Dose Quantification in Carbon Therapy using In-Beam Positron Emission Tomography

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Carbon therapy is a form of heavy ion therapy which uses a beam of accelerated ^{12}C ions to precisely deliver a therapeutic radiation dose to a target [1]. During carbon therapy, nuclear inelastic collisions between primary ions and target nuclei produce a range of fragments along the beam path, some of which are radioactive and decay via positron emission after their creation [1]. Positron Emission Tomography (PET) can be used to obtain the spatio-temporal distribution of positron annihilations in the target. Currently, most image-based quality assurance methods in carbon therapy compare the observed PET images to an expected activity distribution obtained from Monte Carlo simulations [2]. Direct quantification of the delivered dose from observation of the spatial distribution of positron-emitting fragments is difficult due to the complex physics of energy deposition and inelastic collisions [2]. In this study, a method for non-invasive *in-vivo* quantification of the dose distribution resulting from a poly-energetic ^{12}C beam is investigated in one dimension. A relationship between observed positron annihilations and the delivered dose was developed based on the observation that the spatial distribution of each positron-emitting fragment species is unique for each primary beam energy and target material. Linear independence of generated fragment distribution profiles with respect to beam energy between each of three homogeneous phantoms, and with respect to the phantom type for each energy, were established for experimental and Monte Carlo simulation data using cross-correlation and singular value decomposition. Fragment profiles produced by monoenergetic beams with a range of primary beam energies and target phantoms were used to perform factor analysis on activity profiles obtained following the delivery of a randomly-weighted poly-energetic beam, to estimate the proportional contribution of each energy. The calculated set of weighting factors describing the proportional contribution of each energy to the beam were found to be within 6% of ground truth, and subsequently the dose was estimated in the entrance, spread-out Bragg peak and dose tail regions to within 4% of the ground truth value.

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