TOPAS Monte Carlo Simulation of Microdosimetric Spectra and RBE Variation in Proton Spread Out Bragg Peaks

David Ostrowski1,2, Eric Diffenderfer2
1Department of Radiation Oncology, Perelman School of Medicine, University of Pennsylvania; 2Wake Forest University

Proton therapy has become popular due to its macroscopic dose deposition properties despite depth-dependent variation in ionizing density. Since protons act biologically on a microscopic scale, understanding this radiation quality fluctuation on a micron scale may allow physical prediction of biological effect. It has been demonstrated experimentally using Tissue Equivalent Proportional Counters (TEPCs) that microdosimetric lineal energy distributions can predict relative biological effect (RBE) using the modified Microdosimetric Kinetic Model (MKM). The purpose of this study was to develop a Monte Carlo simulation of a TEPC in spread-out Bragg peak (SOBP) using the TOPAS-Geant4 framework to computationally determine lineal energy distributions and RBE as functions of depth. An experimental TEPC simulating a 1 µm diameter interaction site was constructed in a water phantom using TOPAS, which was extended to score individual event energy deposits in the active volume of the TEPC. For varying depths within numerically-constructed SOBPs, lineal energy distributions were determined, and RBE, and RBE-weighted dose, were calculated with the MKM using human salivary gland cell parameters. It was found that frequency-averaged, dose-averaged, and saturation-corrected mean lineal energies, and RBE, were constant in the entrance region, slowly increased in the plateau region, and rapidly increased along the distal edge of each SOBP. RBE was just below 1 in the entrance region, increased to 1.1 in the plateau, and greatly increased to over 1.3 along the distal edge. RBE-weighted dose reached a peak in the distal portion of the plateau and experienced a distal range extension of ~1 mm. This was consistent with experimental results. It was concluded that the TOPAS simulation can be used to determine the depth-dependent fluctuations of microdosimetric quantities and RBE for different SOBPs, and so could be utilized to incorporate biological weighting in proton treatment planning.

David Ostrowski is currently enrolled at Wake Forest University as a physics major. David spent his SUPERS time in the lab of Dr. Eric Diffenderfer.