Qualification and Reproducibility of Proton FLASH Fields Delivered with Prototype High Dose Rate Hardware

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Introduction

Ultra-high dose rate or FLASH radiotherapy has shown promise in pre-clinical studies as a new technique for increasing the therapeutic ratio, namely, by reducing harm to normal tissues while maintaining iso-effective tumor control [1-4]. Some experiments have even shown benefits of FLASH therapy with protons [5,6].

Aim

To evaluate the properties and reproducibility of FLASH fields delivered by prototype proton Pencil Beam Scanning (PBS) hardware using machine log files and film analysis.

Method

PBS is a dynamic delivery technique in which a proton pencil beam is swept over an entire volume as a function of time. This time dependence on the location of dose delivery introduces a need for a specialized definition of dose rate. The region of influence for a pencil beam is limited to the immediate neighborhood of the beam center. Therefore, the effective region of interest for a given point in a field is a few adjacent scan lines. "PBS Dose Rate" at a given point in the field is therefore defined as the accumulated dose at that point divided by the time to deliver the contributing scan lines [8]. More specifically, the total dose to a point in the field is delivered in the time elapsed between the first and last contributing spot.

Two sets of four rectangular 250 MeV spot patterns (fields) were created in a DICOM file. Each field contained 13 spots along the primary scanning axis and either 14, 18, 22, or 26 spots along the orthogonal axis. The spot sigma was 3.3 mm and all spots were spaced 5 mm apart to generate a homogeneous dose distribution. The primary axis for the first and second sets was along the Y and X direction, respectively.

Prototype high dose rate hardware was installed and commissioned on a ProBeam™ proton research gantry [7]. The spot MUs were set such that the biological dose (RBE=1.1) was 8.40 Gy_{RBE}. Each field was measured with film at isocenter under 5 cm depth of high density polyethylene (HDPE).

A logfile analysis tool was developed to compute PBS dose rate for many points on the isocenter plane within the 7.60 Gy_{RBE} (95% of 8.00 Gy_{RBE}) isodose line and report the 10th percentile value.

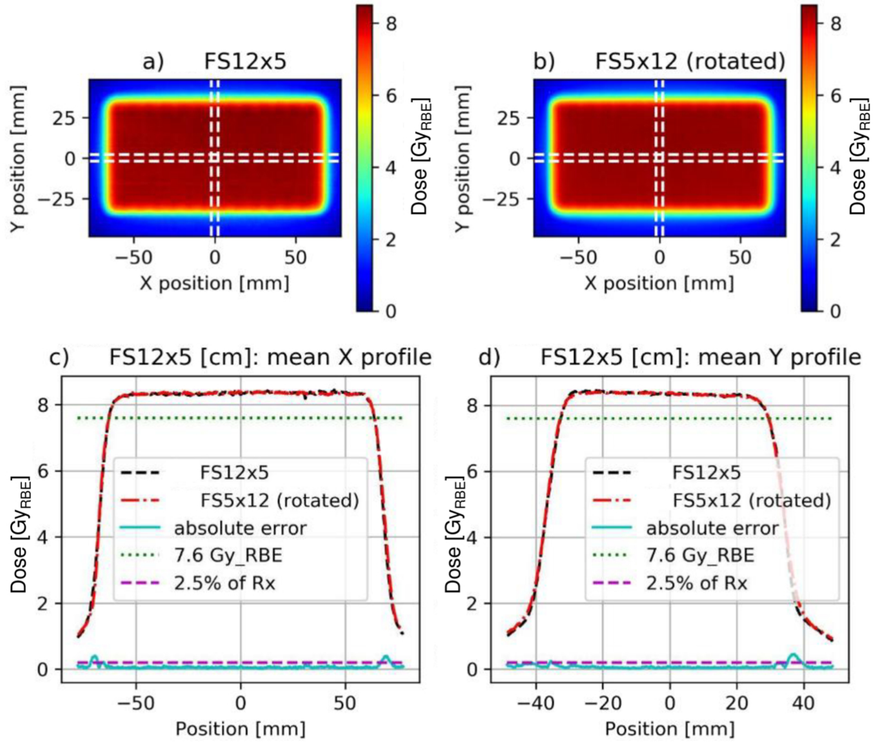
Results

PBS dose rates of 67 Gy_{RBE}/s ±1.5% have been obtained consistently with high reproducibility. These dose rates have been calculated from the machine logfiles according to the method described in Ref [8]. At these FLASH dose rates, a reproducibility of the applied doses per field of 8.65 Gy_{RBE} ±2.06% has been measured using EBT3 film and an Advanced Markus Chamber and UNIDOS electrometer.

Dose homogeneity for all fields at 5 cm depth in HDPE was better than ±2.5%. The size of the 7.60 Gy_{RBE} isodose line at 5 cm depth in HDPE was 5.6 cm by 6.1, 8.0, 10.0, and 12.1 cm regardless of orientation.

In the figure to the right, the film dose at isocenter plane (a, b) and profiles (c, d) for the largest field in each set are shown. In the table below, the size difference calculated original vs. rotated is shown. Percentage of voxels in the target region having dose difference less than 2% of D_{max} are also reported.

Original vs. Rotated Field Sizes [cm]	Size X Diff. at 7.60 Gy_{RBE} [mm]	Size Y Diff. at 7.60 Gy_{RBE} [mm]	Size X Diff. at 4.00 Gy_{RBE} [mm]	Size Y Diff. at 4.00 Gy_{RBE} [mm]	Homog. original [%]	Homog. rotated [%]	Dose Diff. < 2% of D_{max} [% of target]
6x5 vs. 5x6	0.7	0.0	0.0	0.0	1.59	2.01	98.6
8x5 vs. 5x8	0.0	0.4	0.0	0.7	1.93	2.09	97.2
10x5 vs. 5x10	0.4	0.0	0.0	0.0	2.12	1.68	99.3
12x5 vs. 5x12	-0.4	-0.4	-0.7	0.0	2.22	1.58	99.0



Conclusions

We developed a method to verify PBS dose rates using logfile information and successfully implemented qualification and reproducibility procedure to verify that our prototype hardware was able to consistently deliver FLASH fields with dose and dose rate fluctuations of less than 2.5%.

The viability of delivering FLASH fields with prototype ProBeam™ proton pencil beam scanning hardware was also successfully demonstrated. We foresee the prototype being very useful for pre-clinical FLASH studies.

References

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