Personalized Dosimetry for Treatment of Hepatic Cellular Carcinoma using Multiphysics Simulations

UC DAVIS BIOMEDICAL ENGINEERING

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Introduction

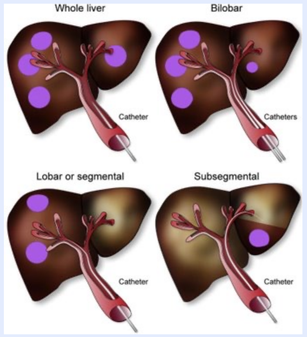

Figure 1. Illustration of the Y90 radioembolization procedure [1].

- Treating liver cancer patients with transarterial radioembolization (TARE) is increasingly used due to its minimally invasive procedure and sparing of adjacent healthy tissues from radiation exposure.
- Complex *physics-based modeling techniques with patient-specific* clinical data shows much promise to support pre- and post-treatment improvement of tumor targeting through high-precision dosimetry.

- However, radioembolization requires quick clinical decision-making at the time of the Y-90 microsphere injection, leading to challenges in implementing accurate but computationally expensive pre-treatment models.
- Models **suffer from multiple uncertainties** if assumptions are made to speed up the computation.

Methodology

- CFDose is a framework that incorporates clinical patient cone-beam Computed Tomography (CBCT) images and then applies physics-based techniques to predict microsphere transport in the patient liver vasculature using computational fluid dynamics (CFD) [2].
- Radiation dosimetry is then performed from the predicted microsphere transport using radiation physics modeling.
- We have demonstrated a proof-of-concept and compared CFDose to post-treatment Positron Emission Tomography (PET) imaging of the yttrium-90 microspheres to assess the accuracy of the predicted radiation dose distribution [3].

References and Acknowledgments

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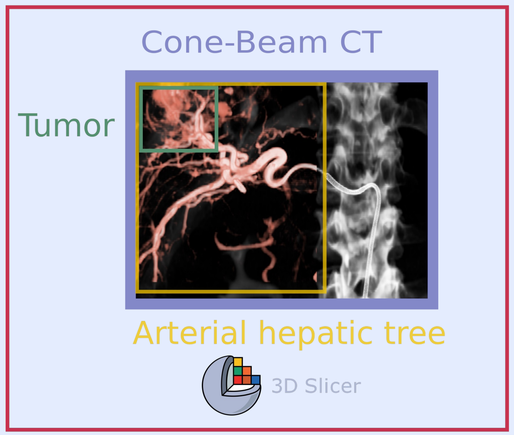
Patient Data



Each patient-specific cone-beam CT scan is processed to assess:

- **Tumor vascularization**
- **Hepatic arterial tree**

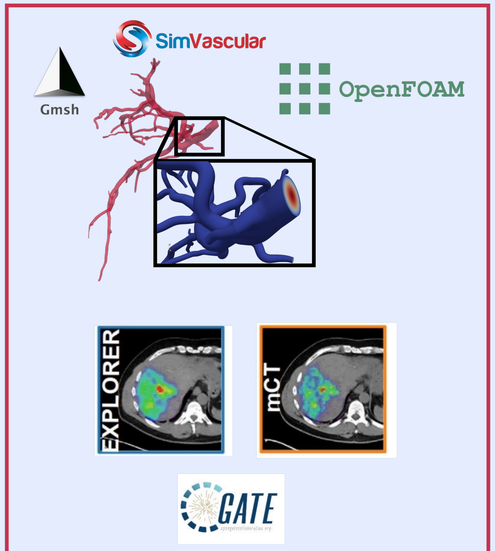
The geometry is then created in 3D slicer to prepare for CFD simulation.

MIRD Formalism

$$D = \frac{A_0[MBq]}{[m]g}$$

CFDose Framework

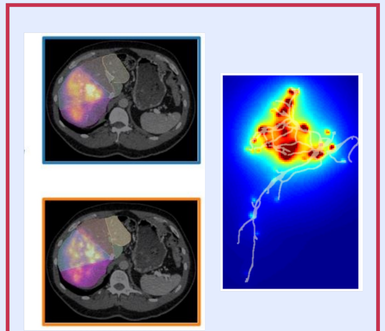
Multiphysics Simulations



CFDose allows for interchanging numerical tools to solve fluid equations.

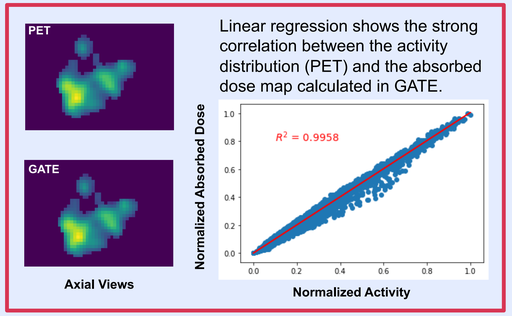
- **SimVascular** allows us to leverage the fast numerical solution techniques for laminar, incompressible flow, with a variety of boundary condition definitions
- **OpenFOAM** has extensive modular modeling libraries, including Volume of Fluid multiphase solvers and discrete phase particle models
- **Gmsh** versatile mesh generation software aids in quickly creating model domain
- **GATE** simulates particle transport inside the medium and provides voxelwise absorbed dose

Dosimetry



Energy deposition and absorbed dose calculation allow the evaluation of the therapeutic procedure.

- Pre-treatment evaluation uses CFD and dose voxel kernel convoluted to calculate absorbed dose in the desired volume
- Post-treatment evaluation uses PET/CT images as input for Monte Carlo simulations with direct calculation of absorbed dose from activity and anatomy images.



Conclusions

In this work, the accuracy of the CFD modeling is improved by parsing out the various sources of uncertainty in intra-patient geometry and microsphere transport model fidelity. These improvements could help reduce the uncertainty in patient-specific predictions of the microsphere distribution between liver segments. Moreover, the calculated absorbed with CFDose and Monte Carlo simulations showed very similar discrepancies (9.0% and 8.8%, respectively) when compared to the reference (MIRD). Due to patient scan variability, both methods could not be applied to the same patient, but these results build confidence that a close match between pre- and post-treatment evaluation can be ultimately obtained.