Abstract

Positron Emission Tomography (PET) of a polymethylmethacrylate (PMMA) phantom via isotope activation from a proton therapy beam is investigated. The distal edge of the activity is characterized by slope determination and curve fitting. Single energy pristine proton beams are compared to spread out Bragg peak (SOBP) composite beams. For the pristine beams, the distal activity fall off is fit well by a linear curve: $R^2$ (Pierson Product) values of 0.9968, 0.9955 and 0.9909 were extracted for 13.5, 17.0 and 21 cm²/g range respectively.

Introduction

The main utility of a proton therapy beam lies in the steep fall off of the distal edge of the radiation distribution due to the Bragg Peak. This characteristic allows for sparing of an organ at risk (OAR) located beyond distal edge of the proton beam. One method of quantifying the radiation distribution is via PET imaging of the position isotope created by the beam in the tissue. It has been suggested that the information obtained from such an image can be used clinically to confirm the accuracy of radiation dose delivery.

Methods and Materials

A PMMA phantom was irradiated with a proton beam at the Hampton University Proton Therapy Institute (HUPTI). The irradiation volume was approximated by a right circular cylinder of diameter 7.0cm and varying lengths. The phantom dimensions were 30x30x10cm. Fig. 1 shows the irradiation geometry setup (left) and the treatment plan using Varian Eclipse (right). After irradiation, scanning commenced in less than 10 minutes via a Philips Big Bore Gemini® PET-CT. Fig. 2 shows the curve irradiation and scan. The DICOM images were imported to the Varian Eclipse Treatment Planning System (TPS) for analysis along with ImageJ®. The pixel dimensions were 2x2mm and the slice thickness was 2mm resulting in a voxel size of 2x2x2mm³. There were two types of proton beam scans: Pristine mono-energetic and Spread Out Bragg Peak (SOBP). The SOBP was achieved via range modulation and passive uniform scanning. For both pristine and SOBP beams, three different ranges were used: 13.5, 17.0 and 21.0cm. For pristine beams, these ranges corresponded to energies of 110.50, 140.43 and 161.20 MeV respectively. The distal and proximal slopes were extracted by fitting a linear curve to the data from the 20% to 80% values. The goodness of the fit was determined via $R^2$ (Pierson Product) least squares fit.

Results

Induced PET signal Proximal Edge: Figure 3 shows the PET signal intensity versus the CT slice number in the PMMA phantom irradiated with a pristine (red curve) and a 10 cm²/g modulated (blue curve) proton beam of 13.5 cm²/g range. PET activity profiles were characterized by the proximal edge and distal falloff. The slope of the proximal edge for both (pristine and modulated) curves are similar. The slope of proximal edge of PET signal induced by three different proton energies (ranges: 13.5, 17.0, and 21 cm²/g, respectively) were: -0.735 (average PMMA PET pixel intensity/slice number) ± 0.06 (standard deviation) and -1.149 ± 0.117 for the pristine and SOBP beams respectively.

Induced PET signal Distal Falloff: The distal falloff of induced PET signal by a pristine and modulated proton beams are showing a discrepancy, with the pristine data trending a significantly sharper falloff. The slope of the SOBP curve was 0.232/average PMMA PET pixel intensity/slice no.) with an $R^2 = 0.9303$. The slope of the pristine curve was greater than a factor of 4 more steep and significantly more linear: 1.0210/average PMMA PET pixel intensity/slice no.), $R^2 = 0.9968$.

Figure 1: Left: Geometrical representation of the irradiation setup. Right: Treatment Planning using Varian Eclipse TPS.

Discussion

The slopes of the distal falloff of induced PET signal by a pristine and SOBP proton beams, respectively, are displayed in Table 1. As can be seen here, the pristine peaks have significantly higher slopes, and are substantially more linear (higher $R^2$). The higher $R^2$ of the pristine curves allows for a more meaningful comparison of the different ranges. Figure 4 shows the distal slope plotted as a function of range. As can be seen, the lower values have more sharp fall offs. It is thought that the shorter ranges leads to less scattering which results in steeper slopes for the lower ranges. The difference between the SOBP and pristine curves is believed to lie in part due to the different isotopes that are responsible for the positrons being emitted. The 1/13 of $^{18}O$ is 122 seconds, so that an amount of the activity can be attributed to this isotope. Figure 5 shows a benchmark Monte Carlo® 240 second simulation of two coaxial cylindrical phantoms containing a line source of $^{18}F$ and $^{18}O$. The initial activity of both sources is 100,000 Bq. The 1/13 life obtained from fitting the histogram of $^{18}O$ events (122.22s) is within 0.01% of the nominal value.

Conclusion

The activity created in a PMMA phantom as a result of irradiation by pristine and SOBP proton therapy beams has been quantified via PET imaging. The differences between the curves can likely be explained in part by the difference in isotope constituency. Efforts are ongoing to better understand this difference via Monte Carlo simulation.

References

3. See http://www.openpetecollaboration.org