Detection and analysis of scattered protons for verification of FLASH lung tumor proton therapy

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Introduction

Ultra-high dose rate (FLASH) proton therapy (PT) delivers a high dose of protons in a fraction of a second, lowering the normal tissue toxicity. The plateau region of the proton beam might be used as a shoot-through technique. Available proton beam energies at medical centers allows for lung cancer irradiation, which will stop the Bragg peak outside the patient. Protons will be scattered in various directions from the tumor due to large-angle scattering. The surrounding low-density lung tissue will produce less scattering, thus the high-density materials can be visible during measurement.

Charged particles exiting the patient during therapy might be used to determine the beam range in the patient. That can be achieved with a method called interaction vertex imaging (IVI). The basis of the method is to reconstruct the trajectories of the scattered charged particles and find the point of creation (vertex) [1]. The production of scattered particles can also give an information about the position of high-density anatomical structures on the beam path, which can be useful for lung cancer therapy. The purpose of this work was to test a new idea of verifying FLASH proton therapy by analyzing scattered protons from tissue-equivalent plastics.

Methods

We collected the experimental data at the Northwestern Medicine Chicago Proton Center (NMCPC). We placed 4-cm long, 1.9-cm diameter cylindrical tissue-equivalent inserts of various density into a Styrofoam holder (Figure 1) and irradiated them with a stationary proton pencil beam with energies ranging 40 MeV to 220 MeV. The two-plane tracking detector of a preclinical proton CT scanner [2] detected scattered protons at a rate of about 1 million particles per second. The energy detector of the scanner provided the trigger signal for data acquisition.

We back-projected the registered particle tracks onto the plane containing the beam axis. The profile of the signal was then analyzed and compared to the output from a TOPAS simulation.

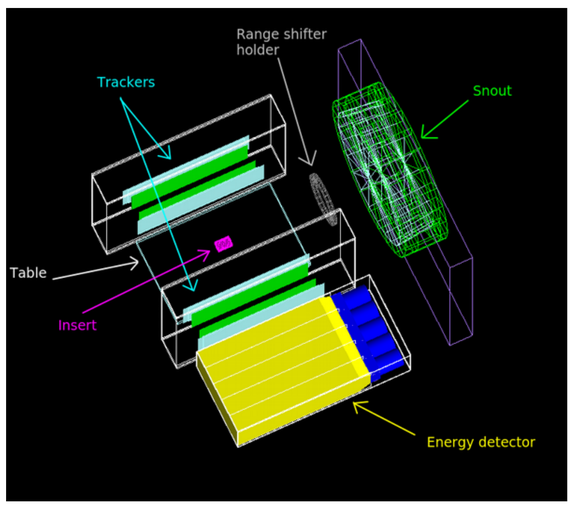

Figure 1. Scheme of experimental setup implemented in TOPAS.

Experimental conditions and beam model parametrization

The NMCPC has a 230 MeV IBA cyclotron and four treatment rooms: two inclined-beam rooms, one fixed beam room and one 360 gantry room. The experiment was conducted in the fixed-beam room (see Figure 2). To define the beam parameters for the MC simulations commissioning data and additional measurements were used.

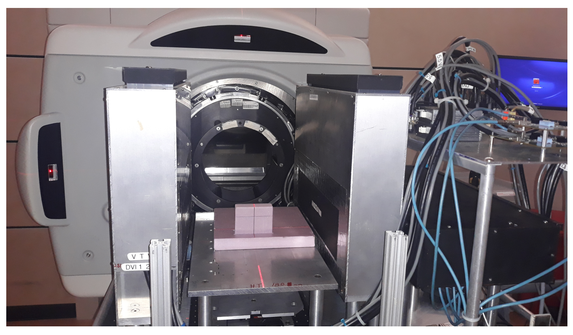

Figure 2. Experimental setup.

The lateral beam size was measured at isocenter with Lynx detector and the virtual source distance (VSD) was estimated based on lateral beam size at different distance from the beam nozzle. The agreement of the beam size between measurements and simulations was of the order of 3%. The dosimetric calibration was performed using the IBA Matrix PT in solid water and was cross-calibrated with the IBA PPC05 chamber in a water tank for absolute dose. The absolute dose measurements agreed with the TOPAS simulation within 0.17%.

Results

Figures 3 and 4 shows the back-projected profile of the protons along the beam axis scattered from a tissue-equivalent inserts: spinal cord (1.07 cc/g) and cortical bone (1.75 cc/g). The protons had a nominal energy of 140 MeV and 200 MeV for spinal cord and cortical bone, respectively. The profiles show the position and size of the insert with millimeter accuracy. Both results from measurements and simulation of T profile (Figure 3 and 4, first column) reflects the size of insert of 4 cm. The FWHM of lateral profiles (V profile, Figure 3 and 4, second column) were 22.7 mm and 18.4 mm for spinal cord and 16.7 mm and 15.1 mm for cortical bone fitted from measurements and simulation, respectively.

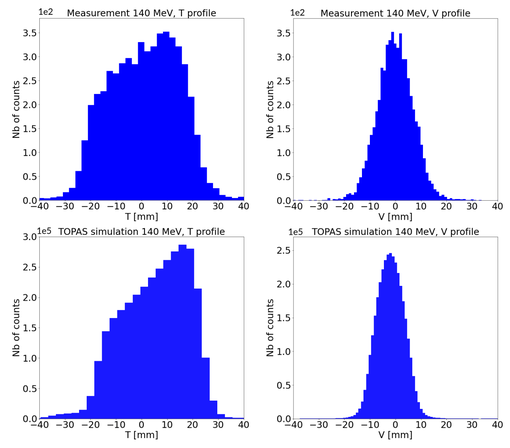

Figure 3. The back-projected profiles of spinal disc insert from measurement (upper row) and simulation (lower row).

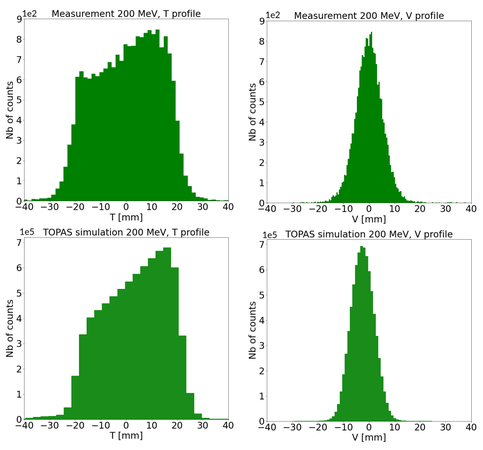

Figure 4. The back-projected profiles of cortical bone insert from measurement (upper row) and simulation (lower row).

Conclusions and Future Work

This study shows that the profiles of backprojected scattered protons may be used to monitor the position and size of tumors surrounded by low-density material during high-dose-rate delivery of protons. This technique appears suitable for intra-treatment monitoring of FLASH radiation therapy of lung tumors with shoot-through beams. The MC simulations with a well-defined patient geometry and beam model could be used to predict the expected beam scattered proton profile during the treatment and would form the basis for verification. Further experiments will include setups with lung motion phantoms and comparison with refined TOPAS simulations.

Bibliography

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Acknowledgments

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