PhD Thesis Title: Heterogeneous multiscale Monte Carlo models for radiation therapy using gold nanoparticles

Author: Martin P. Martinov
Email: martinov@physics.carleton.ca
Institution: Carleton University
Supervisor: Rowan M. Thomson
Graduation Date: December, 2019
Available Online: https://curve.carleton.ca/9cd50b37-8012-4a23-82be-51779c046ba3

ABSTRACT:

Gold NanoParticle (GNP) dose-enhanced radiation Therapy (GNPT) is a proposed radiotherapy approach which aims to improve dose localization. In complement to experimental techniques, Monte Carlo (MC) radiation transport simulations are used for GNPT dosimetry. Simulations on a tumour scale require complex geometry models that are reliable and efficient, two traits often in contention. This work introduces a general MC framework and the Heterogeneous MultiScale (HetMS) model, towards an efficient and accurate GNPT simulation. The HetMS model combines distinct geometries of varying detail on different length scales into one simulation.

The HetMS framework is implemented in the fast MC code EGSnrc. EGSnrc, with custom applications and geometries, is cross-validated with PENELOPE and Geant4-DNA MC codes. It is tested for self-consistency, passing the electron Fano cavity test. Simulations of microscopic scoring cavities containing GNPs across a centimeter-scale phantom were constructed using the HetMS method, enabling fast MC calculations of tissue dose on a tumour scale. Dose Enhancement Factors (DEFs), ratio of dose to tissue with GNPs over dose to tissue without, were determined at various tumour positions for many different GNPT scenarios.

A cell model, with nucleus and cytoplasm as two concentric spheres, containing GNPs is simulated. Less realistic but efficient modelling approaches of gold in the cell (e.g., a contiguous gold volume) are insufficient for realistic DEF calculations. The cell DEFs are sensitive to the distribution of GNPs within the cell, with the highest DEFs for nucleus and cytoplasm when GNPs are in close proximity to the nucleus. By investigating the variable cell/nucleus size and the fluctuations in gold to a target cell and 12 neighbouring cells, the expected variation in cell DEF is determined.

The above models are combined to create a more detailed GNPT simulations. The cell DEFs are calculated at many positions within a tumour-sized volume. Then, combined with the DEF variations computed previously provide a range of expected cell DEFs at each position within the tumour. These simulations provide many useful metrics towards the GNPT; e.g., the lesser DEFs expected for a cluster of cells, the depth at which the primary fluence attenuation from gold drops DEF below unity, and the feasibility of the different GNP configurations.

References to author publications that relate specifically to the dissertation:

1. **Martinov, Martin P.**, and Rowan M. Thomson. "Heterogeneous multiscale Monte Carlo simulations for gold nanoparticle radiosensitization." *Medical Physics* 44.2 (2017): 644-653. **DOI**: ttps://doi.org/10.1002/mp.12061
2. **Martinov, Martin P.**, and Rowan M. Thomson. "Technical Note: Taking EGSnrc to new lows: Development of egs++ lattice geometry and testing with microscopic geometries." *Medical Physics* 47.7 (2020): 3225-3232. **DOI**: https://doi.org/10.1002/mp.14172