Abstract

Department of Medical Physics

Towards dynamic collimation in pencil beam scanning proton radiotherapy

Blake R. Smith

Dynamically collimated proton therapy is currently a theoretical treatment modality that utilizes a beamlet- and energy-specific aperture to collimate the intended flux of protons delivered during pencil beam scanning proton therapy. This work focuses on the development of this novel treatment modality and characterizing the resulting primary and secondary radiations using both measurement techniques and Monte Carlo calculation methods. The integration of an experimental prototype is demonstrated with a commercial pencil beam scanning dose delivery system.

The first part of this work is dedicated to the theoretical development and application of mathematical optimization methods within a research-based treatment planning system. A new spot scanning delivery technique is proposed to maximize the achievable target conformity and reduce the total delivery time dominated by the sequencing of the collimating components during treatment to less than a minute per treatment field. Errors in the delivery of a treatment were simulated in order to evaluate the sensitivity of the idealized treatment plans. The plans were most susceptible to target under-dosing dominated by a steep changes in fluence from the peripheral beam spots. However, these effects could be mitigated by applying a minimum collimator offset from a collimated beamlet.

An experimental dynamic collimation system prototype was designed and manufactured in-house. A delivery framework was created to integrate the prototype system into a clinical pencil beam scanning proton therapy dose delivery system. Experimental measurements of collimated proton beamlets were acquired to benchmark the Monte Carlo

calculation models of the primary proton beamline and prototype collimator in addition to the Monte Carlo radiation transport physics.

Proton dosimetry was carried out using ionization chambers and two-dimensional dosimeters including film and scintillation plates. Prior to the experimental characterization of asymmetric beamlet models using Monte Carlo methods, extensive dosimeter response characterization was performed. Range-equivalent thicknesses, dose response, and linear energy transfer saturation effects within clinical proton beam qualities were studied.

Monte Carlo simulations of composite treatment plans were performed to study primary and secondary radiation effects. Secondary neutron generation and patient doses were estimated and cross compared with similar studies published on the secondary neutron production from uniform scanning treatments with brass apertures. Estimates of radioactive isotope production were compared to exposure measurements while experimentally characterizing the asymmetric proton beamlets from the prototype. Finally, treatment planning differences were evaluated from the impact of using a non-focused collimator.

This work builds upon the existing literature of treatment planning and delivery techniques unique to a dynamic collimation system and serves as an initial benchmark and investigation into dynamic collimators in proton therapy. Proof-of-principle integration of an experimental prototype is demonstrated along with an experimental benchmark for the development and application of Monte Carlo calculation methods in MCNP6 and Geant4-based Monte Carlo codes. Future work may include the development of a clinical prototype and integration of Monte Carlo methods within a clinical treatment planning system.