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Linear Energy Transfer Weighted Beam Orientation Optimization for Intensity-Modulated Proton Therapy

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JOINT AAPM | COMP MEETING

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Purpose

- In IMPT, the variation in biological effectiveness leads to the discrepancy between the constant RBE prediction and experimental observations.
- We previously developed an automated IMPT BOO algorithm using group sparsity regularization[1], to automatically select beam angles and create treatment plans with superior physical dose distribution.
- A BOO method incorporating biological effectiveness is still unavailable. In this study, we developed a novel BOO framework integrating physical and biological doses.

Methods

Linear Energy Transfer weighted BOO (LETwBOO)

The LET and dose product (LET×D) is incorporated into the group sparsity based BOO to encourage selecting proton beams and generate fluence map, which 1) minimize LET×D in the OARs; 2)maintain LET×D to the target; and 3) achieve superior physical dose distribution.

Objective function

$$\underset{x\geq 0}{\text{minimize}} \sum_{k\in\mathcal{T}} \alpha_k \|A_k \boldsymbol{x} - p_k\|_2^2 + \sum_{k\in\mathcal{O}} \alpha_k \|A_k \boldsymbol{x}\|_2^2 + \sum_{b\in\mathcal{B}} \lambda_b \|\boldsymbol{x}_b\|_2^{1/2}$$

Physical dose constraint

Group sparsity to select beams

$$+ \sum_{k\in\mathcal{T}} \beta_k \left\| \left((LD)_k^{\text{ref}} - (L\circ A)_k \boldsymbol{x}\right)_+ \right\|_2^2 + \sum_{k\in\mathcal{O}} \beta_k \|(L\circ A)_k \boldsymbol{x}\|_2^2$$

LETxD constraint

- $\mathcal{B}$: the set including all feasible beams;
- $\boldsymbol{x}$: vector of the intensities of scanning spots of all candidate beams;
- A: dose calculation matrix to transform $\boldsymbol{x}$ to dose;
- L: LET calculation matrix to transform $\boldsymbol{x}$ to LET;
- $L\circ A$: the elementwise multiplication of L and A to calculate LETxD;
- p_k: prescription dose of target volume k ($k \in \mathcal{T}$);
- $(LD)_k^{\text{ref}}$: reference LET×D value target volume k;

Evaluations

- 600-800 non-coplanar candidate beams;
- Three patients with skull base tumor (SBT) and three patients with bilateral H&N cancer around were tested;
- Dose and LET calculation are based on matRad[2] ;
- Compared with 1) conventional plan optimizing physical dose with manually selected beams (*MAN*); 2) the same MAN plan reoptimized with additional LET×D constraint (*LETwMAN*);

Results

- The LETwBOO plans show superior physical dose and LET×D sparing for the OARs.
- On average, the [mean, maximal] doses of OARs in LETwBOO are reduced by [2.85, 4.6] GyRBE from the MAN plans in the SBT cases and reduced by [0.9, 2.5] GyRBE in the H&N cases, while LETwMAN is comparable to MAN.
- cLET×Ds of PTVs are comparable in LETwBOO and LETwMAN, where c is a scaling factor of 0.04 μm/keV.
- On average, in the SBT cases, LETwBOO reduces the OAR [mean, maximal] cLET×D by [1.1, 2.9] Gy from the MAN plans, compared to the reduction by LETwMAN from MAN of [0.7, 1.7] Gy. In the H&N cases, LETwBOO reduces the OAR [mean, maximal] cLET×D by [0.8, 2.6] Gy from the MAN plans, compared to the reduction by LETwMAN from MAN of [0.3, 1.2] Gy.

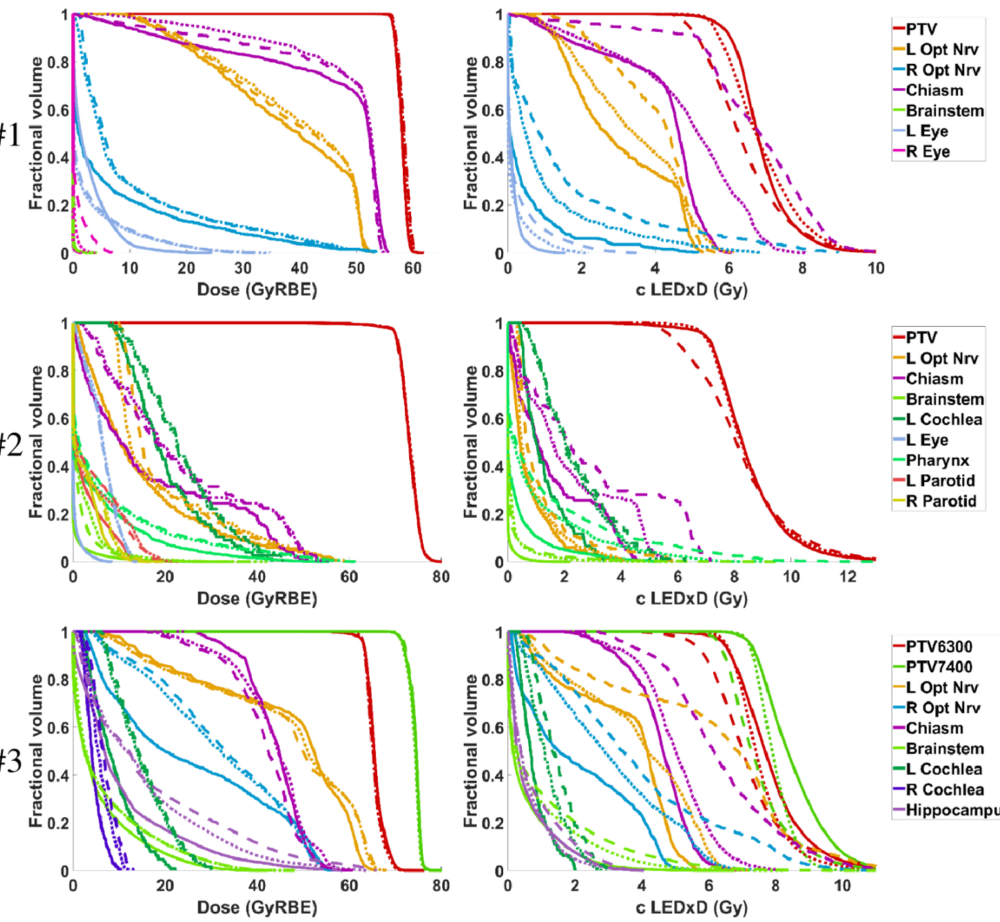

Figure 1. Comparison of dose and cLET×D between LETwBOO (solid), LETwMAN (dotted) and MAN (dashed) for the SBT patients.

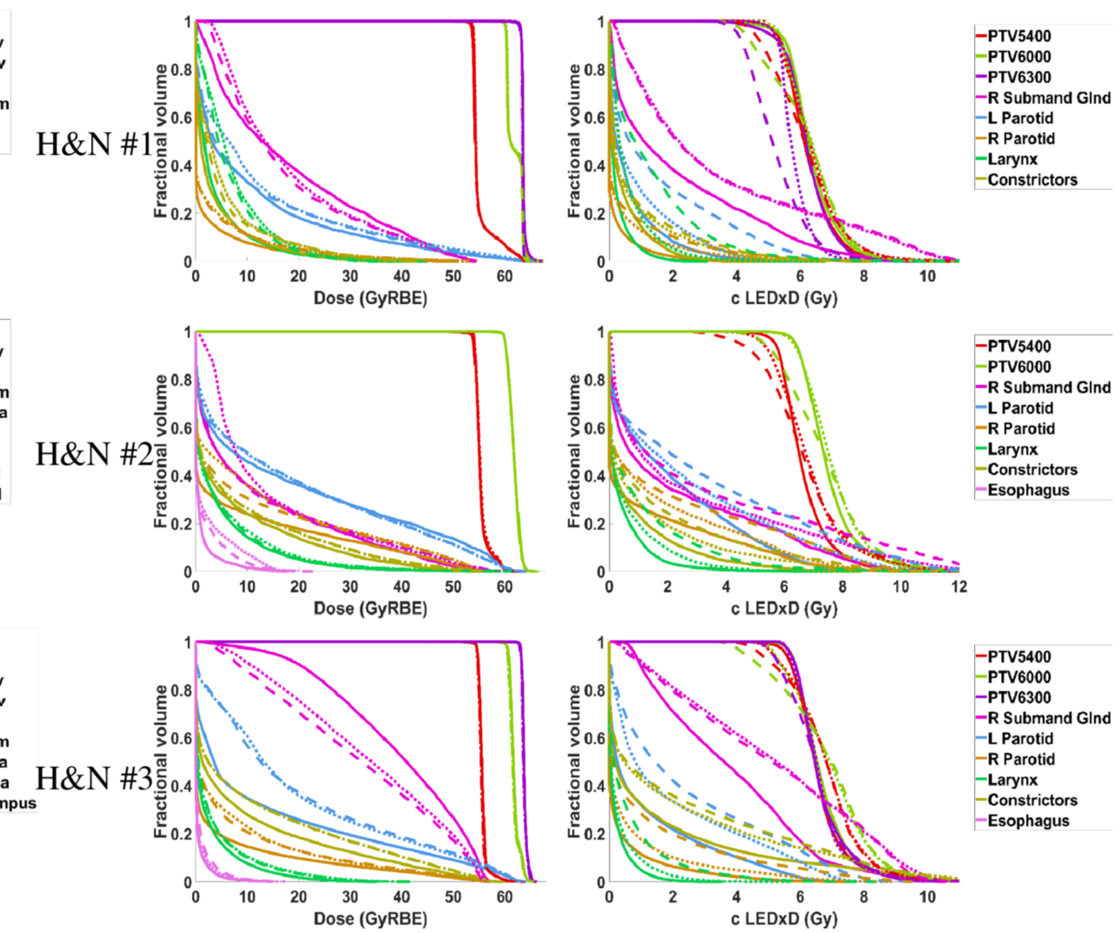

Figure 2. Comparison of dose and cLET×D between LETwBOO (solid), LETwMAN (dotted) and MAN (dashed) for the H&N patients.

Conclusion

We developed a novel LET weighted BOO method for IMPT to generated plans with improved physical and biological OAR sparing compared with the plans unaccounted for biological effects from BOO.

Reference

[1] Gu W, et al. Medical physics. 2018 Apr;45(4):1338-50.

[2] Wieser HP, et al. Medical physics. 2017 Jun;44(6):2556-68.