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Physics Contribution

Linear Energy Transfer Painting With Proton Therapy: A Means of Reducing Radiation Doses With Equivalent Clinical Effectiveness

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Summary

Protons with higher linear energy transfer (LET) have been shown to increase relative biological effectiveness. This study investigated whether dose per fraction could be traded for an increase in LET in the target while keeping the clinical effectiveness the same.

Purpose: The purpose of this study was to propose a proton treatment planning method that trades physical dose (D) for dose-averaged linear energy transfer (LET_d) while keeping the radiobiologically weighted dose (D_{RBE}) to the target the same.
Methods and Materials: The target is painted with LET_d by using 2, 4, and 7 fields aimed at the proximal segment of the target (split target planning [STP]). As the LET_d within the target increases with increasing number of fields, D decreases to maintain the D_{RBE} the same as the conventional treatment planning method by using beams treating the full target (full target planning [FTP]).
Results: The LET_d increased 61% for 2-field STP (2STP) compared to FTP, 72% for 4STP, and 82% for 7STP inside the target. This increase in LET_d led to a decrease of D with 5.3 ± 0.6 Gy for 2STP, 4.4 ± 0.7 Gy for 4STP, and 5.3 ± 1.1 Gy for 7STP, keeping the D_{RBE} at 90% of the volume (D_{RBE}, 90) constant to FTP.
Conclusions: LET_d painting offers a method to reduce prescribed dose at no cost to the biological effectiveness of the treatment.

Introduction

The linear energy transfer (LET) for protons increases with depth to a maximum at the very distal edge of the beam. It has been shown (1-4) that protons with higher LET have an increased relative biological effectiveness (RBE) compared to photons. It has also been shown (5) that proton RBE may increase with decreasing α/β ratio of the parameters of the linear quadratic model.

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In the present work, we investigated whether increased LET in the target could be used as a means to reduce the prescription dose, D, while maintaining the same RBE-weighted total dose (D_{RBE}) in the target. The prostate was chosen as a test target because its symmetrical geometry is reproducible among patients, which reduced the effect of interpatient variability on our statistical analysis. It has also been shown (6) that prostate cancer has a low α/β ratio (1.5 Gy), which helps magnify the effect of RBE on the biological dose.

Methods and Materials

Patient selection criteria and constraints

Eight patients treated with proton pencil beam scanning were selected for this study by using the following criteria: (*1*) localized tumor with no spread to seminal vesicles, that is, T1 or T2 category with N0 and M0, so intra patient variability could be assumed to be low; and (*2*) selection of the body size was a compromise between the minimum deliverable energy (100 MeV) to cover the target proximally and the maximum deliverable energy (230 MeV) to cover the target distally for a posterior oblique beam.

Patients considered for this retrospective study were prescribed 79.20 Gy (RBE) to the prostate in 44 fractions of 1.80 Gy (RBE) each. The following constraints were used to evaluate plan coverage: 98% of the planning target volume (PTV) should receive 95% of the prescribed dose; 99% of the clinical target volume (CTV) should receive 98% of the dose; there should be no "hot" spots over 107% for the same structures. Criteria for other organs followed standards according to quantitative analysis of normal tissue effects in the clinic (QUANTEC) (7, 8).

Target volume contouring

A method of target contouring was proposed that divides the original CTV into beam-specific proximal target segments (Fig. 1).

When a field covers the full target (full target plan [FTP]), the largest components of dose-averaged LET (LET_d) are deposited immediately distal to the target (Fig. 2a). However, Figure 1 shows the proposed splitting of the target (split target plan [STP]), where each beam was aimed at the proximal part of the target, and the most distal point was located past the isocenter in the direction of the beam. The size of the Bragg peak in the axial direction was extracted from the treatment planning system (TPS) and was used to extend the segment of the target in the beam direction, and 5 mm was the distance used to extend the target laterally. These extensions created an

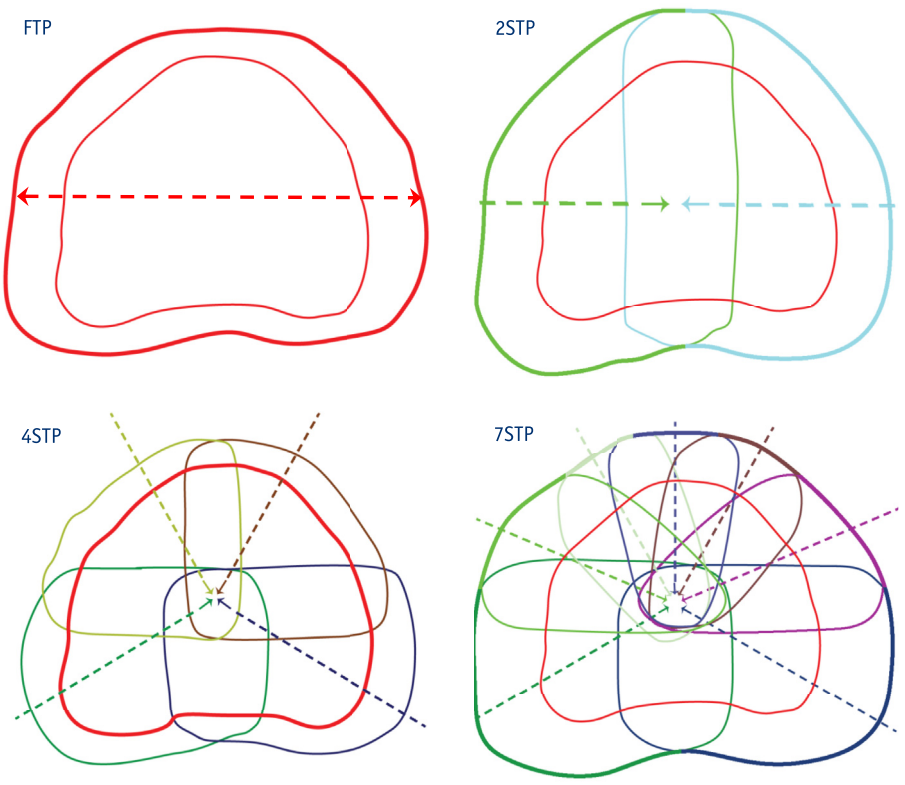

Fig. 1. Target segmentation. Dotted lines represent the beam direction for each case. The line is paired with a corresponding contour of same color, which represents the segment of the target that the beam is covering. The inner red contour represents the clinical target volume. FTP = full target plan; STP = split target plan. A color version of this figure is available at www.redjournal.org.