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Magnetically Focused Proton Irradiation of Small Volume Radiosurgery Targets Using a Triplet of Quadrupole Magnets

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INTRODUCTION

Proton therapy is an advantageous choice for the irradiation of tumors in proximity of critical structures due to rapid dose fall off and high dose deposition at target compared to dose at the surface of the patient (ie, peak-to-entrance dose ratio (P/E)). However, with target fields below 1.0 cm, as often encountered in proton radiosurgery, multiple Coulomb scattering (MCS) broadens proton beams leading to diminished P/E advantages and reduced dose delivery efficiency (DDE). Magnetic focusing tends to counteract MCS and is a promising method to reduce these undesirable effects. The purpose of this research is to investigate the advantages of proton magnetic focusing with a triplet of quadrupole rare earth permanent magnets.

MATERIAL AND METHODS

Monte Carlo simulations of 127 MeV protons were performed using a model of the Gantry 1 clinical beam line at James M Slater MD Proton Treatment and Research Center (JMSPTRC). Dose deposition of proton beams transported through a triplet of quadrupole magnets was compared to that of beams without magnetic focusing. Four triplet sets of magnets were used, each with a different magnetic field gradient (which determines focusing strength). Initial beam diameters were 5, 6, 8, 12, 15, 18, and 20 mm for both focused (MF3) and unfocused (UNF) beams. Optimized simulation parameters were used as a basis for proton experiments to evaluate the real world effectiveness of magnetic focusing.

RESULTS

Preliminary experimental results showed 10 mm UNF beams produced target sizes of 4.2 mm diameter that were comparable to 12, 15 and 18 mm MF3 beam target sizes. However, the P/E ratios and DDE for the MF3 beams were 11.2 – 33.5% larger and up to 2.2x greater depending on the strength of the focusing magnet used. Similarly, 8 mm UNF beams produced target diameters of 3.3 mm comparable to targets of 20 mm MF3 beams with P/E ratios 67% larger and DDE 3.4x greater than the UNF beam. In addition, 6 mm UNF beams (2.7 mm target) matched 8 mm MF3 beams with P/E dose improvements of 23.7% and 1.2x gains in DDE. Finally, 5 mm UNF beams (2.5 mm target) matched 8 mm MF3 beams that were focused with a stronger magnet and showed P/E dose improvements of 66.7% and 2.2x gains in DDE.

CONCLUSION

Magnetically focused proton beams using a triplet of rare earth permanent quadrupole magnets showed improvements of P/E dose ratios and DDEs compared to unfocussed beams. Clinically, such improvements could reduce radiation damage to normal tissue and deliver enhanced dose to the target in less time compared to unfocussed collimated beams (the current standard of practice in radiosurgery). The potential benefits to the patient are reduced treatment times, less

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target motion during treatment and reduced dose to surrounding "normal" tissue.