Planning and Delivery Performance of the Halcyon™ Platform for Multiple Small Targets with a Single Isocenter

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Introduction

Numerous studies have reported on the safety and effectiveness of stereotactic radiosurgery (SRS) for the management of brain metastases, leading to a gain in popularity throughout the radiation oncology community. The relatively recent development and advancements of high-precision treatment delivery systems and image guidance has expanded the availability of SRS to linac-based radiation therapy centers. The use of volumetric modulated arc therapy (VMAT) with high-definition multileaf collimators (HDMLC) has further improved the accuracy and conformality of SRS, especially when treating multiple cranial metastases with a single-isocenter treatment.

A new type of linac has recently been introduced by Varian Medical Systems (Palo Alto, CA), named Halcyon™, that exhibits a number of advantages over more traditional c-arm linacs. These include a 4 times faster gantry rotation speed, ring-shaped enclosure to eliminate collisions, and new type of dual layer MLCs. The Halcyon™ MLCs exhibits a travel speed that is twice as fast as existing MLCs, reduced leakage, improved penumbra, and smaller dosimetric leaf gap (DLG). This improved MLC design, along with an improved treatment workflow and 6FFF capabilities, makes the Halcyon™ a potentially favorable treatment unit for multi-met SRS treatment.

Methods

10 patients, each with 6-10 cranial metastases with volumes ranging from 0.11-8.57cc and prescription doses from 15-24 Gy, were retrospectively studied. The clinical plan for each patient was generated with multi-aperature dynamic conformal arc (DCA) with non-coplanar beam arrangement. Additional plans were generated with Halcyon Version 1 with coplanar arcs, Halcyon Version 2 with coplanar arcs, HDMLC with coplanar arcs, and HDMLC with non-coplanar arcs. Standard cranial treatments typically make use of non-coplanar beam arrangements, but the coplanar HDMLC arrangement was chosen to serve as a direct MLC comparison as the Halcyon is currently only capable of coplanar arrangements. All same-case plans were generated with the same planning protocol and normalization. Plans were evaluated based on Conformity Index (CI), Gradient Index (GI), V12Gy, V6Gy, V3Gy, and brain mean dose.

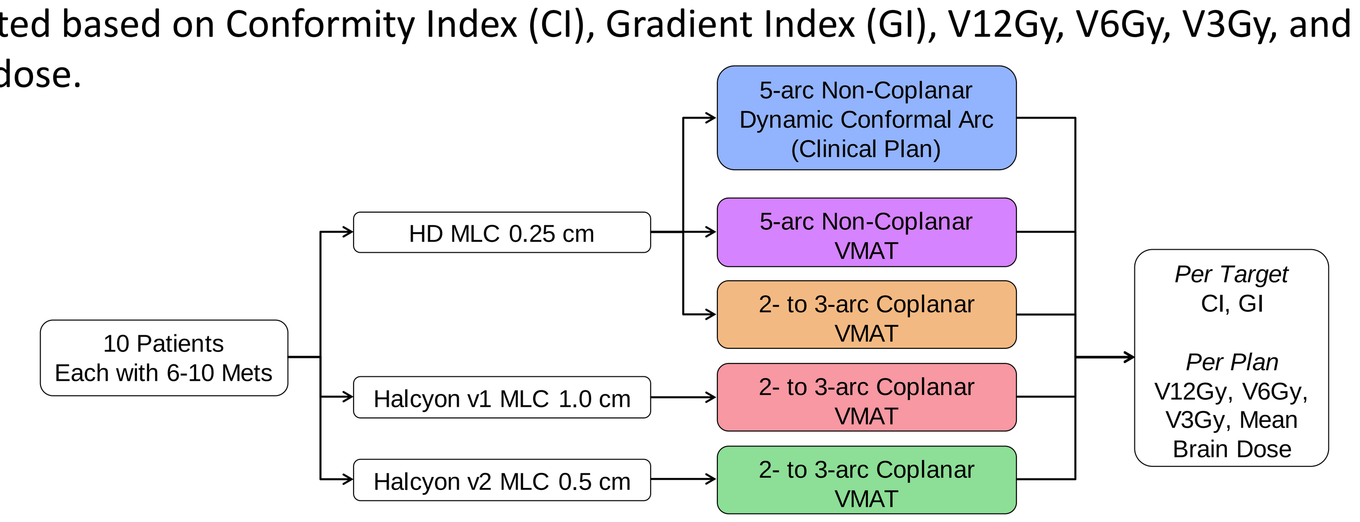

Figure 1. Study design

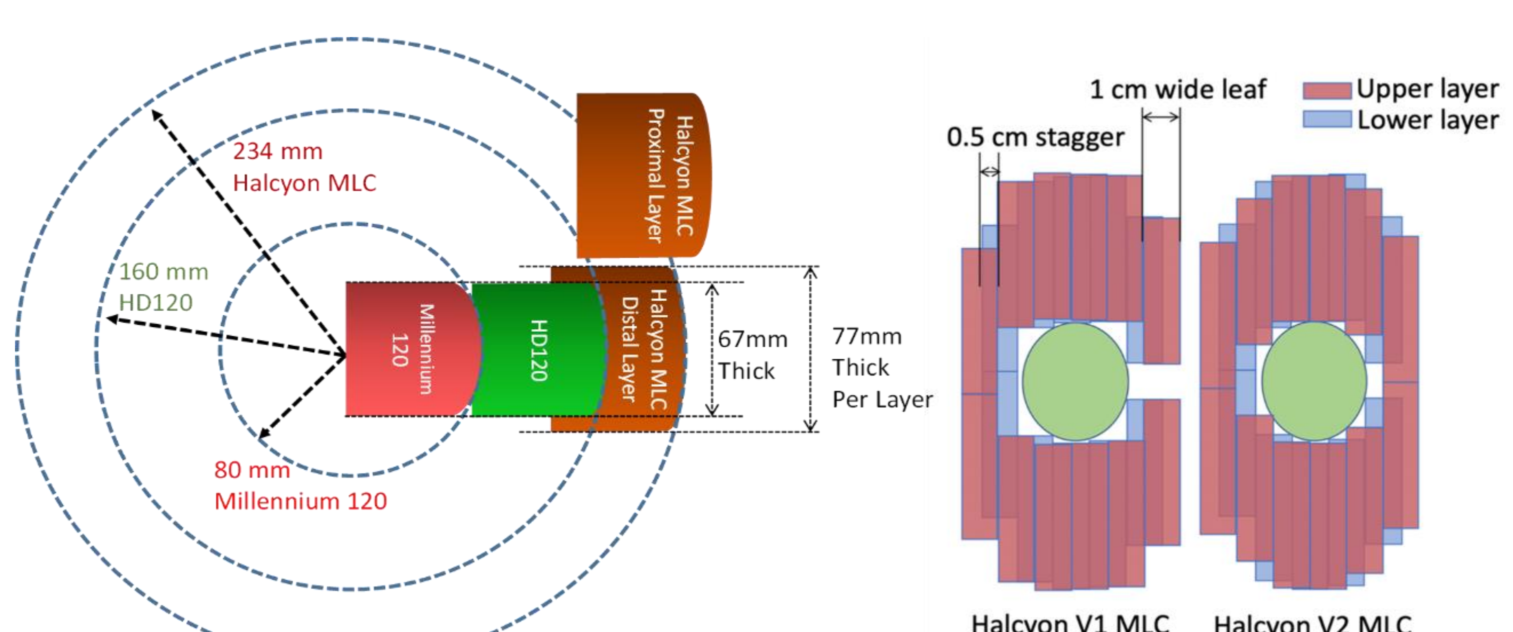

Figure 2 (left) MLC Design comparison of current dual-layer Halcyon MLC (brown) vs. 0.25cm wide HD-120 MLC (Green) showing increased leaf thickness and rounding radius. (right) Different between Halcyon MLC version 1 and version 2: v2 enables upper layer to be used for beam shaping, effectively producing 0.5cm modulation resolution

Conformity and Gradient Index Across Techniques

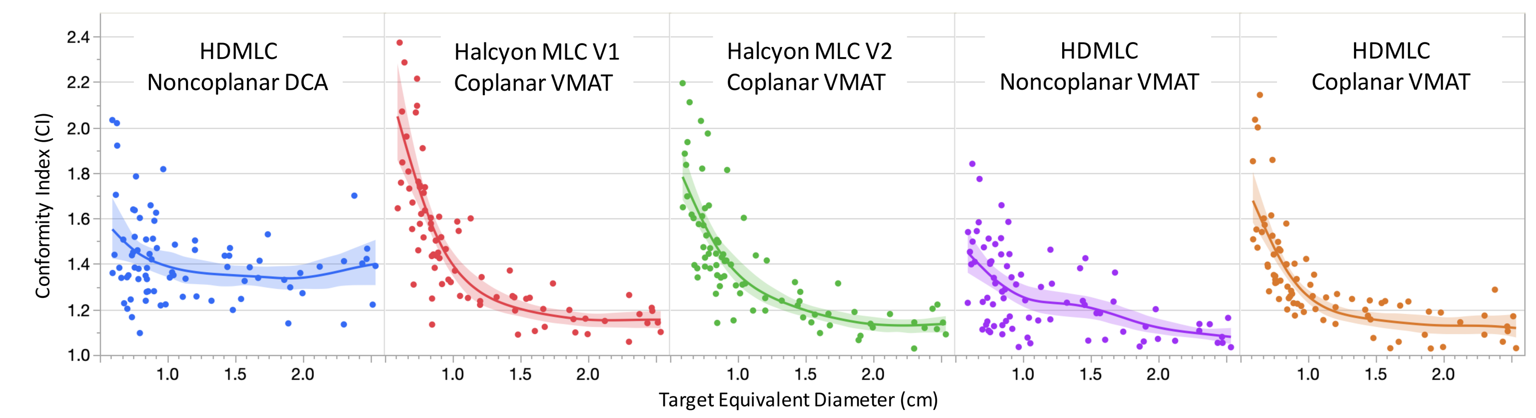

Figure 3 Comparison of conformity index (CI) as a function of target equivalent diameters for five planning and delivery techniques. Dots are the actual individual CI for an individual target. Solid lines are fitting lines using spline model; and shared area are 95% confidence interval of fit.

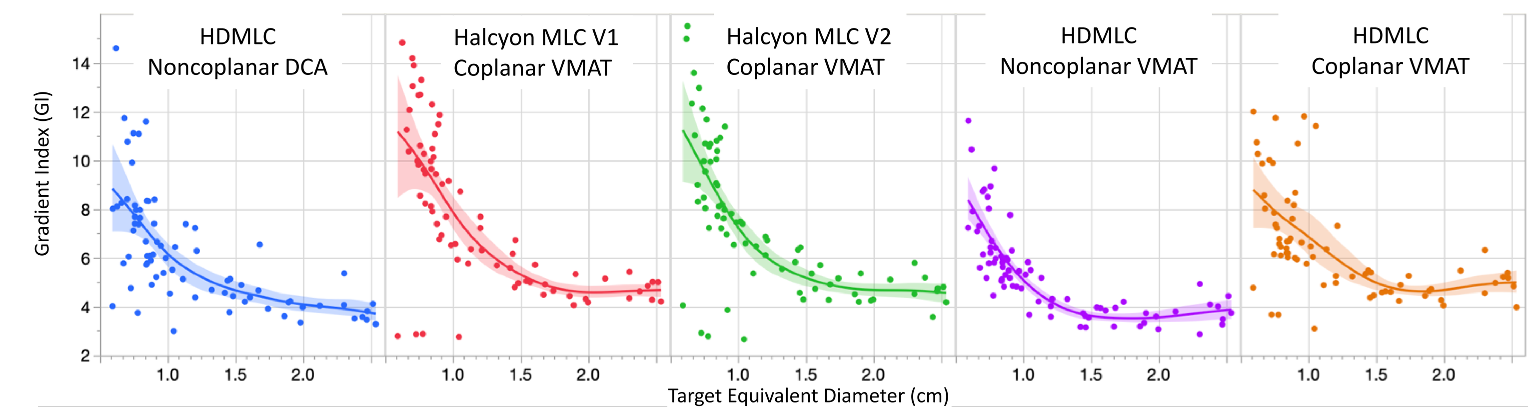

Figure 4 Comparison of gradient index (GI) variation as a function of target equivalent diameters for five planning and delivery techniques. Dots are the actual individual GI for an individual target. Solid lines are fitting lines using spline model; and shared area are 95% confidence interval of fit. Only GIs less than 15 are included to avoid data skewing due to bridging 50% isodose line.

1a. CI difference (top - left) for targets with diameter < 1 cm

	HD MLC Noncoplanar VMAT	HD MLC Coplanar VMAT	Halcyon MLC V1 Coplanar VMAT	Halcyon MLC V2 Coplanar VMAT
HD MLC Noncoplanar DCA	**-0.112±0.276 ($p = 0.014$)**	-0.016±0.294 ($p = 0.637$)	**0.226±0.363 ($p < 0.001$)**	**0.089±0.284 ($p = 0.044$)**
HD MLC Noncoplanar VMAT		0.096±0.260 ($p = 0.065$)	**0.338±0.381 ($p < 0.001$)**	**0.200±0.300 ($p < 0.001$)**
HD MLC Coplanar VMAT			**0.242±0.241 ($p < 0.001$)**	**0.105±0.185 ($p < 0.001$)**
Halcyon MLC V1 Coplanar VMAT				**-0.137±0.232 ($p < 0.001$)**

1b. CI difference (top - left) for targets with diameter > 1 cm

Sub-Table 2	HD MLC Noncoplanar VMAT	HD MLC Coplanar VMAT	Halcyon MLC V1 Coplanar VMAT	Halcyon MLC V2 Coplanar VMAT
HD MLC Noncoplanar DCA	**-0.194±0.149 ($p < 0.001$)**	**-0.193±0.13 ($p < 0.001$)**	**-0.129±0.164 ($p < 0.001$)**	**-0.154±0.148 ($p < 0.001$)**
HD MLC Noncoplanar VMAT		0.001±0.135 ($p = 0.596$)	**0.065±0.149 ($p = 0.002$)**	0.040±0.135 ($p = 0.084$)
HD MLC Coplanar VMAT			**0.064±0.095 ($p < 0.001$)**	**0.039±0.093 ($p = 0.016$)**
Halcyon MLC V1 Coplanar VMAT				-0.025±0.074 ($p = 0.082$)

1c. GI difference (top - left) for targets with diameter < 1 cm

Sub-Table 3	HD MLC Noncoplanar VMAT	HD MLC Coplanar VMAT	Halcyon MLC V1 Coplanar VMAT	Halcyon MLC V2 Coplanar VMAT
HD MLC Noncoplanar DCA	**-1.12±2.80 ($p = 0.004$)**	0.34±4.71 ($p = 0.220$)	**1.76±4.34 ($p < 0.001$)**	**1.52±3.66 ($p < 0.001$)**
HD MLC Noncoplanar VMAT		**1.46±3.53 ($p < 0.001$)**	**2.88±3.23 ($p < 0.001$)**	**2.641±2.66 ($p = 0.001$)**
HD MLC Coplanar VMAT			**1.41±3.03 ($p = 0.002$)**	**1.18±4.06 ($p = 0.020$)**
Halcyon MLC V1 Coplanar VMAT				-0.24±2.543 ($p = 0.136$)

1d. GI difference (top - left) for targets with diameter > 1 cm

Sub-Table 4	HD MLC Noncoplanar VMAT	HD MLC Coplanar VMAT	Halcyon MLC V1 Coplanar VMAT	Halcyon MLC V2 Coplanar VMAT
HD MLC Noncoplanar DCA	**-0.66±0.95 ($p < 0.001$)**	**0.62±1.17 ($p < 0.001$)**	**0.73±0.8896 ($p < 0.001$)**	**0.66±0.9276 ($p < 0.001$)**
HD MLC Noncoplanar VMAT		**1.28±1.146 ($p < 0.001$)**	**1.39±1.007 ($p < 0.001$)**	**1.32±0.8818 ($p < 0.001$)**
HD MLC Coplanar VMAT			0.11±0.906 ($p = 0.350$)	0.04±1.075 ($p = 0.200$)
Halcyon MLC V1 Coplanar VMAT				-0.06±0.623 ($p < 0.810$)

Table 1 Mean and standard deviation values of per-target paired CI/GI difference between different planning techniques. Values shown were generated using CI and GI from the corresponding technique indicated in the top row minus the technique indicated in the left-most column. Bold text indicates statistical significance found between the corresponding techniques using Wilcoxon Signed Rank test.

Dose Spillage and Planning Efficiency

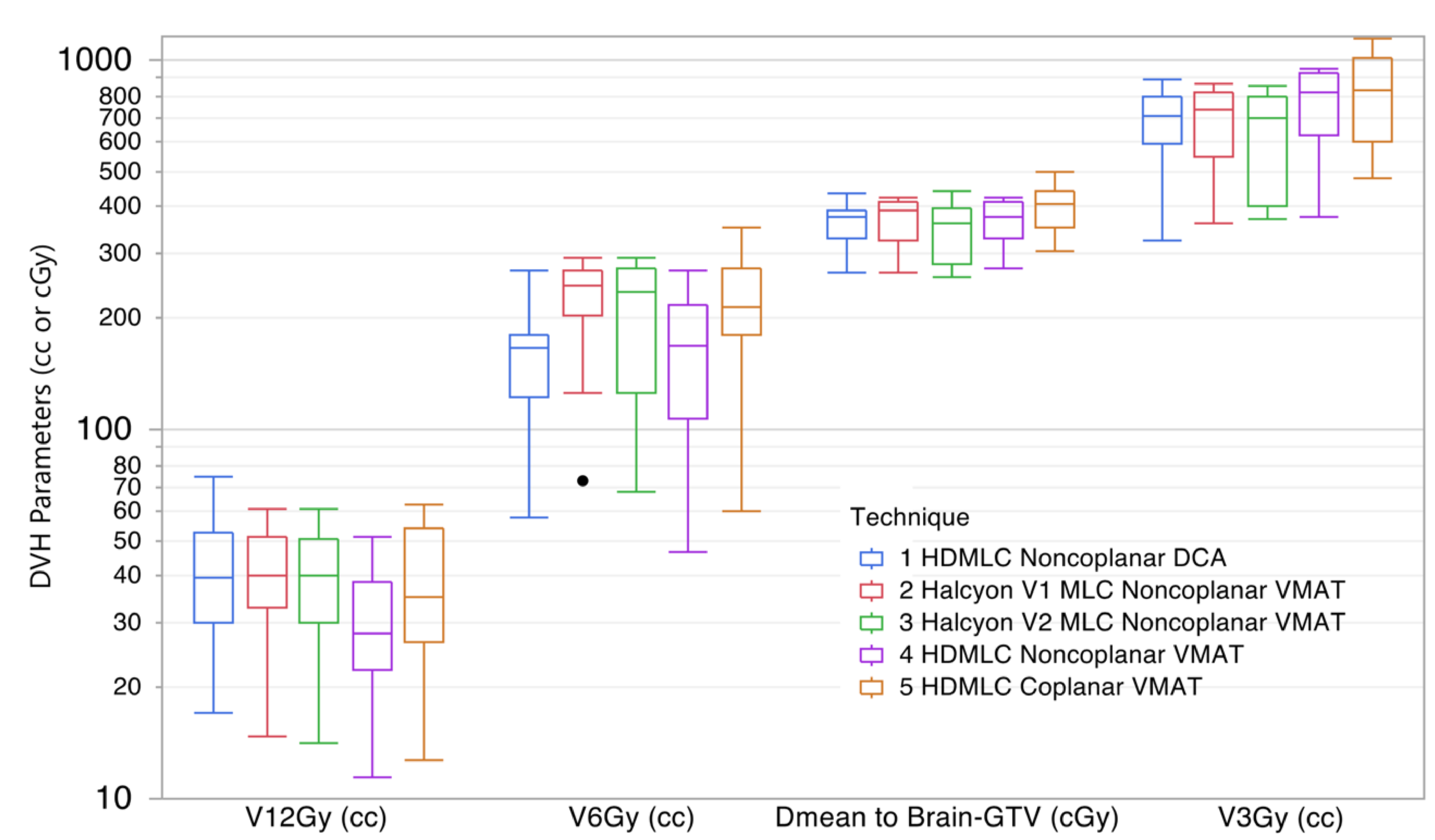

Figure 5 Comparison of dose spillage to normal brain tissue from 5 different techniques. Parameters shown are V12Gy, V6Gy, and V3Gy in cc, and mean dose to brain-GTV volume in cGy. Within each box there are 10 plans summarized.

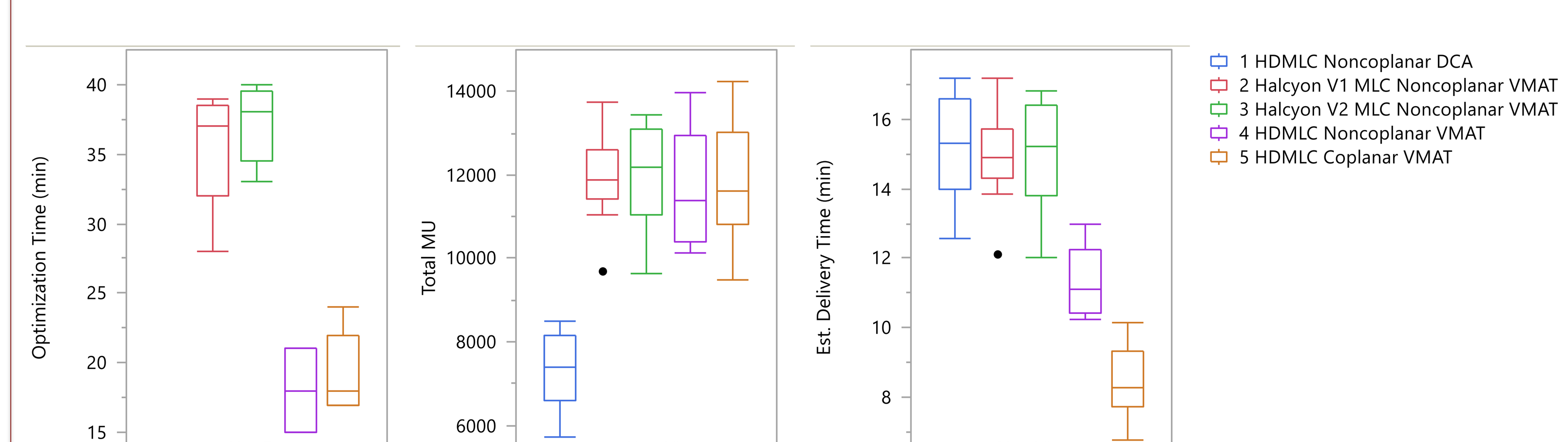

Figure 6 Optimization and delivery efficiency comparison across different planning strategies. For optimization, only 5 patients were included and, because it does not include VMAT optimization, DCA was omitted from the optimization time chart. For delivery efficiency, both total MU and estimated delivery time are shown. Estimated delivery time was calculated using the dose rate and gantry rotation speed limits plus 1 min per non-zero couch angle due to additional time required for setup and verification.

Dose Distribution Comparison

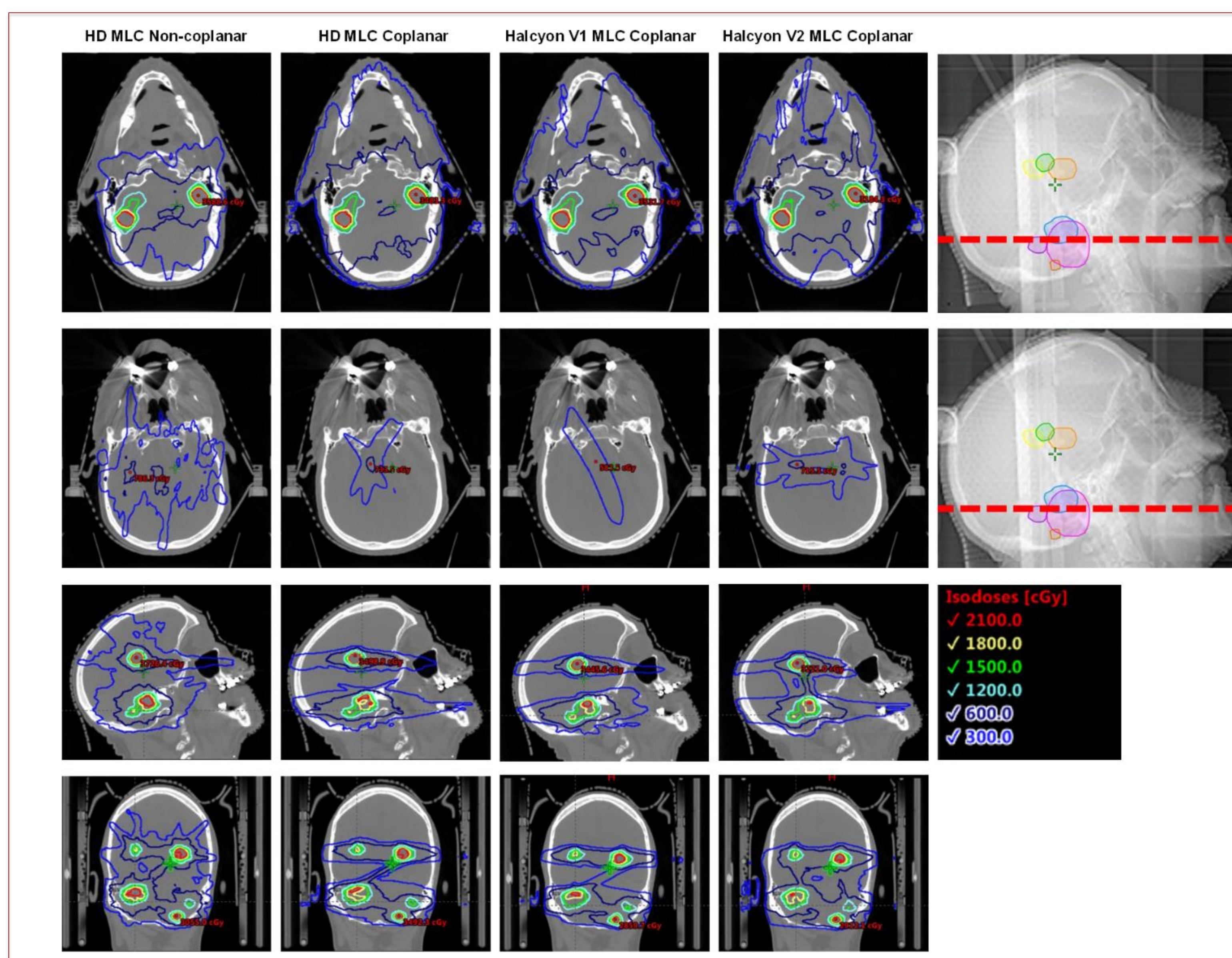

Figure 7 Illustration of dose fall-off characteristics across multiple different delivery techniques, both in and outside the target plane. Non-coplanar beam arrangements in general have better dose fall-off in the target plane (top row), but bears more low dose spread to tissue between target planes (2nd row).

Conclusion

The dual-layered stacked and staggered MLC design implemented in the Halcyon has shown to effectively conform to small targets with a diameter >1cm. However, for targets with <1cm diameter, the limitation of coplanar beam arrangements on the Halcyon leads to inferior plan quality compared to non-coplanar treatment on a c-arm linac with HDMLCs.