethos is fully offset by the geometric accuracy of daily online adaptation.

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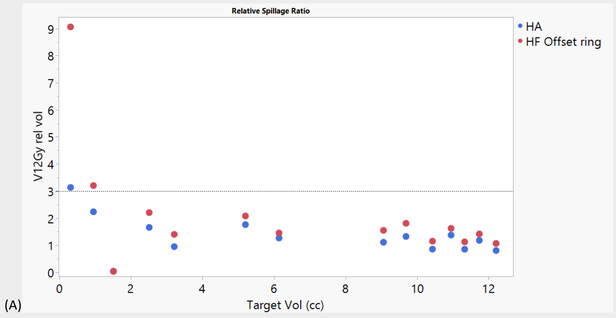
INTRODUCTION

Stereotactic Radiosurgery (SRS) requires steep dose gradients to maximize local tumor control while minimizing normal brain tissue exposure. While Varian HyperArc (HA) on standard C-arm linacs represents a gold standard for non-coplanar SRS, the Varian Ethos platform introduces the powerful capability of daily online adaptation to account for target morphological changes and inter-fraction motion. However, Ethos planning utilizes coplanar arrangements and a different optimization engine. This study first evaluates the optimal geometric tuning ring configuration for Ethos High Fidelity (HF) inverse planning, then compares this optimal configuration against clinical HyperArc plans to establish a strict target volume threshold where Ethos adaptive SRS becomes a dosimetrically acceptable alternative.

METHODS AND MATERIALS

Patient Cohort: 14 patients previously planned and treated with HyperArc SRS on a TrueBeam machine (Range: 0.31 cm^3 to 12.21 cm^3).
Optimization Arms: Five distinct planning configurations were generated for each patient (N=70 plans total):
1) Control (No Ring): Standard planning mode without High Fidelity (HF).
2) HF (No Ring): High Fidelity mode active, no geometric ring constraints.
3) HF Aggressive (1mm Gap): HF active with a ring placed 1mm from the target edge.
4) HF Standard (2mm Gap): HF active with a ring placed 2mm from the target edge.
5) HF Offset (5mm Gap): HF active with a ring placed 5mm from the target edge.
Statistical Analysis: Direct matched-pair comparisons were analyzed using the non-parametric Wilcoxon Signed-Rank Test via JMP to account for the dependent nature of the paired datasets. he relationship between target volume and relative spillage discrepancies ($\frac{V_{12Gy}}{Target\ vol}$) was evaluated using a Spearman rank correlation (ρ).



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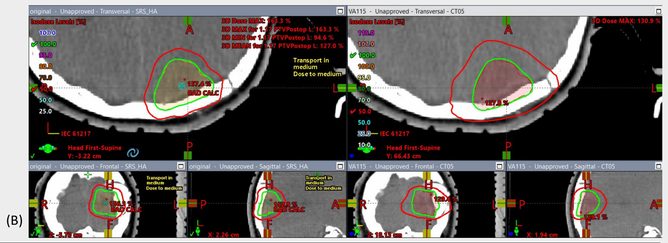

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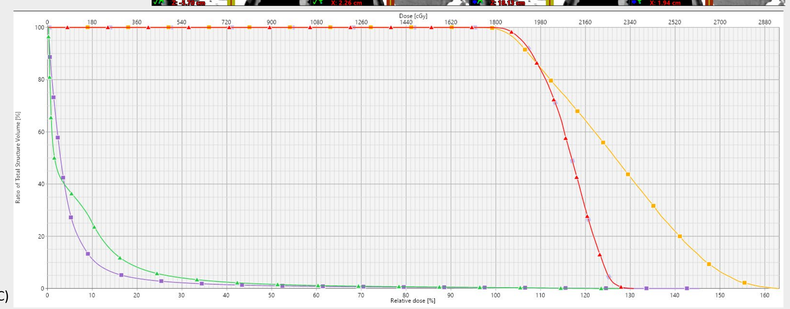

(C)

Figures. Dosimetric Comparison and Scale-Dependent Convergence. (A) Relative healthy brain spillage as a function of target volume across all 14 cases. (B) Representative isodose distribution comparing HA and Ethos HF Offset plans for an 11.3cc target cavity. (C) Corresponding Dose-Volume Histogram (DVH) for the 11.3cc case showing target coverage (HA PTV: orange; Ethos PTV: red) and normal brain sparing (HA: purple; Ethos: green).

RESULTS

Determining the Best Ethos Ring Configuration

- Transitioning to High Fidelity mode (HF No Ring) yielded a 23% decrease in absolute healthy brain V_12Gy spillage (15.18cm^3 →11.67 cm^3) and sharpened the Gradient Index (GI) from 5.24 to 4.27 compared to the standard non-HF control (p = 0.0001).
- Ring Optimization: Incorporating geometric tuning rings further restricted spillage. The HF Offset (5mm Gap) ring yielded the lowest overall absolute healthy brain V_12Gy spillage (9.81 cm^3), achieving a 35.4% total spillage reduction compared to the non-HF control.
- Because the 5mm Offset ring provides equivalent or superior relative tissue protection compared to the tighter 1mm and 2mm configurations while allowing the optimizer sufficient geometric breathing room to maintain smooth, highly predictable profiles, the HF Offset (5mm Gap) was selected as the optimal Ethos configuration.

Ethos (5mm Offset) vs. HyperArc (HA)

- Matched-pair analysis demonstrated a statistically significant advantage for HA, yielding a mean PCI of 0.877 compared to 0.791 for the Ethos HF Offset (p = 0.0001). However, both platforms achieved high-quality, clinically acceptable plans exceeding standard literature conformity thresholds (PCI > 0.75).
- HA achieved a statistically superior dose fall-off (GI = 2.992) compared to the coplanar Ethos HF plan (GI = 4.052, p = 0.0001), resulting in an average absolute V_12Gy excess of +2.28 cc on Ethos.

Establishing the Target Volume Threshold

- Below the Threshold (< 3.0 cm^3): For small targets, the relative spillage ratio on Ethos escalated rapidly compared to HA, which maintained a tight relative ratio. Because these small targets are typically treated with single-fraction SRS, keeping the normal brain V_12Gy below the QUANTEC 5 to 10 cm3 safety limit is difficult with Ethos large gradient (GI>4)
- Above the Threshold (≥ 3.0 cm^3): The relative spillage ratios converged dramatically. For lesions > 3.0 cm^3, the average relative spillage ratio difference dropped to a negligible 0.31 (1.10 for HA vs. 1.41 for Ethos). Spearman rank correlation confirmed a strong negative correlation between target volume and the relative spillage difference between the two platforms (ρ = -0.52, p = 0.056), verifying scale-dependent convergence.

DISCUSSION

- Conformity vs. Spillage: While HyperArc's non-coplanar planning and dedicated SRS optimization achieve a statistically superior conformity index (p = 0.0001), the Ethos HF engine's mean PCI of 0.791 remains well above the standard peer-reviewed clinical acceptability threshold of >0.75. This demonstrates that coplanar Ethos HF plans can deliver highly conformal, clinically viable SRS treatments.
- The Physical Gradient Gap: The true differentiator remains the intermediate dose fall-off (GI = 2.992 vs. 4.052, p = 0.0001). This gap is driven by the physical limitations of coplanar MLC delivery on Ethos compared to HyperArc's dedicated non-coplanar SRS trajectories and stereotactic collimation.
- The 3.0 cm^3 Adaptive Trade-Off: For tumors < 3.0 cm^3, the gradient penalty of a coplanar Ethos plan is severe, making HA the clinical choice. However, for targets ≥ 3.0 cm^3 —where fractionated SRS (fSRS) is standard and tissues are protected through fractionation—the minor physical spillage penalty of Ethos is may be outweighed by the platform's ability to perform daily online adaptation to track inter-fraction cavity collapse or tumor shrinkage.

Metric	HyperArc (HA)	HF Offset ring (5mm)	Mean difference	Statistical test (p-value)
Mean GI	2.992	4.052	1.060	0.0001
Mean PCI	0.877	0.791	0.086	0.0001
Mean V12Gy	9.956	7.672	2.28	0.0002

CONCLUSIONS

- The HF Offset (5mm Gap) is the optimal tuning ring configuration for Ethos SRS, maximizing healthy brain sparing.
- For targets ≥3.0 cm^3, Ethos HF inverse planning provides comparable target conformity and acceptable gradient index metrics, establishing it as a highly viable platform for adaptive fractionated SRS.

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