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# Evaluation of spot size using volumetric repainting technique on a ProteusPLUS PBS Proton Therapy System

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**Abstract.** Volumetric repainting is considered as one of the techniques for motion mitigation in proton therapy. Faster layer switching time to deliver a volumetric repainting proton plan is very critical to reduce the overall treatment time. Recently, IBA (proton therapy vendor at the Miami Cancer Institute) has implemented a “field regulation” – a new feature to reduce the switching time between layers by applying a magnetic field setpoint to specific groups of magnets. In order to investigate the impact of field regulation and volumetric repainting technique on the spot size, several spot maps were generated. The spot sizes were measured at the isocenter and four off-axis points using the Lynx 2D scintillation detector. The average difference in spot size between two delivery sequences (“down” vs. “up” directions) for given energy at all five locations was  $0.6\pm 0.5\%$ . The measurement results from the current study demonstrated that the impact of field regulation on the spot size was very minimal, and this was true for both the volumetric and non-volumetric techniques on a ProteusPLUS proton system with a PBS dedicated nozzle.

## 1. Introduction

In recent years, pencil beam scanning (PBS) is becoming a preferred technique in proton therapy in comparison to the passive scattering techniques such as double-scattering and uniform scanning. One of the key dosimetric differences between these two techniques is that PBS produces more conformal dose distributions compared to the passive scattering technique [1]. PBS technique allows the dose deposition in the volume by delivering a single pristine pencil beam such that its properties – spot shape, spot position, range, and intensity – can be varied. Since the PBS technique irradiates one position at a time, this possesses challenges in treating mobile tumors due to the interplay effect [2]. Several motion management techniques such as breath-hold [3], gating [4], tracking [5], layer repainting [2], and volumetric repainting [2, 6] are mentioned in proton therapy.

For repainting techniques, the time to switch energy layers becomes critically important. Although volumetric repainting for motion mitigation was quite well known in the proton therapy community, the clinical application of the volumetric repainting technique is very limited. The volumetric repainting implies repetitive scanning through the whole target volume [2, 6]. One of the volumetric repainting strategies can be such that the irradiation begins from the distal to the most proximal layer (Dist-Prox or “down” direction) followed by irradiation from the most proximal to the distal layer (Prox-Dist or “up” direction). This strategy necessitates the fast layer switching in both the “down” and “up” directions.



At the Miami Cancer Institute, a ProteuPLUS proton therapy system with a PBS dedicated nozzle (Ion Beam Applications, Louvain-la-Neuve, Belgium) is used for the patient treatment. For the current clinical treatment delivery, different types of magnets are employed in order to transport the proton beam from the cyclotron to the treatment room. The clinical commissioning of the system was done for the beam delivery in the “down” direction only with a site configuration that has all magnets being regulated in the current (CR). Recently, IBA has implemented a “field regulation” (FR) – a new feature to reduce the switching time between layers in order to decrease the total delivery time. In FR mode, the layer switching is accomplished by applying a magnetic field setpoint (instead of a current setpoint) to three specific groups of magnets (B1234E, B1Gx, and B2Gx) in the beamline. The B1234E are four 30° bending magnets connected in series, whereas B1Gx is the first bending magnet of the gantry (45°), and B2Gx is the last bending magnet of the gantry (135°). The quadrupoles, on the other hand, are non-field regulated magnets. The fluctuations of current to the quadrupoles and variations in the magnetic field in B1234E, B1Gx, and B2Gx during “down” and “up” directions can potentially change the spot size of a given energy, thus adding to the beam delivery uncertainty that can affect the quality of the delivered volumetric repainting plan.

One of the primary dosimetric components of the PBS proton beam model within RayStation (RaySearch Laboratories, Stockholm, Sweden) treatment planning system is in-air spot size (hereafter referred to as spot size). Since the clinical treatment and beam model are based on the CR, it is imperative to investigate the impact of FR before its clinical use. In this study, we focused on the spot size and sought to understand how the combination of FR and volumetric repainting technique affects the spot sizes of various energies on a ProtusPLUS proton therapy system with a PBS dedicated nozzle. The difference in spot sizes measured in CR and FR modes is expected to be minimal, and this hypothesis needs to be validated in a clinical environment.

## 2. Materials and Methods

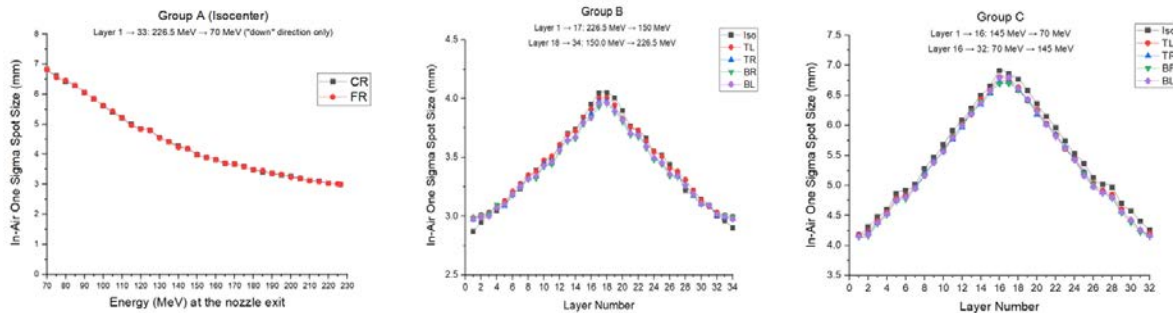
The energies produced by the cyclotron at our proton center ranges from 70 MeV to 226.5 MeV. For more details on the ProteusPLUS beam delivery system, readers are advised to refer to publications by Rana *et al* [7] and Lin *et al* [8]. For spot profile measurements, we utilized the Lynx 2D (IBA Dosimetry, Schwarzenbruck, Germany) – a gadolinium-based scintillation detector that has active surface area of 300 mm × 300 mm and a resolution of 0.5 mm [9]. For our experimental setup, the Lynx detector was set up at the isocentric plane such that the gantry angle is 90°, and the beam is perpendicular to the Lynx.

Spot size measurements included three groups of energies (Groups A, B, and C), as illustrated in figure 1. Group A included a spot map consisting of a total of 33 layers with a delivery sequence of energies starting from 226.5 MeV to 70 MeV (“down”). Group B included a spot map of 34 layers with a beam delivery sequence of energies starting from 226.5 MeV to 150 MeV (“down”) followed by 150 MeV to 226.5 MeV (“Up”). Group C included a spot map of 32 layers with beam delivery sequence of energies starting from 145 MeV to 70 MeV (“down”) followed by 70 MeV to 145 MeV (“Up”). For all three groups, each layer consisted of a single spot.

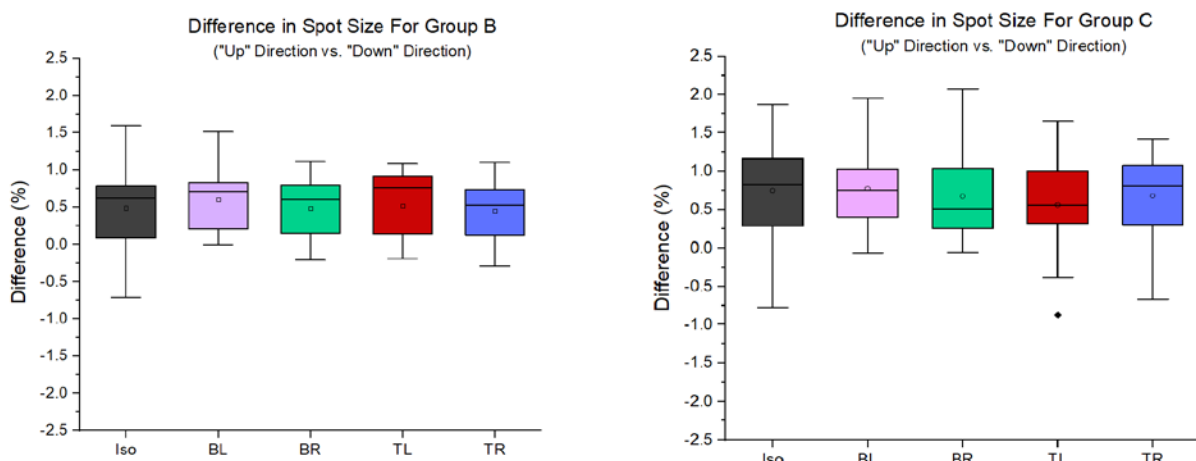
Figure 2 shows the x and y coordinates of five measurement locations: isocenter (0, 0) and four off-axis points: top-left (TL; -10 cm, 10 cm), top-right (TR; 10 cm, 10 cm), bottom-left (BL; -10 cm, -10 cm), and bottom-right (BR; 10 cm, -10 cm). For each of these measurement locations, 2 different spot maps were generated for beam delivery sequences, as provided in figure 1. For example, the TL point has two spot maps – one for Group B and one for Group C (figure 1), and the X and Y positions of a spot in both the groups for TL are -10 cm and 10 cm, respectively, with respect to the isocenter (0, 0). For measurement at the isocenter, an additional spot map with the beam delivery sequence of Group A was generated. In order to mimic a real clinical treatment delivery scenario, spot maps were delivered in continuous mode (i.e., without pausing the beam after delivering each layer). For spot profile data acquisition, the Lynx plug-in within myQA software (IBA Dosimetry, Schwarzenbruck,



absolute deviation of 0.3%. Figure 4 shows the spot sizes for Groups B and C energies, respectively, at five different measurement locations (Iso, TL, TR, BR, and BL) using FR mode. The difference in spot size between two delivery sequences (“down” vs. “up” directions) in FR mode for given energy at all five locations was within  $\pm 2.0\%$  (Figure 5).



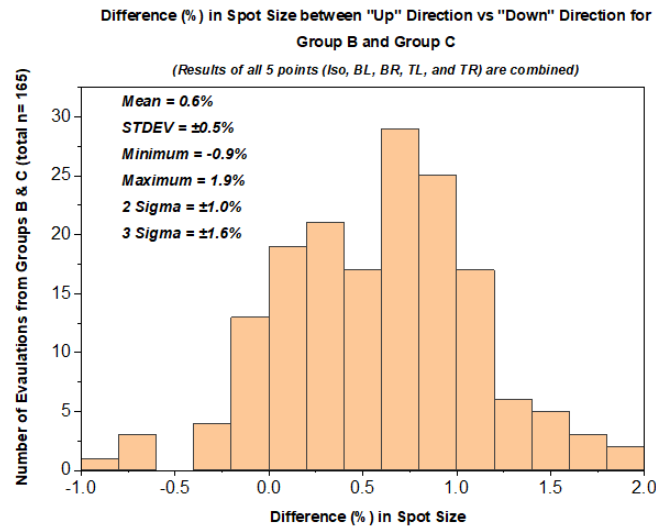
**Figure 3.** (left panel) Spot size measurements (Group A) at the isocenter in “down” direction using current regulation and field regulation; (middle panel) spot sizes for Group B at five different measurement locations (Iso, TL, TR, BR, and BL) using field regulation; (right panel) spot sizes for Group C at five different measurement locations (Iso, TL, TR, BR, and BL) using field regulation.



**Figure 4.** The difference in spot sizes between “up” and “down” directions at five different measurement locations (Iso, TL, TR, BR, and BL) using field regulation (FR). The difference was calculated by subtracting the spot size of given energy during “up” direction from the spot size of the same energy during the “down” direction.

#### 4. Discussion

In this study, we investigated variations in spot size as a result of FR feature on a ProteusPLUS proton system with a PBS dedicated nozzle. For the “down” direction of Group A energies, we noticed a very minimal deviation (within  $\pm 0.5\%$ ) in spot sizes at the isocenter when comparing FR against the CR. For Groups B and C, which included the combination of FR and volumetric repainting (i.e., “down” direction followed by “up” direction), the difference in spot size between “up” and “down” directions was within  $\pm 2\%$ , which is less than spot size tolerance of  $\pm 10\%$  recommended by the AAPM TG224 [10]. This was true for measurement locations at the isocenter as well as four off-axis points (BL, BR, TL, and TR). Further analysis of Group B and Group C results combined yielded the average difference of  $0.6 \pm 0.5\%$  with 3 sigma of  $\pm 1.6\%$ . (Figure 7). These results indicate that the combination of FR and volumetric repainting has a very minimal impact on the spot size.



**Figure 5.** Combined results of Group B and Group C at all five points (Iso, BL, BR, TL, and TR) showing the difference in spot size between “up” vs. “down” directions.

The current study was focused on determining the impact of FR on the spot size. Other two fundamental dosimetric parameters spot position and range were not investigated in this study. This is the limitation of our work. The beam delivery design in FR includes a Hall Probe positioned at the entrance/exit of the B1Gx, B2Gx, and one magnet of the B1234E quadruplet. This allows the measurement of the magnetic field of the above-mentioned magnets in real-time. The fluctuations in the magnetic field detected by Hall probes can potentially cause the displacement of positions of the spots and range. Our future work will address the question – how does the combination of FR and volumetric repainting impact the spot position and range?

## 5. Conclusion

The impact of FR on the spot size was very minimal, and this was true for both the volumetric and non-volumetric techniques on the ProteusPLUS proton system with a PBS dedicated nozzle.

## 6. References

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