Delivery of Proton Monoenergetic Arc Therapy (PMAT) and Measurement with Radiochromic Films

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INTRODUCTION

- Proton Monoenergetic Arc Therapy (PMAT) has been shown to have valuable features, including:
  1. Increasing the linear energy transfer (LET) within a target without compromising uniformity or conformity (1).
  2. Minimizing entrance dose due to an increase of plateau-to-peak ratio, potentially allowing an increase of the therapeutic index (2).
- The dosimetric difficulty of PMAT: **since beams are coming from multiple directions, directionally dependent dosimetry devices would be difficult to implement**.
  - Volumetric dosimeters could prove useful, but none have been widely implemented for proton radiotherapy, therefore **2D dosimetry, such as radiochromic film, must be used.**
  - **Quenching effects are well documented within radiochromic film dosimetry of proton and heavy ion radiotherapy** due to high LET within the Bragg peak (3, 4, 5).

AIMS

1. Prove the quenching effect affects the dose **within the target** in PMAT, **instead of along the distal edge** as in conventional proton radiotherapy.
2. Quantify the level of effect the quenching effect has on dose within the target.
3. Provide a quenching effect correction method that allows for accurate 2D dosimetry assessment of PMAT plans.

METHOD

1. Single-energy PMAT plan was created with an in-house optimizer (see **Figure 1**).

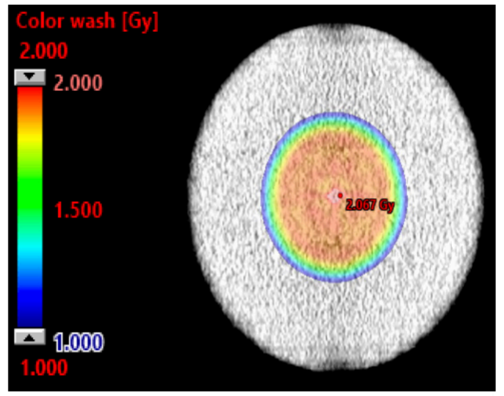


Figure 1. Display of single-energy PMAT plan in the treatment planning system (TPS) that produces homogenous dose to a circular target using 360-degrees of rotation with 1-degree of separation between beams; an energy of 116.235 MeV was selected to place the Bragg peak deposition approximately at the film's center (the plan was created to deliver 2 Gy, then later converted to 4 Gy within the treatment machine).

2. Gafchromic EBT3 film was placed within a water-equivalent circular phantom with a diameter of 20 cm. The phantom was set centered with the axis of a rotating stage.
3. A single 116.235 MeV energy beam with range 10.1 cm produced via pencil beam scanning from an IBA Proteus Plus cyclotron was used to deliver dose through a horizontal fixed gantry such that spot delivery of every angle was coincided with the rotation of the phantom.
4. Exposed film was scanned with a multichannel flat bed scanner, and the optical density recorded.
5. Dose within the TPS was adjusted to correct the quenching effect present in regions of high LET throughout the film according to the Anderson *et al* (5) method:

$$Film\ Under-Response = -0.0251 * LETd + 1.02 \quad (1)$$

RESULTS

(a) (b)

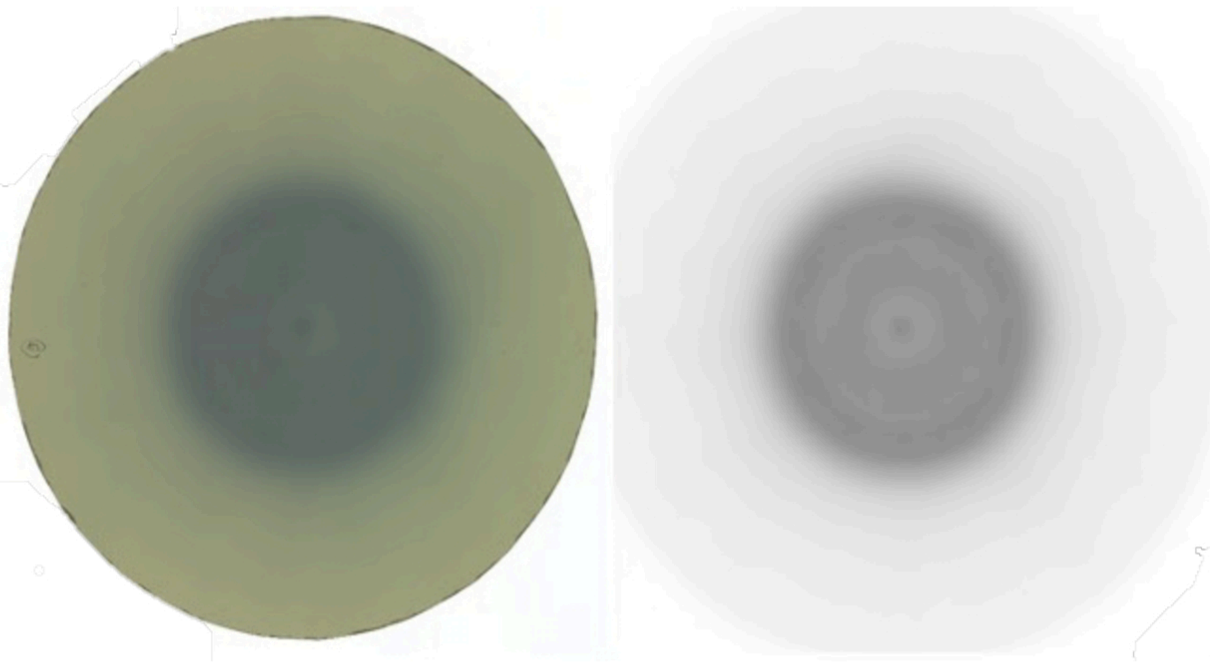
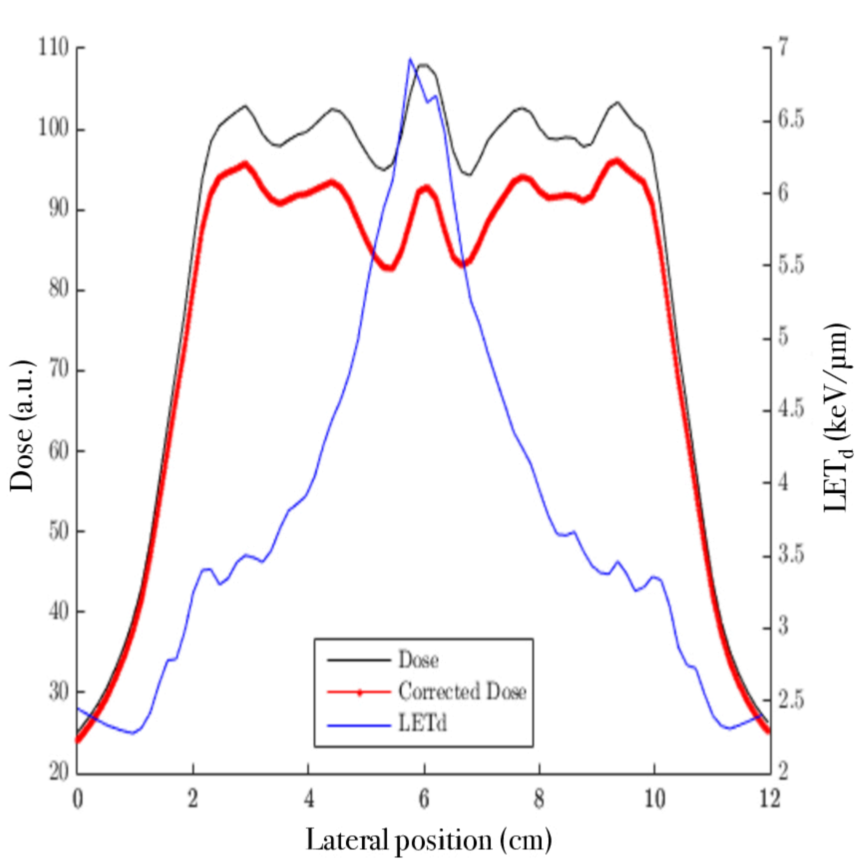


Figure 2. **(a)** Measured PMAT dose distribution on EBT3 Gafchromic film. **(b)** View of a plane's dose distribution predicted from the TPS after correcting for quenching effects by method of Anderson *et al* (5).

(a) (b)



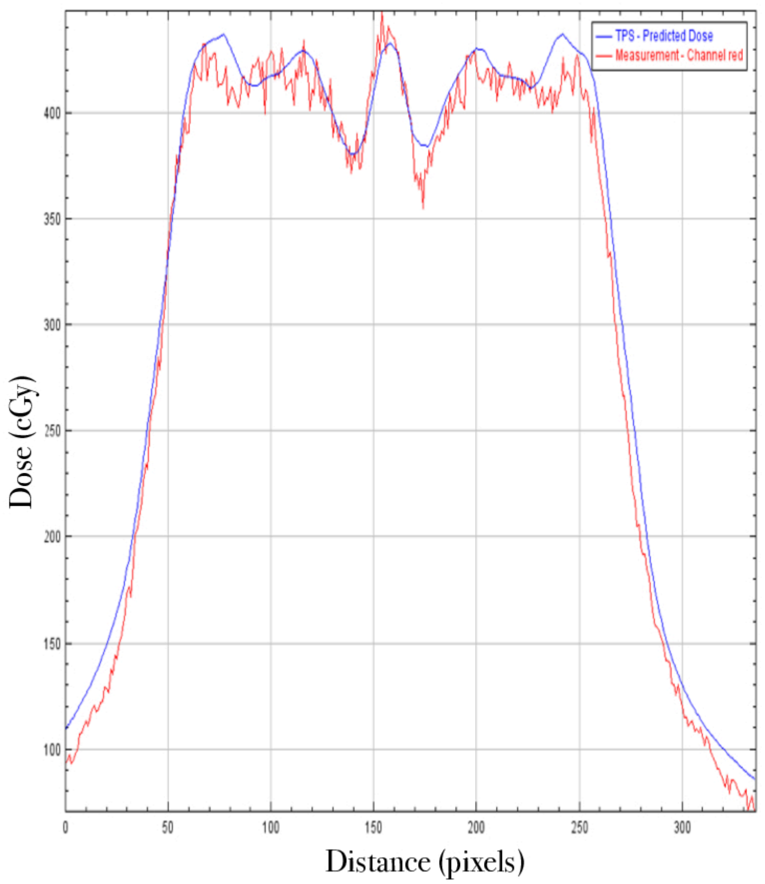


Figure 3. **(a)** Vertical central profiles of the TPS planned dose distribution, the quenching-corrected distribution, and the dose-averaged LET (LETd) for the delivered PMAT plan. From methods given by Anderson *et al* (5), under-response in the film is evaluated as -0.0251 * LETd + 1.02, equaling a relative dose reduction of 15% in the film. **(b)** Vertical central profiles of dose from **Figure 2** comparing measured and predicted dose, once quenching effects are corrected in the TPS.

CONCLUSIONS

- There is a **15% absolute uncorrected signal reduction** observed in our Gafchromic EBT3 film due to the quenching effect.
- The relative difference between the quenching-corrected and measured **signal is 5% higher at the center of the target than at the periphery** due to higher LET.
- Measured corrected-dose and experimental measurement **profiles agree within the red channel uncertainty of 2.6% associated with Gafchromic EBT3 films** (6).

- **PMAT plans can be correctly made and delivered** onto a rotating phantom, inversely simulating the setup of a rotating gantry onto a fixed dosimetry device.
- **Radiochromic film is an accurate 2D dosimetry option for PMAT plans.**

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