

Analysis of Beam Characteristics by Filter Design using Monte Carlo Simulation

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1. Introduction

Charged Particle Therapy (CPT) or hadron therapy is one of external beam therapy to treat tumor. Charged particles are accelerated to approximately 70% of the speed of light and applied to patients in order to treat cancer within the body. Hadron therapy allows the tumors to be treated with non-invasive procedures such as surgery. To conduct hadron therapy, it is important to deliver energy precisely to cancer cells. For this reason, Monte Carlo (MC) simulations is a necessary process in hadron therapy.

Hadron composed of heavy ion such as proton, neutron, helium, carbon, neon etc. Application of He ions provides a distinct clinical advantage. First, dose distributions with attributes such as a sharper Bragg peak and lateral penumbra (reduced range straggling and scattering) compared to protons, and similar potential for tumor control with a substantially reduced fragmentation tail compared to carbon ions. [5].

In order to use low energy helium ion in hadron therapy and to achieve an acceptable homogeneity of the Spread Out Bragg Peak (SOBP) either the peak positions along the beam have to be quite close to each other or longitudinal peak shape needs to be broadened at least few millimeters by means of a properly designed filter [1].

In this study, we calculate depth-dose distribution for hadron therapy using the MC code, TOPAS [2]. To compare the Bragg peak in depth-dose distribution along filter design, we make different shape, thickness filter design in TOPAS.

2. Methods

2.1 Monte Carlo simulation

Tool for Particle Simulation (TOPAS) is the MC simulation dedicated to proton therapy. TOPAS was developed to use database and physical models in GEANT-4, which is the general radiation MC simulation developed for nuclear and particle physics as well [2].

The water phantom is placed center with 200 mm x 200 mm x 200 mm size and helium beam is irradiated at a distance of 6 m from water phantom. The filter is placed in front of the water phantom as a distance of 300 mm from the water phantom. The entire assembly geometry was imported to TOPAS geometry same as Figure 1.

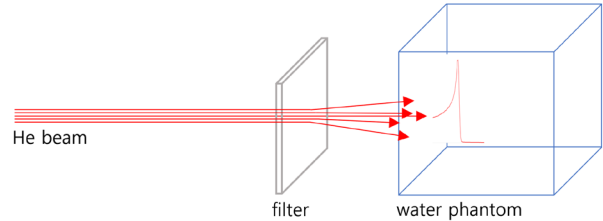


Fig. 1. Schematic view of water phantom, beam and filter geometry.

Before simulations, we calculated result of depth dose distributions for helium beam with 10 MeV steps and energy range 160-690 MeV in the water phantom are shown in Figure 2. It shows that how deep Bragg peak is in simulation environment conditions I made. As the penetration depth deeper, maximum deposited energy of Bragg peak is lower and Bragg peak width is wider.

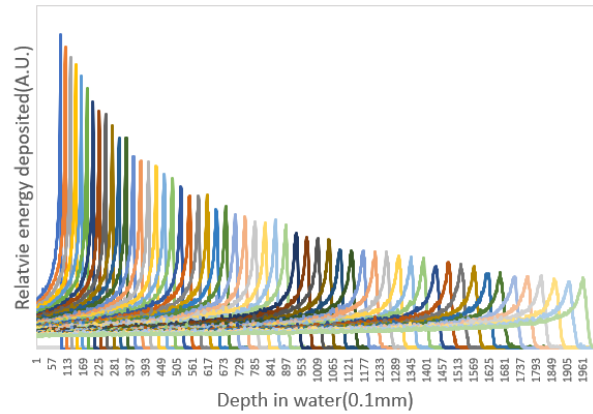


Fig. 2. Pristine depth dose distributions in water phantom for helium beam with energy range 160-690 MeV.

2.2 Filter design modeling

A certain amount of beam energy spread is need to uniformly give energy to the tumor. One of the methods to make beam energy spread is to penetrate the filter. Filter in our simulation, consisting of lung substitute material Gammex LN300, is used. Default geometry, filter has 260 mm x 260 mm x 2 mm size. To comparison of Bragg peak change, we set up with two type of filter shape, with ripple shape and without ripple shape, and two type of thickness, 2 mm 3 mm. The ripple shape filter of 3mm just change height of the triangular structure to 2.6mm.

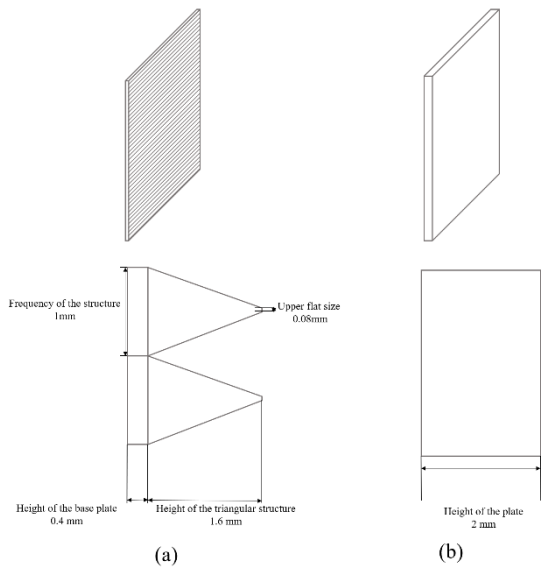


Fig. 3. Schematic view of filter (a) with ripple shape and (b) without ripple shape.

2.3 Spread Out Bragg Peak (SOBP)

One of the main aims is to have a full irradiation coverage of the tumor volume. It longitudinally generates a Spread Out Bragg Peak (SOBP) that deposits the delivered dose in the treatment volume. SOBP is achieved by superimposing different beams with slightly different energies and weights [4]. We made SOBP assuming an environment that evenly transfers energy to 3 cm tumor at a depth of 6 cm.

3. Result

3.1 Depth-dose distribution curves along filter design

In Figure 4, according to the thickness of without ripple shape filter thicker, the depth of the Bragg peak decreases 0.5 mm and 0.8 mm. Bragg peak width (BPW₈₀) of without ripple shape filter is 2% and 5% wider than the pristine Bragg peak. Bragg peak height of the without ripple shape decreases 3.8% and 1.9%. These Bragg peak properties result of placing the without ripple shape filter of 2mm and 3mm front of the water phantom is because of coulomb scattering.

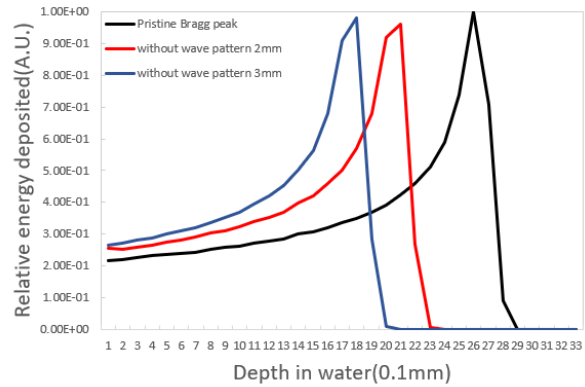


Fig. 4. Comparison with the pristine Bragg peak and without ripple shape filter. These filters thickness is 2 mm, 3 mm respectively.

All simulation conditions were identical, we just change from without ripple shape to with ripple shape filter. In Figure 5, according to the thickness of with ripple shape filter thicker, the depth of Bragg peak decreases 0.4 mm and 0.7 mm, similar as without ripple shape filter. But, Bragg peak width (BPW₈₀) of with ripple shape filter is 199%, 684% wider than pristine Bragg peak. The Bragg peak height of with ripple shape filter decreases 30.6% and 43.5%. These Bragg peak properties result of placing the with ripple shape filter of 2 mm and 3 mm in front of the water phantom is because of multiple scattering coulomb scattering.

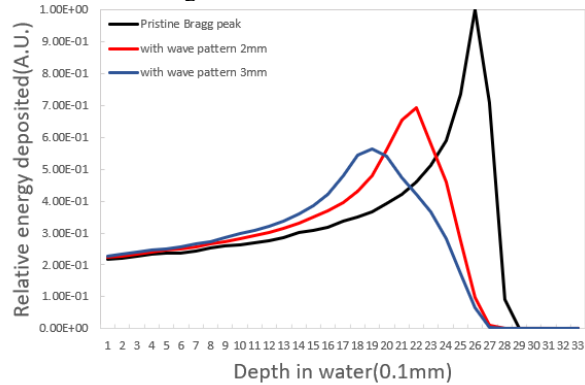


Fig. 5. Comparison with the pristine Bragg peak and with ripple shape filter. These filters thickness is 2mm, 3mm respectively.

3.2 Spread out Bragg peak homogeneity

Figure 6 shows that each SOBP made by using a step of 3.7 mm the Bragg peak and gave different weights. SOBP deviation of without ripple shape filter (Blue) has $\pm 29.39\%$. But, SOBP deviation of with ripple shape filter (red) has $\pm 0.31\%$. This result show that SOBP plateau of with ripple shape filter has more homogeneous than the other.

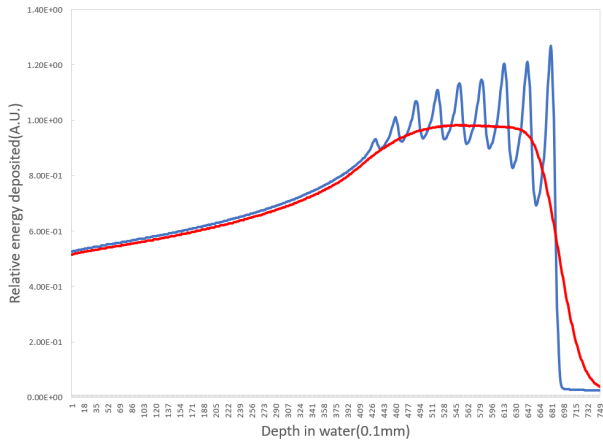


Fig. 6. Influence of ripple shape filter on SOBP homogeneity and distal fall-off for He beam

4. Conclusion

In this study, we analyzed of beam characteristic by filter design. Multiple scattering occurs due to ripple shape, which result in beam energy spread. This result of ripple shape changes dramatically Bragg peak height, width. And filter thickness thicker, multiple scattering more occur. According to this beam energy spread, the homogeneity of SOBP increases, which can give tumor uniform dose. The ripple shape filter proposed is vital part of the beam modeling system for active beam scanning with synchrotron accelerators and filter need to more optimization. In Further study, we optimize the filter thickness and distance of filter from water phantom to get more homogeneous SOBP.

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