A Multiscale Adult Female Breast Computational Mesh Model for External Beam and Internal Radionuclide Circulating Lymphocyte Dose

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Introduction

Radiopharmaceutical therapy (RPT) delivers radionuclides through vasculature, but the modeling of discrete organ vasculature is absent for many organs in reference mesh-type computational phantoms utilized in Monte Carlo dosimetry. To enhance the anatomical accuracy and multiscale blood capture of the adult female breast, explicit models of large vessels and capillaries are necessary to map out the modes of radiopharmaceutical delivery and localized dose.

Purpose: To construct a combined, multiscale and multi-tissue model with applications in short and long-range radiopharmaceutical dose delivery. In addition to vasculature, this model includes micro and macro-scale organ parenchyma for dosimetric coupling of different tissues for radionuclide absorbed fractions and S values.

Methodology

Morphological data for nulliparous breast components were collected and used to create a refined model of macroscale adipose and glandular breast tissue within the ICRP adult female MRCP. In addition to refined organ tissues, a sample of rat mesentery containing capillaries was imaged and segmented for conversion into a polygon mesh compatible with the Monte Carlo Particle and Heavy Ion Transport code System (PHITS). The use of this tissue sample was validated by literature of vessel counts of glandular and adipose tissue, as well as comparisons to overall capillary blood density.

The resulting blood fraction occupied by the microscale model extended throughout the adipose and glandular tissues via Monte Carlo internal reflection were used to calculate the amount of blood assigned to the breast in ICRP Publication 145 captured at the microscale, as well as the remaining blood to capture at the macroscale.

Macroscale blood was created using a Constrained Constructive Optimization (CCO) C++ vessel generating algorithm to generate venous and arterial blood. Parameters of this algorithm were tuned for 100% blood capture of Publication 145 in combination with the microvasculature. This algorithm also provides complete centerline points for circulating lymphocyte dose tracking.

Results

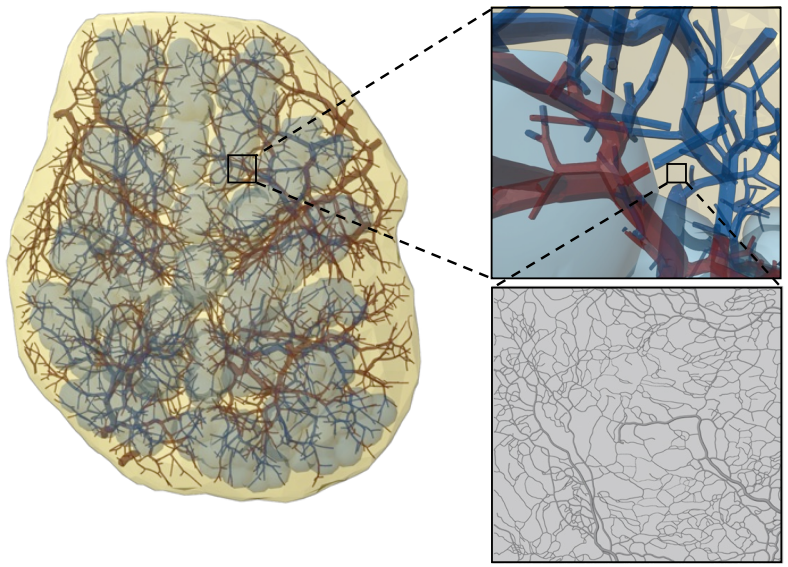

Figure 1: Whole Breast Macroscale Vascularization and Subdivision into Microscale Composite Tissue Capillary Network

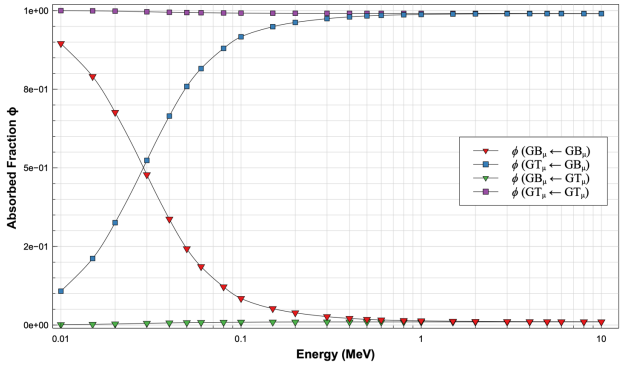

Figure 2: Microscale Electron Absorbed Fractions for Glandular Tissue Composite Tissue

Conclusions

- The first multiscale, dosimetrically-coupled 3D model of breast vasculature.
- The explicit discretization of adipose and glandular tissue components and blood.
- 100% of total blood capture at both the macroscale and capillary level.

Future Work

- Alter size and distribution of macroscale breast tissue to a sampled family of height-weight phantoms for closer agreement to patient specific model external beam dosimetry.
- Use delipidating tissue clearing methods to apply microvascular segmentation methodology on glandular tissue samples for glandular acini and ductal microvasculature.

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