Development of a Monte Carlo Simulation for the Measurement of Microdosimetric Spectra in Proton Beam Spread out Bragg peaks

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The purpose of this study was to develop and verify a Monte Carlo simulation of the microdosimetric spectra of the spread out Bragg peak (SOBP) for clinical modulated proton beams using Geant4 with the TOPAS Monte Carlo toolkit. Since the overall biological impact of radiation on tissue is dependent on radiation track structure at cellular length scales, an understanding of the full energy deposit spectra of clinical proton beams at different energies and depths at the micron scale is necessary to understand the true impact of radiation on different irradiated tissue sites. A simulation of the physically relevant components of our tissue equivalent proportional counter (TEPC) was created and placed in the path of simulated SOBPs while TOPAS recorded individual particle energy deposits in the TEPC’s 1 μm diameter simulated volume. Comparing our simulation to the range 3.0 cm modulation 1.5 cm (R3M1.5) SOBP spectra published by Rollet et. al. [1], we verified that the overall behavior of our simulation was in line with known data. In further data collected with R3M1.5 and R25M10 beams, we determined that the dose distribution spectra increase in main peak lineal energy with increasing depth, increasing rapidly on the far distal edge of the SOBP. This distal edge lineal energy shift is accompanied by an exponential increase in the radiation quality factor. This shift, from particle segregated spectra, was found to be due to proton shift rather than the generation of higher LET particles. From this data, we concluded that the equivalent dose of both SOBPs reaches its maximum along the far distal edge of the SOBP due a rightward shift of proton lineal energies, and so the distal fall-off region of the SOBP between about 0 and 50% relative dose is expected to experience the most biological damage.