Proton Relative Biological Effectiveness (RBE) Determined using a Monte Carlo DNA Damage Simulations

Purpose

Determine tissue-specific proton relative biological effectiveness (RBE) as a function of fraction size, dose-rate and position within the spread out Bragg peak (SOBP).

Methods

A general formula derived from the linear-quadratic (LQ) model is developed to determine a dose-weighted RBE for mixed radiation fields, including position-dependent mixtures of protons in the SOBP. Biologically motivated formulas with just two biological parameters (θ and θ/κ) are used to link trends in α and α/β to double strand break (DSB) induction. DSB induction for protons is determined using the Monte Carlo Damage Simulation (MCDS). Because θ and θ/κ are independent or a weak function of radiation quality, cell- and tissue-specific estimates of α and α/β for a reference radiation (e.g., x-rays or 6 MV photons) can be used to determine cell- and tissue-specific radiosensitivity parameters for protons.

Results

For constant fraction size, proton RBE increases as α/β decreases. The approach predicts that the RBE for cell survival is always greater than or equal to the RBE for DSB induction. For very low energy protons (0.1 MeV), the proton RBE ranges from 3.2 for DSB induction to 12.3 for cell survival (α/β = 1.5 Gy). Near the proximal edge of the SOBP, the predicted RBE is close to unity. In the center of the SOBP, the dose-weighted RBE ranges from about 1.13 (α/β = 10 Gy) to 1.15 (α/β = 1.5 Gy). The estimated RBE 5 mm from the Bragg peak ranges from 1.5 (α/β = 10 Gy) to 1.9 (α/β = 1.5 Gy).

Conclusion

The biologically motivated approach provides a convenient and useful formalism to help incorporate tissue-, fraction-size and position-dependent RBE information into proton therapy treatment planning.