Comprehensive Dosimetric and Delivery Tradeoffs for Proton Dynamic Arc Therapy vs. IMPT for Nasopharyngeal Cancer

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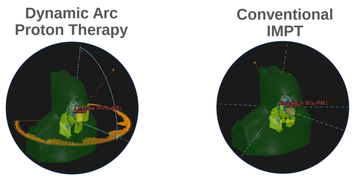
Purpose

Recent Phase 3 trial literature provides evidence for IMPT as the standard-of-care treatment for oropharyngeal cancer. Proton dynamic arc therapy (DynamicArc) potentially offers further refinement of IMPT. The goal of this work was to compare DynamicArc versus IMPT for anatomically complex nasopharynx cases.

Methods:

- Eight patients were retrospectively planned using DynamicArc (1 each coplanar/noncoplanar partial arc, no range shifter) and compared to paired IMPT plans (4-6 fixed fields, 7.5cm range shifter).



Paired-design (n=8)
Wilcoxon signed rank test ($p<0.05$)
LET_d comparisons
Treatment delivery time comparisons

- RayStation 2023B-generated plans shared contours/prescriptions and were robustly optimized/evaluated (±3.5mm setup,±3.5% range) with Monte Carlo dose calculation (0.5% uncertainty, 40,000ions/spot).
- Target D99% and OAR endpoints (Gy[RBE=1.1]) were compared with Wilcoxon signed-rank tests ($p<0.05$). LETd was evaluated within OAR voxels receiving ≥45Gy[RBE=1.1], summarized as median LETd boxplots, and visualized with dose-LETd density maps. Treatment times were estimated and compared using spot delivery, layer switching, and imaging/room-entry assumptions.

Results:

CTV coverage D99% endpoint showed statistically significant increases in CTV_High coverage ($p<0.05$) when using DynamicArc and general improvement on CTV_Mid and CTV_Low coverage. Moreover, OAR sparing was maintained or improved ($p<0.05$ for mean dose improvement on pterygoids, submandibular, tubarials). Some midline structures, such as larynx and cord, displayed higher D0.03cc values likely from increased low dose wash. Notably, some patients saw reductions in D0.03cc (>5Gy) for serial organs like the optic nerve and chiasm as well as reductions in mean (>10Gy) for lens. High-dose median LETd changes with DynamicArc were OAR-specific. Dose- LETd density maps showed differences in the low-dose/high- LETd and high-dose/low-LETd tails of the distributions, often with minimal changes in dosimetric endpoint. DynamicArc decreased spots/layers and beam-on time (6.7 vs 9.9min) with large time savings estimated when accounting for between-field room entry, gantry/couch repositioning, and post-move image verification for IMPT (6.7 vs 29.4min).

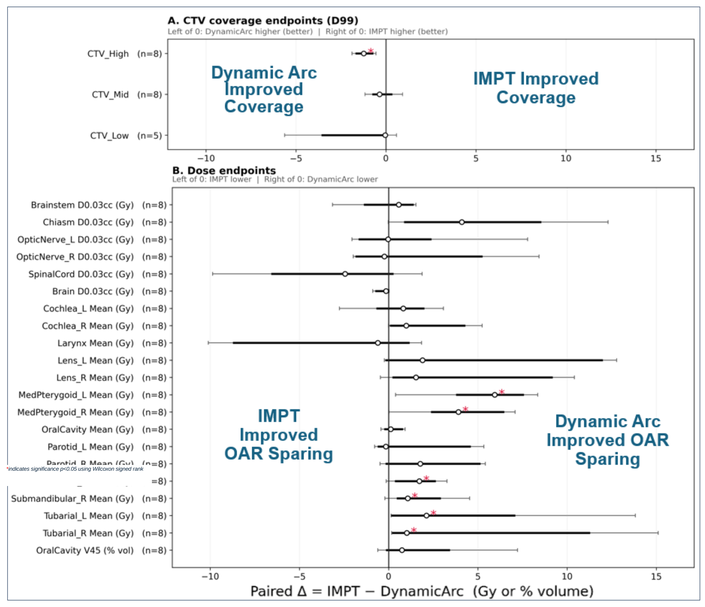


Figure 1. Forest plot of paired differences (IMPT – DynamicArc) for (A) tiered target D99 coverage (% of target Rx) and (B) OAR endpoints. The dot represents the paired median difference, thick bar represents the interquartile range, and the thin line represents the bootstrap 95% confidence interval.

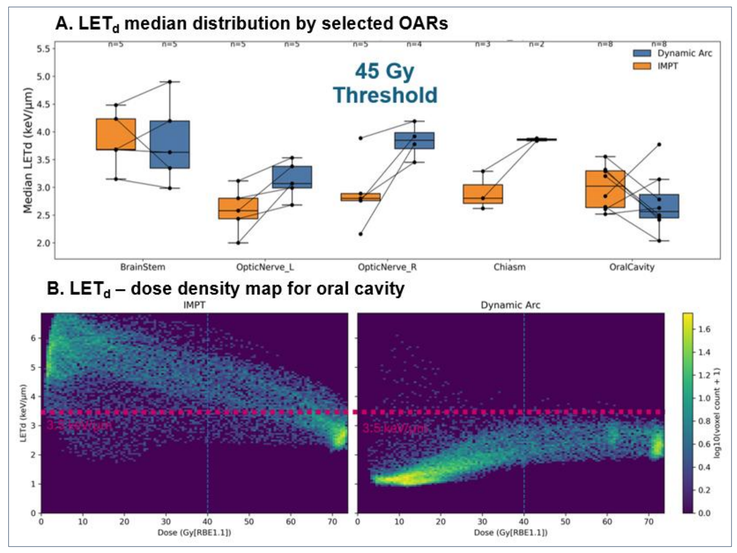


Figure 2. (A) LET_d median distribution for selected OARs at the 45 Gy threshold between IMPT and DynamicArc. (B) LET_d – dose density map for oral cavity.

KEY POINTS

DynamicArc improved target coverage (Figure 1A) while improving OAR sparing for multiple organs (Figure 1B).

The median LETd was in a similar range (2-5 keV/µm) between DynamicArc and IMPT, while some organs showed an increase and some showed a decrease in median LETd in the high dose region (threshold 45 Gy[RBE1.1]) (Figure 2A).

Specifically, oral cavity showed little change between IMPT and DynamicArc mean dose but had a median LETd decrease. The density map revealed a change in underlying LETd-dose distribution with most points shifting under 3.5 keV/µm, regardless of dose when using DynamicArc (Figure2B).

Interestingly, no LET optimization was performed. A change in underlying LETd-dose distribution, even without a change in overall endpoint dose, may have a biological effect and will be further investigated.

DynamicArc also achieved better beam on/overall times by reducing average spots/layers and removing the need to re-enter after every field (Table 1).

Table 1. Plan complexity/delivery parameters by IMPT and DynamicArc for the initial and boost phase.

IMPT				
	Avg Spots	**Avg Layers**	**Avg Fields**	**Estimated Time (min)**
Initial	26219	221	5.5	Beam On: 9.9 Total: **29.4**
Boost	18610	203	5.5	Beam On: 7.7 Total: **27.2**
DynamicArc				
	Avg Spots	**Avg Layers**	**Avg Fields**	**Estimated Time (min)**
Initial	16741	164	2	Beam On/Total: **6.7**
Boost	12306	165	2	Beam On/Total: **5.5**

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