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Gradience-boosted automatic robust dose-mimicking for proton therapy

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Purpose

Dose-mimicking aims to generate treatment plans based on a reference dose distribution. The importance of dose-mimicking has grown substantially due to the increasing demand for rapid plan adaptation in adaptive radiotherapy—particularly in proton therapy, where dose uncertainty remains a significant concern. However, developing a unified, automated dose-mimicking module for proton therapy is challenging, especially when planning a dose equivalent to or superior to the reference dose. We proposed a generally applicable dose-mimicking framework for proton therapy planning, combined with a gradient-boosted (GB) approach.

Methods

A GB cost function was designed and implemented for robust dose-mimicking. Ten clinically implemented plans from RayStation were used as references for automated dose-mimicking validation. The cost-function gradients during optimization were analyzed to demonstrate the effectiveness of the GB approach. Percentage differences of dose-volume histogram (DVH) metrics between reference and auto-generated plans were calculated. Moreover, the homogeneity index (HI) of the clinical target volume (CTV) was also calculated. All dose-mimicking was performed on an in-house treatment planning system.

Results

The GB approach increased the cost-function gradients during optimization by 85.3% for organs at risk (OARs) and 54.1% for targets. After GB optimization, gradients decreased by 63.2% in OARs and 9.57% in targets, indicating that the GB approach enables further improvement in plan quality. The HI of CTV in the reference was 0.20±0.14, and for the GB dose-mimicking plans, it was 0.16±0.10. The dose difference ($Plan_{in\text{-}house} - Plan_{reference}$, %) for CTV D_{95} was 0.80±2.00%, for CTV D_2 was -2.69±3.22%, for OARs was -3.39±7.59%, demonstrating improved dose conformality.

Conclusion

This feasibility study demonstrates the potential of the GB approach in proton dose-mimicking. Owing to its plug-and-play nature, the proposed approach may have broader applicability in adaptive and general radiotherapy planning.

Table 1. Summary of DVH metric comparisons across the cost functions

	CTV HI	ΔCTV D_{95}	ΔCTV D_2	ΔOARs
Reference	0.20±0.14			
Directly	0.25±0.13	-2.48±2.87%	0.64±0.75%	-3.77±8.36%
Automatic	0.18±0.11	0.67±1.46%	-1.10±2.79%	-2.91±7.25%
Automatic+GB	0.16±0.10	0.80±2.00%	-2.69±3.22%	-3.39±7.59%

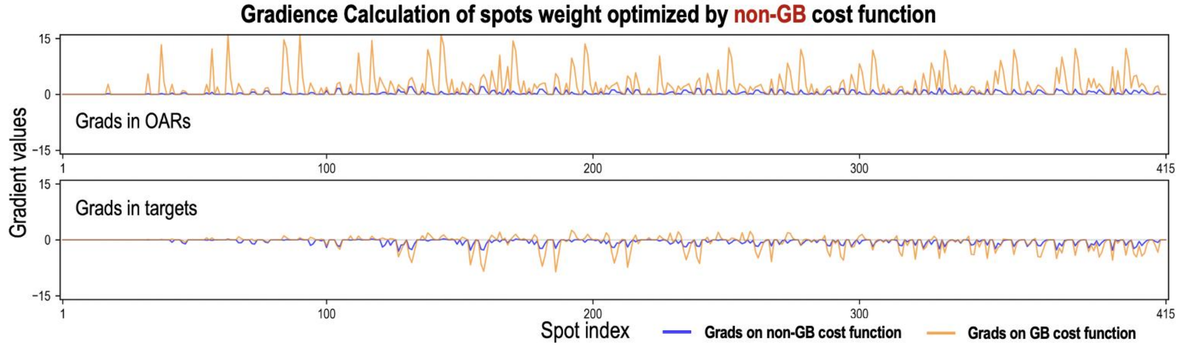

Figure 1. A comparison of the gradient between the non-GB cost function and the GB cost function.

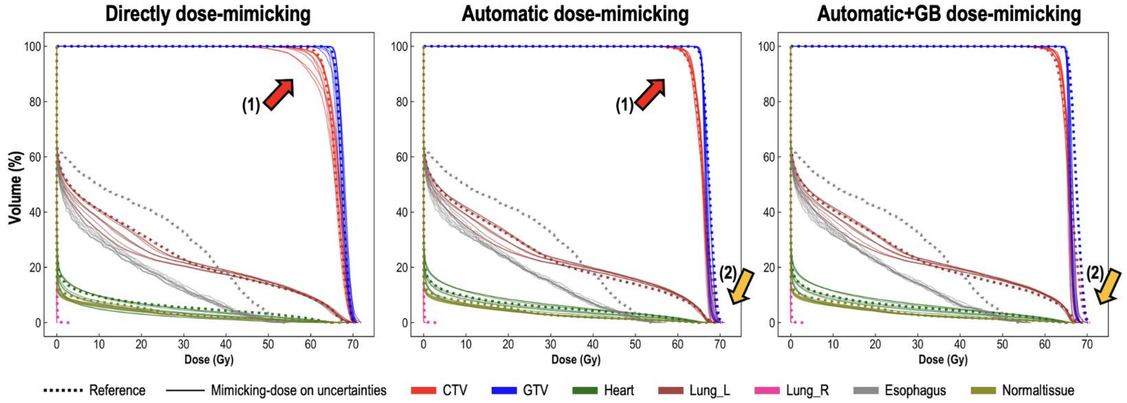

Figure 2. Example of dose optimizations (opt) using different cost functions.

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