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Evaluation of a Knowledge-Based Planning Model for Ocular Tumors: Effects of Beam Energy and MLC Size

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ABSTRACT

Knowledge-based planning (KBP) can reduce planning time and inter-planner variability, but its performance may be affected by treatment parameters not represented in the model's training data.

This study evaluated the robustness of an in-house RapidPlan model for ocular tumors across different beam energies and multileaf collimator configurations.

The model was retrospectively applied to 24 patients, with four HyperArc plans generated per patient using 6MV-FFF or 10MV-FFF beams with standard or high-definition MLCs, for a total of 96 plans. All plans prescribed 25 Gy in one fraction and were normalized to PTV D95% = 25 Gy.

High-definition MLCs improved conformity, dose gradient, maximum dose, and optic nerve sparing. The use of 10MV-FFF beams reduced monitor units, modulation, and beam-on time. EPID quality assurance pass rates remained high across all configurations.

These findings demonstrate that the ocular KBP model can generate high-quality plans across beam energies and MLC types without retraining.

INTRODUCTION

Stereotactic treatment planning for ocular tumors is challenging because small targets are located near critical structures, requiring highly conformal dose distributions and rapid dose falloff. Manual planning can also be time-consuming and subject to inter-planner variability.
KBP may improve planning consistency and efficiency, but models may not perform reliably outside the conditions represented in their training data. This study evaluated whether an ocular RapidPlan model trained with 6MV-FFF beams and standard MLCs could maintain plan quality when applied to 10MV-FFF beams and HD-MLCs.

METHODS AND MATERIALS

An in-house ocular RapidPlan model was retrospectively applied to 24 patients. All plans prescribed 25 Gy in one fraction and were normalized to PTV D95% = 25 Gy.
Four HyperArc plans were generated per patient:

- 6MV-FFF with standard MLC
- 10MV-FFF with standard MLC
- 6MV-FFF with HD-MLC
- 10MV-FFF with HD-MLC

A total of 96 plans were evaluated for plan quality, organ-at-risk dose, monitor units, modulation factor, beam-on time, and delivery accuracy. EPID-based QA used a 3%/1 mm gamma criterion. Results were reported as median, interquartile range, and range. Paired sign tests were used, with $p < 0.05$ considered significant.

RESULTS

Plan quality: HD-MLCs improved conformity (PCI = 0.89), produced steeper dose gradients (GI = 3.30), and reduced global maximum dose across both beam energies ($p < 0.001$).
Optic nerve sparing: HD-MLCs reduced optic nerve Dmax for both 6MV-FFF plans (4.77 vs. 3.93 Gy) and 10MV-FFF plans (5.99 vs. 5.67 Gy; $p < 0.001$).
Delivery efficiency: Compared with 6MV-FFF, 10MV-FFF significantly reduced monitor units, modulation factor, and beam-on time by approximately 3 minutes, regardless of MLC type ($p < 0.001$).
Skin dose and QA: Skin Dmax was lower with 10MV-FFF when standard MLCs were used ($p < 0.001$), but no significant difference was observed with HD-MLCs. EPID 3%/1 mm QA pass rates remained high across all planning configurations.

DISCUSSION

Although the model was trained only with standard-MLC, 6MV-FFF plans, it maintained or improved performance when applied to configurations outside its training dataset. HD-MLCs primarily improved dosimetric quality, particularly conformity, dose gradient, and optic nerve sparing. In contrast, 10MV-FFF beams primarily improved delivery efficiency. The ability to rapidly generate several high-quality plans may allow clinicians to compare configurations and select the most appropriate plan for each patient without the time demands of repeated manual optimization.

CONCLUSIONS

The ocular KBP model demonstrated robust performance across beam energies and MLC configurations without retraining. HD-MLCs improved plan conformity, dose gradients, and optic nerve sparing, while 10MV-FFF beams improved treatment-delivery efficiency. These results support flexible clinical use of the model and the rapid comparison of multiple plans for patient-specific treatment selection.

Figure 1. Isodose distributions of all treatment methods. Red = GTV, Orange = PTV, Blue = Optic Nerve, Blue isodose wash = 50% isodose line, Red isodose wash = global max. From left to right (6MVFFF standard) (10MVFFF standard) (6MVFFF HD) (10MVFFF HD)

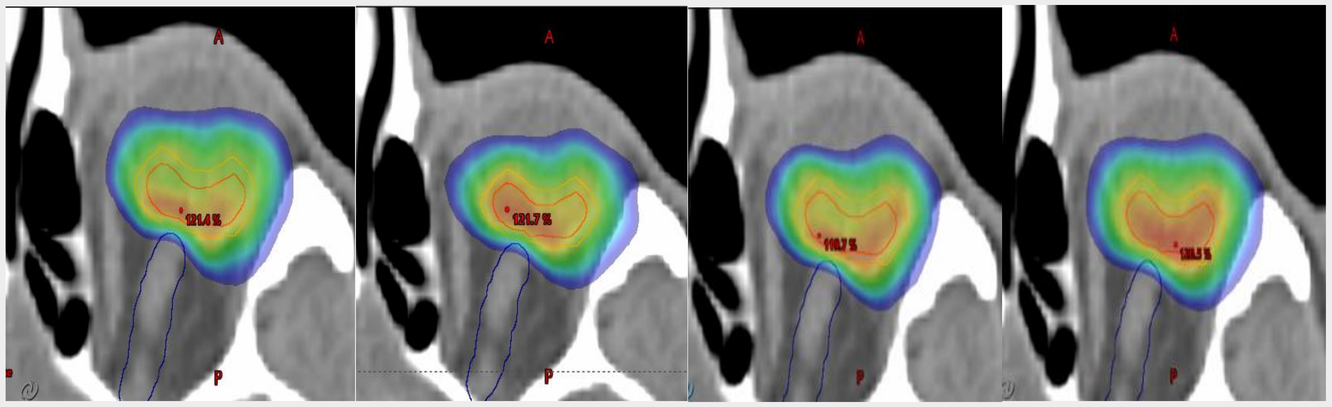

Table 1. Plan quality, dosimetric, and delivery metrics across energies and MLC types. Values reported as median (IQR, range). P-values from paired sign tests. Statistically significant p-values are bolded.

Metric	Std MLC 6FFF	Std MLC 10FFF	HD MLC 6FFF	HD MLC 10FFF	6 vs 10FFF (Std)	6 vs 10FFF (HD)	Std vs HD (6FFF)	Std vs HD (10FFF)
PCI	0.86 (0.04, 0.79–0.91)	0.87 (0.03, 0.77–0.91)	0.89 (0.03, 0.79–0.93)	0.89 (0.04, 0.79–0.92)	0.152	0.093	**<0.001**	**<0.001**
GI	3.40 (0.49, 2.76–4.13)	3.70 (0.61, 2.89–4.51)	3.30 (0.52, 2.63–3.93)	3.63 (0.45, 2.91–4.30)	**<0.001**	**<0.001**	**0.002**	0.541
Global Max Dose (%)	124.78 (3.37, 121.18–131.97)	125.74 (2.98, 122.09–134.43)	121.59 (4.24, 116.87–130.21)	122.31 (3.43, 120.49–129.29)	0.064	**<0.001**	**<0.001**	**<0.001**
PTV Min (Gy)	23.98 (0.41, 22.70–24.29)	23.65 (0.52, 22.24–24.29)	24.18 (0.21, 23.33–24.44)	24.00 (0.38, 22.64–24.34)	**<0.001**	**0.011**	**<0.001**	**<0.001**
Optic Nerve D_{max} (Gy)	4.77 (3.39, 1.08–20.83)	5.99 (3.89, 1.60–20.83)	3.93 (3.40, 0.86–20.66)	5.67 (3.58, 1.75–20.73)	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Lens D_{max} (Gy)	4.95 (6.26, 1.53–28.35)	5.81 (6.03, 1.70–29.11)	4.84 (5.76, 1.45–28.24)	5.25 (5.56, 1.68–28.99)	**<0.001**	**<0.001**	0.064	**<0.001**
Lacrimal Gland D_{mean} (Gy)	3.10 (5.87, 0.70–19.37)	3.51 (6.16, 1.03–19.78)	3.04 (6.85, 0.74–19.54)	3.35 (7.32, 1.05–19.76)	**<0.001**	**<0.001**	0.064	**0.002**
Skin D_{max} (Gy)	26.07 (12.24, 5.29–30.28)	23.86 (9.32, 4.70–27.11)	26.25 (10.75, 4.95–30.02)	26.19 (10.56, 4.31–30.18)	**<0.001**	0.210	0.064	0.064
Monitor Units	9761.62 (1567.52, 6860.47–18093.81)	7213.54 (927.40, 5499.20–9105.12)	9965.83 (2394.59, 6818.69–13283.77)	6478.60 (822.44, 5520.91–10457.69)	**<0.001**	**<0.001**	**0.028**	**<0.001**
Modulation Factor	3.90 (0.63, 2.74–7.24)	2.89 (0.37, 2.20–3.64)	3.99 (0.96, 2.73–5.31)	2.59 (0.33, 2.21–4.18)	**<0.001**	**<0.001**	**0.028**	**<0.001**
Beam-On Time (min)	6.97 (1.12, 4.90–12.92)	3.01 (0.39, 2.29–3.79)	7.12 (1.71, 4.87–9.49)	4.63 (0.59, 3.94–7.47)	**<0.001**	**<0.001**	**0.028**	**<0.001**
EPID QA 3%/1mm (%)	97.15 (3.00, 92.00–99.30)	98.85 (0.73, 98.20–99.80)	92.90 (3.25, 90.00–98.70)	99.90 (1.60, 90.90–100.00)	0.109	**<0.001**	0.344	0.549

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