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JOINT AAPM | COMP MEETING

A Comprehensive Comparative Study of Proton Flash Techniques for Conformal Pencil Beam Scanning Radiotherapy: Pristine Bragg Peak Vs. Spread-out Bragg Peak

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INTRODUCTION

- Proton for Conformal FLASH Therapy :
  - Offers the ability to deliver highly conformal dose distributions while sparing surrounding normal tissues.
  - Multiple delivery techniques have been developed to optimize target coverage while maintaining ultra-high dose rate.
- Objectives of this study:
  - To perform a head-to-head evaluation between the Single-Energy Pristine Bragg Peak (SEPBP) and the Spread-Out Bragg Peak (SOBP) planning technique for FLASH therapy.
  - Dosimetric comparison: Evaluate and compare target coverage, dose conformity, dose homogeneity, and normal tissue sparing between the SEPBP and SOBP plans.
  - Dose rate assessment: Quantify and compare the achievable dose-rate distributions and high-dose rate coverage of SEPBP and SOBP plans to assess their potential suitability for proton FLASH therapy.

METHODS

- Single-Energy Pristine Bragg Peak technique:
  - Using range compensators and range shifters to modify dose depth curve to achieve Bragg peak tracking.
  - Beam-specific range compensation synergy with inverse multi-field optimization for PBS FLASH planning.
  - Achieving highly conformal FLASH plans dosimetry equivalent to conventional IMPT.
- Spread-Out Bragg Peak technique:
  - Using ridge filters to generate spread out Bragg peaks (SOBPs).
  - Integrated with PBS inverse intensity optimization to produce a single-field optimized (SFO) treatment plan.
  - Single-energy delivery compatible with FLASH dose rates.
- A fast Monte Carlo dose MC2 calculation engine was used for high accuracy dose and dose rate calculation.
- Used a TG119 C-Shape target that surrounds a central avoidance structure.
- Each technique used equivalent plan parameters: 15Gy delivered using 3 beam angles, the same clinical goals, and similar minimum monitor units.

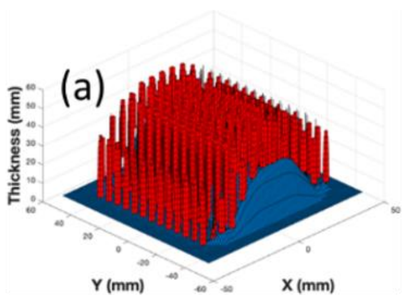

Figure 1: A comparison of distinct conformal FLASH-RT techniques utilizing a mini ridge filter (miniRF) with the Spread-Out Bragg Peak planning technique and a range compensator with the Single Energy Pristine Bragg Peak technique to deliver 15 Gy to a C-shaped target: (a) the pin-shaped miniRF, (b) the range compensator (RC).

RESULTS

- Coverage was normalized to 95% of the target volume receiving 100% of the prescription.
- Both the SEPBP and SOBP techniques met all clinical standards.
  - Maximum target dose: 114.4% (SEPBP) and 116.4% (SOBP).
  - Conformity index: 1.52 (SEPBP) and 1.9 (SOBP).
  - SOBP had increased target heterogeneity and low dose spillage.
- The SEPBP method was able to achieve FLASH ratios higher than the SOBP method.
  - Ridge filter modulates depth while also increasing lateral spread via multiple Coulomb scattering, using the same beam current (minimum monitor unit setting) results in reduced delivered dose intensity compared with a pristine Bragg peak (Fig. 1c); consequently, the SOBP approach yields lower dose rates than SEBP.
  - From a FLASH perspective, SOBP may be advantageous when it can deliver a uniform single-field dose at FLASH dose rates, which could more consistently elicit a FLASH effect.

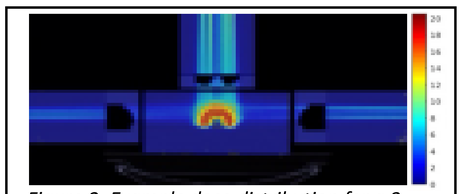

Figure 2: Example dose distribution for a 3-field beam arrangement for the SEBP technique

	Single Energy Pristine Bragg Peak	Spread Out Bragg Peak
Hotspot	↓	↑
Paddick Conformity Index	↑	↓
Heterogeneity Index	↑	↓
Integral dose	↑	↓

Table 1: Direct comparison of Single Energy Pristine Bragg Peak and the Spread Out Bragg Peak planning technique dose evaluation metrics.

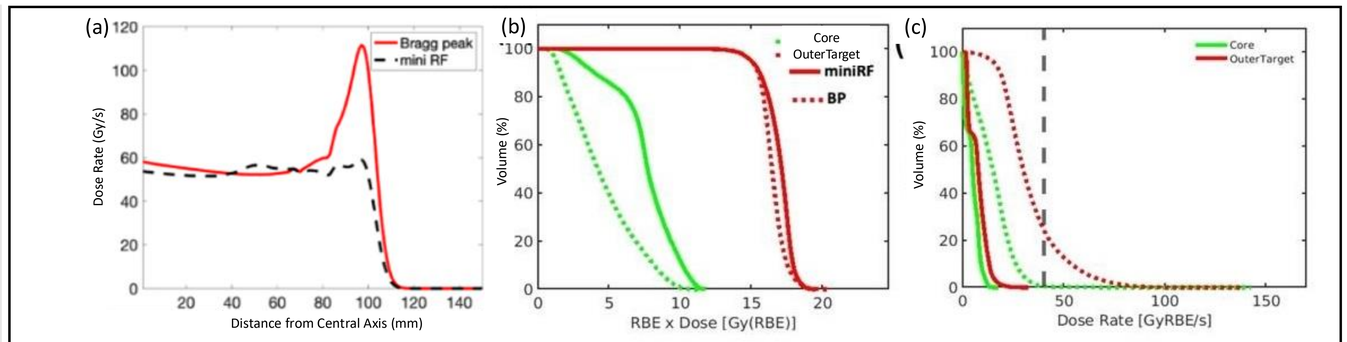

Figure 3: (a) Comparison of dose rate profiles at the beam's center with a beam angle of 0 degrees. (b) Comparison of the dose volume histograms (DVH) for the target and inner core between the two plan types. (c) Dose rate volume histograms (DRVHs) for the phantom patient using a SEPBP and SOBP based plan with a minimum of 400 MMU.

CONCLUSIONS

- Plan comparison:
  - SEPBP and SOBP planning techniques produce comparable and clinically acceptable dosimetric outcomes and target coverage, dose conformity, and normal tissue sparing were maintained in both approaches. In general, SEPBP achieve better plan quality.
  - Under identical beam delivery parameters, SEPBP plans generated higher dose-rate capabilities than shown in SOBP delivers.
  - SEPBP technique may facilitate improved conformity and higher dose-rate irradiation potentially improving its applicability for FLASH proton therapy.
- Future work:
  - Expand analysis to a larger patient cohort and additional disease sites to assess the generalizability of dosimetric and dose-rate trends.
  - Evaluate the robustness of SEPBP and SOBP plans for various anatomical sites.
  - Explore further FLASH-specific planning considerations for SEPBP plans including maximizing dose rates and utilizing spot merging.

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