Utilizing the Bragg Peak for Proton Flash Radiation

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INTRODUCTION

FLASH radiation therapy is of great interest recently due to the potential to increase the therapeutic index by decreasing normal tissue toxicity but maintaining the tumor response. FLASH radiation therapy involves ultra-high dose rates, typically exceeding 40 Gy/s. Prior studies have involved investigation of FLASH electron therapy *in vivo* studies, showing promising results [1]. Proton FLASH has also shown to decrease acute cell loss and late fibrosis in whole abdomen irradiation compared to standard dose rate proton irradiation with dose rates of 1 Gy/s [2]. However, previous studies with proton FLASH used the entrance region of the depth dose curve. This is study is the first to create a usable spread out Bragg peak for FLASH irradiation of mouse whole abdomen. Use of the Bragg peak for proton FLASH radiation will further enhance the normal tissue sparing capabilities by incorporating the spatial advantage of proton physical characteristics.

AIM

- To create a custom ridge filter to be used with a fixed proton beam line
- To verify the resulting spread out Bragg peak characteristics suited for *in vivo* mouse whole abdomen irradiation
- To verify feasibility of FLASH irradiation using a spread out Bragg peak

METHOD

- IBA Proteus Plus C230 cyclotron is used to deliver FLASH proton beams into the research room
- Research room is equipped with small animal radiation research platform (SARRP) with conebeam imaging capabilities [3]
- Custom ridge filter (RF) was created using a 3D printer (Qidi Tech X-max) to create a spread out Bragg peak (SOBP)
- IBA Zebra multi-layer ionization chamber was used to verify generation of SOBP
- Gafchromic film is used to verify resulting field profile suited for irradiation of mouse whole abdomen
- Dose and dose rate is measured according to the IAEA TRS-398 protocol and using a NIST-traceable calibrated Advanced Markus chamber (PTW Frieberg)
- Custom mouse holder with range shifter was used to irradiate mouse whole abdomen with the SOBP

RESULTS

- The double scattered system was used to create a flat uniform field profile at the isocenter (Fig. 1)
- A 3D printed ridge filter (Fig. 2) was placed between the first and second scatterer in the proton beam line
- Positioning of the ridge filter was optimized to create an SOBP with a width of 2.83 cm from the proximal to distal 90% dose level
- A maximum dose rate of 130 Gy/s was achieved at the middle of the SOBP
- Standard dose rate of 0.5 Gy/s was achieved by changing only the cyclotron output beam current; all other irradiation settings and beam line materials were consistent with the FLASH settings
- The final beam collimating aperture was placed closest to the mouse to have minimal air gap to reduce in-air scattering and lateral spread of the beam

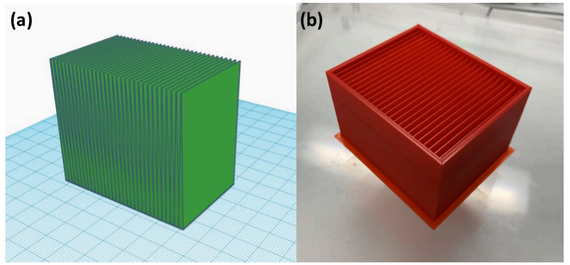

Figure 2: (a) 3D rendering of the ridge filter. Each ridge has a triangular shape with the wide portion having a width of 2 mm and a height of 5 cm. (b) A photo of the resulting 3D printed ridge filter. A case was built around the ridges to ensure that the filter is mechanically sound.

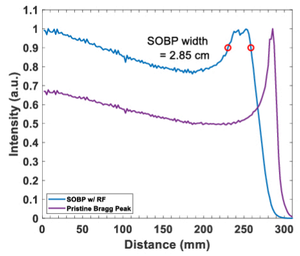

Figure 3: Depth dose curve measured from a multi-layer ionization chamber of the pristine Bragg peak of a 230 MeV (range ~32 g/cm^2) double scattered proton beam (purple) compared to the SOBP generated with the ridge filter (blue). The SOBP has a flat region (from the proximal to distal 90% dose level) of 2.85 cm, which is large enough to fit a mouse whole abdomen.

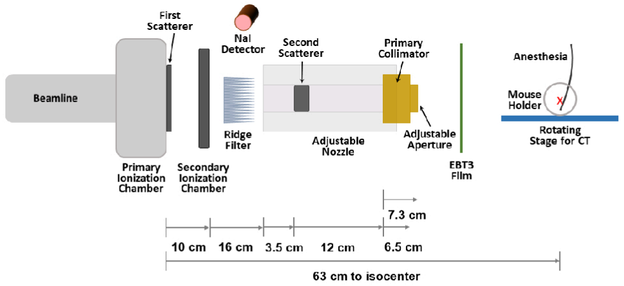

Figure 1: Schematic diagram of proton beam line with the distances between components. Range shifting material is placed after the second scatterer and before the last adjustable aperture. The aperture is placed closest to the mouse to minimize the air gap to reduce in-air scattering and lateral spread of the beam.

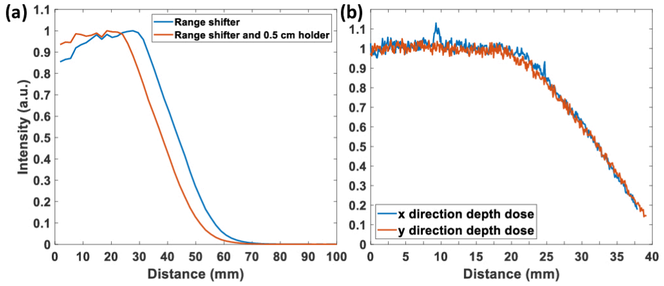

Figure 4: (a) Depth dose curve measured with the multi-layer ionization chamber with the range shifters in place. The 0.5 cm holder was to hold the mouse in place. The red line is representative of how the dose was deposited along the beam direction inside the mouse. (b) Depth dose curves were obtained in both the x- and y-directions using Gafchromic film. The film measurements agreed with ion chamber measurements. Film was placed at an angle along the beam direction and then corrected so that the film would not affect the depth dose characteristics.

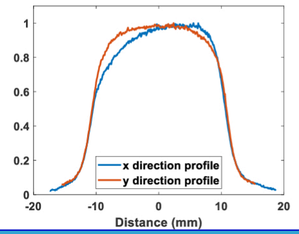

Figure 5: Beam profiles determined using film in the x- and y-direction (blue and red, respectively) for the resulting 20 x 20 mm^2 beam used for irradiation of mouse whole abdomen. Field uniformity is adjusted by changing the location and material of the second scatterer.

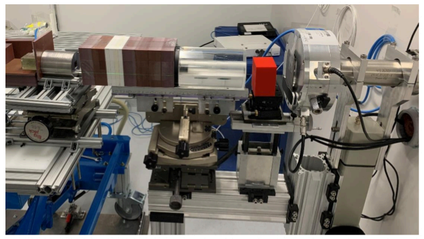

Figure 6: Photo of beam line with range shifting material and ridge filter. A custom QA device [3] is shown in the photo. This was used to place film in the spread out Bragg peak

CONCLUSIONS

- A ridge filter was designed and tested to create a spread out Bragg peak with a width of 2.85 cm, suitable for irradiation of mouse whole abdomen
- A uniform field of 20 x 20 mm^2 was created at the middle of the SOBP with a maximum dose rate of 132 Gy/s under FLASH conditions and 0.5 Gy/s under standard dose rate conditions
- The only changes to the experimental set up between FLASH and standard irradiations were to the cyclotron output beam current
- Depth dose characteristics were verified for the SOBP with the appropriate range shifters with both a multi-layer ionization chamber and film
- Future ridge filters will be optimized using simulation data so that the losses in the material are minimized, resulting in higher dose rates

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REFERENCES

[1] Favaudon V, Caplier L, Monceau V, et al., *Sci Transl Med* 2014
[2] Diffenderfer, E.S., Verginadis, I, Kim, MM, et al., *IJROBP* 2020
[3] Kim MM, Irmen P, et al., *Phys Med Biol* 2019

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