PhD Thesis Title: Assessment of Magnetic Field Effect in MRI-guided Carbon Ion Radiotherapy Using Monte Carlo Method

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ABSTRACT:

Nowadays, there are many interests in applying magnetic resonance imaging (MRI) –guidance for radiotherapy (RT). On the other hand, carbon-ion (C-ion) RT needs to be equipped with a more accurate image-guided system due to its high sensitivity to geometric uncertainties. The idea of applying MRI guidance in C-ion therapy involves challenges such as dose distortion in the patient. For this purpose, this research was conducted in 3 steps. In the first step, the impact of the magnetic field inside a homogeneous water phantom on the total dose, dose equivalent and fluence profiles of C-ion beams in therapeutic energies were calculated. Moreover, the impact of the presence of tissue heterogeneities and geometric changes of heterogeneity layers on the magnitude of dose disturbances and deviation of C-ion beams were investigated. In the next step, the impact of anatomical changes on the radiation dose variation of the prostate and bladder was calculated for a potential scenario of MR-guided C-ion RT of prostate cancer (MRgCT). In the last step, to evaluate the water equivalency of possible materials used in C-ion dosimetry in both scenarios of presence and absence of the magnetic field, the water equivalent ratio (WER) index was calculated. To achieve these goals, the water equivalent beamline of the Heidelberg hospital, Germany, where its technical data was available, was simulated using the FLUKA Monte Carlo code. The impact of 0.5, 1.5 and 3 Tesla (T) perpendicular magnetic fields applied to a homogeneous water phantom on a total dose, dose equivalent, and fluence profiles of C-ion beams at therapeutic energies of 100, 220 and 310 MeV/nucleon (MeV/n), were obtained. To investigate the effect of inhomogeneity and geometric changes of tissue layers, a multi-layer tissue phantom was simulated and the effect of a 1.5 T magnetic field, at 220 MeV/n energy, was assessed. To evaluate the impact of anatomical changes on dose variation, carbon beams with 250 MeV/n energy perpendicular to a pelvic phantom including the prostate, bladder, and rectum were simulated under the influence of a 1.5 T transverse magnetic field. Besides that, water equivalent ratio values of bladder, brain, prostate, muscle, bone, PMMA, POM, PET, Ti, Au, and Pt were evaluated in the presence and absence of a 3 T magnetic field. The results of this study showed that the total dose, dose equivalent, and fluence transverse profiles centers, in the range of the studied field strength and energy, are ranging from 0 to 10.5 mm. The maximum longitudinal displacement of the Bragg peak depth influenced by a 3 T field was equal to 0.8 mm reduction. The presence of heterogeneity, in particular air, leads to a magnitude of 30% change in the central axis dose. The results of the effect of anatomical changes on dose variation showed that changing the bladder diameter from 10 to 5 cm reduces the bladder dose by 92 %. Changing the diameter of the rectum from 5 to 3 cm leads to a 20 and 26 % reduction in prostate and bladder dose, respectively. The WER value does not change importantly with magnetic field application. In summary, the effect of a magnetic field on carbon beams depends on the strength of the magnetic field applied to the transport medium, the beam energy, the arrangement of the heterogeneous layers through the beam path, and the size and location of the heterogeneity medium.

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