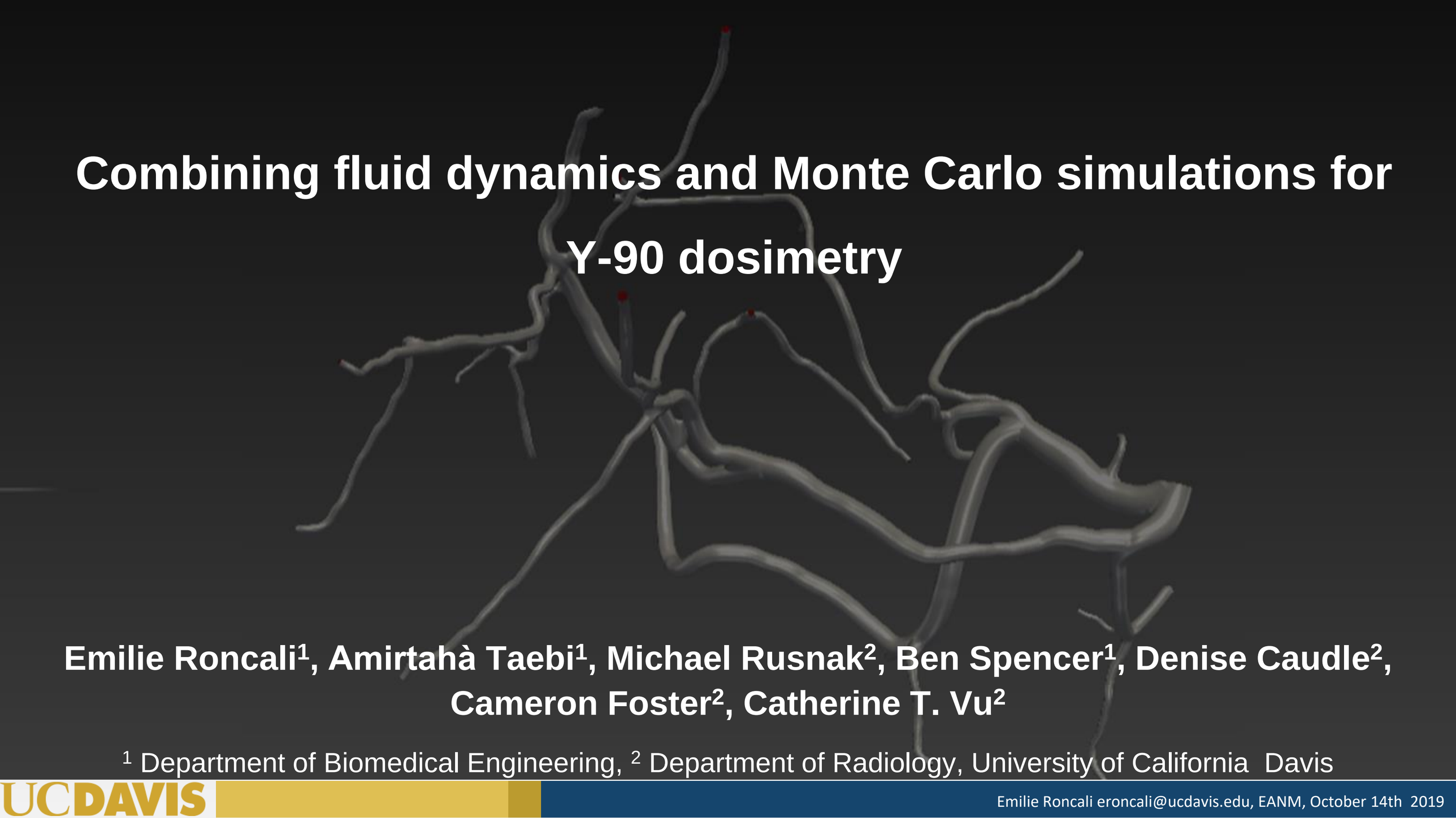
Combining fluid dynamics and Monte Carlo simulations for Y-90 dosimetry



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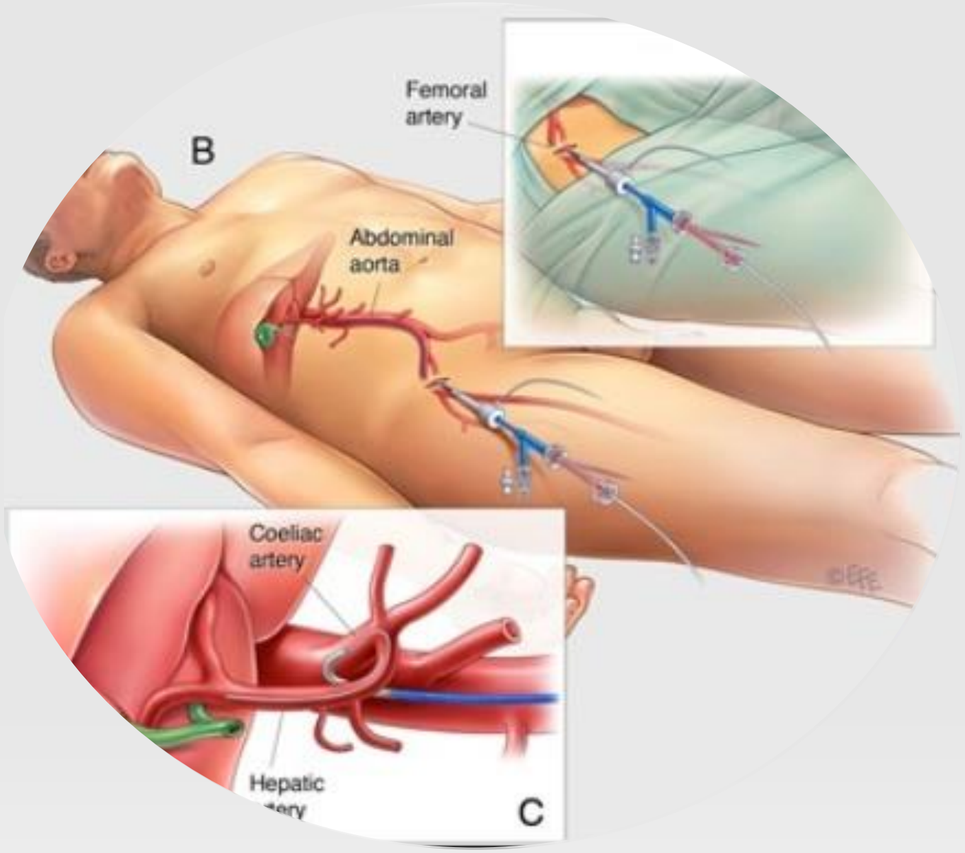
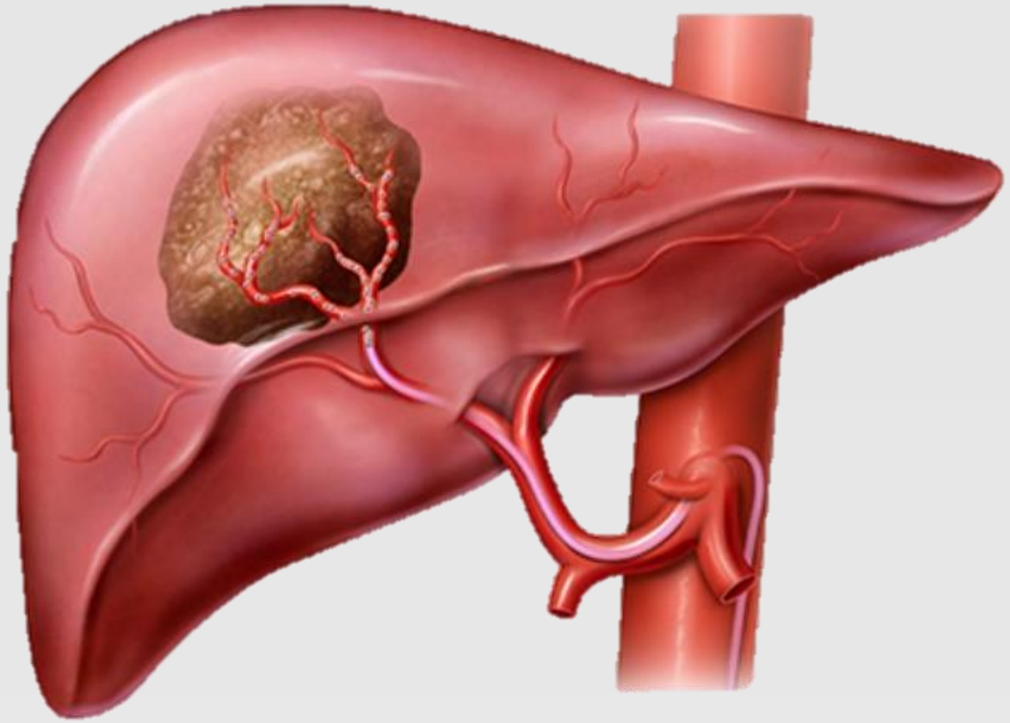
Transarterial Radioembolization (TARE)





Dose Prediction Challenges in Radioembolization

Planning

Patient referral

Y-90 physics calculation

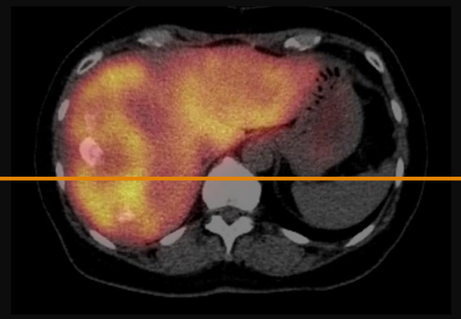
MIRD general equation

$$AD = \sum_{sources} \tilde{A}_{source} \cdot S(target \leftarrow source)$$

or

BSA for resin microspheres

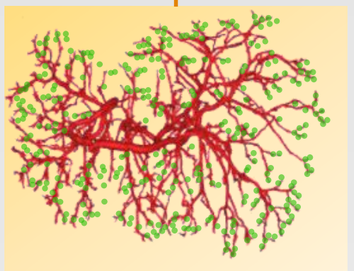
Hepatic angiogram



^{99m}Tc-MAA SPECT

Microsphere transport **simulation**

Hepatic artery **segmentation**

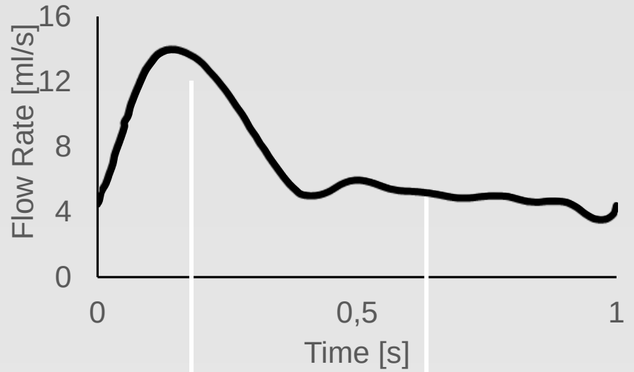


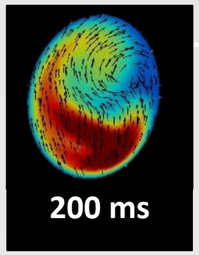
Personalized 3D dosimetry with Fluid Dynamics

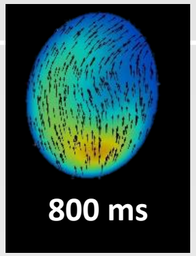
Segmentation and CFD Simulation

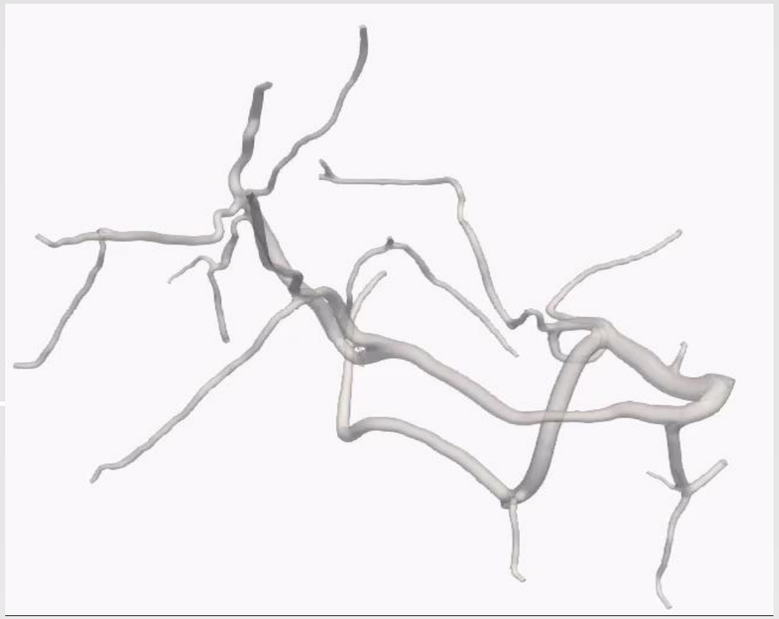
Planning CBCT

Meshing
Blood fluid properties
Boundary conditions

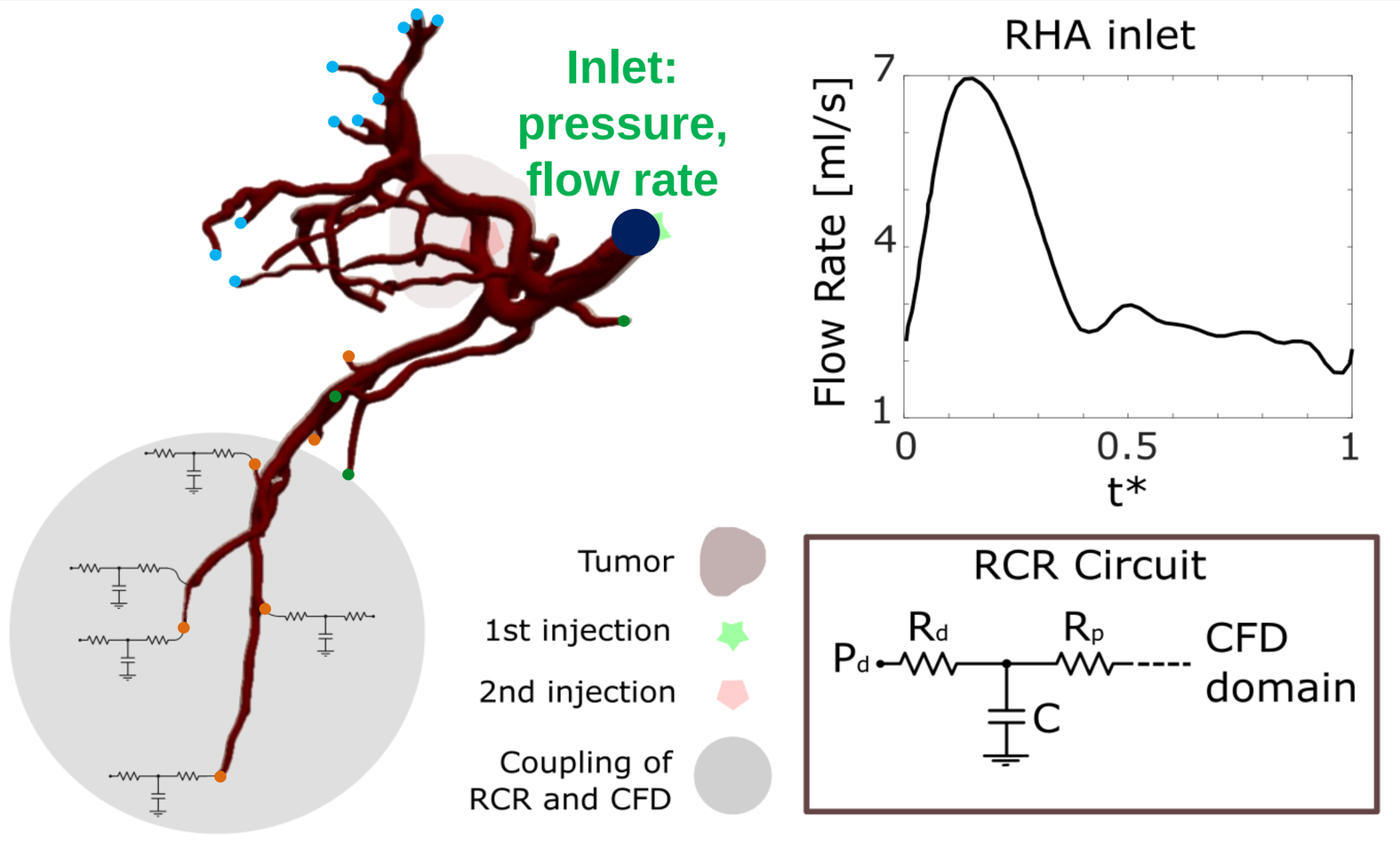








Flow Simulation: Multiscale Modeling

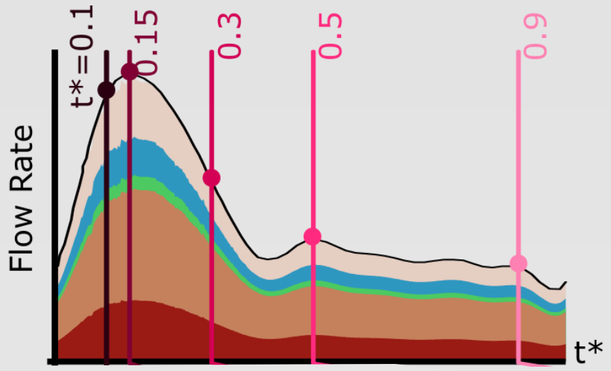


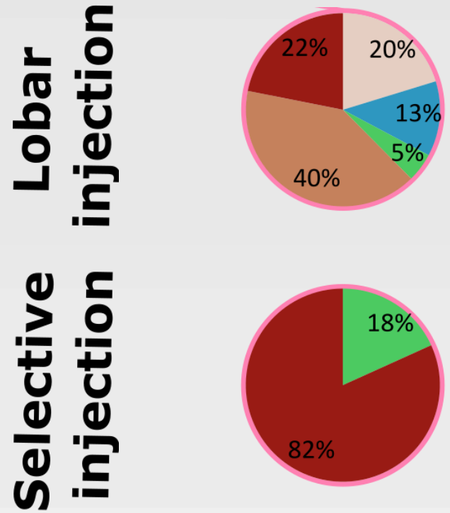
- Segmented branches > terminal arterioles

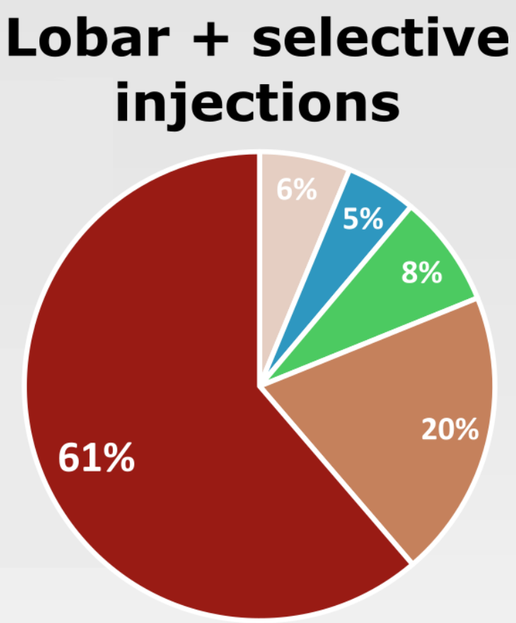
→ Segmented arterial tree combined with RCR Windkessel model for arterioles

- RCR circuit tuned using whole-body 0D model

Blood Flow and Microsphere Distribution







- Lobar injection: segments received 5%-40%
- Selective injection: tumor received 82%

→ Tumor received 49% micro-spheres after both injections

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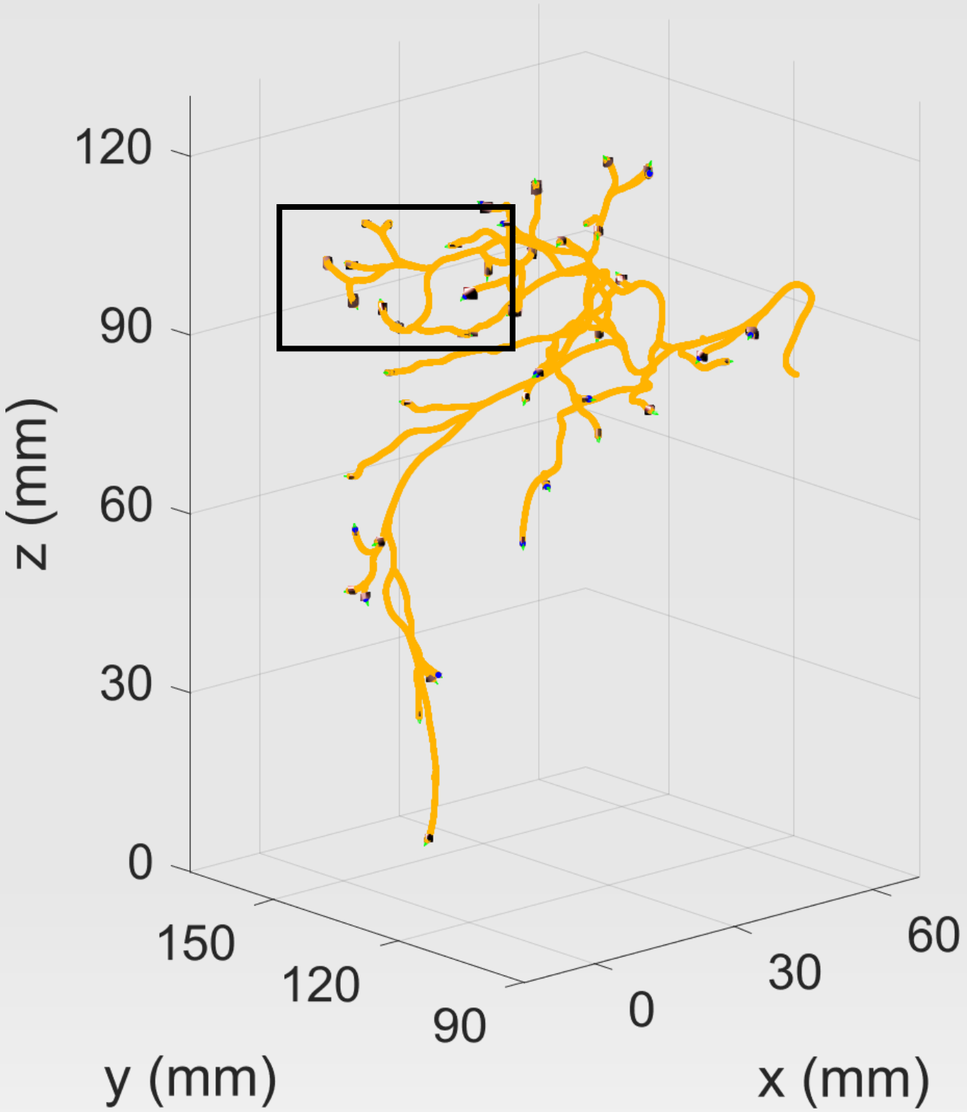
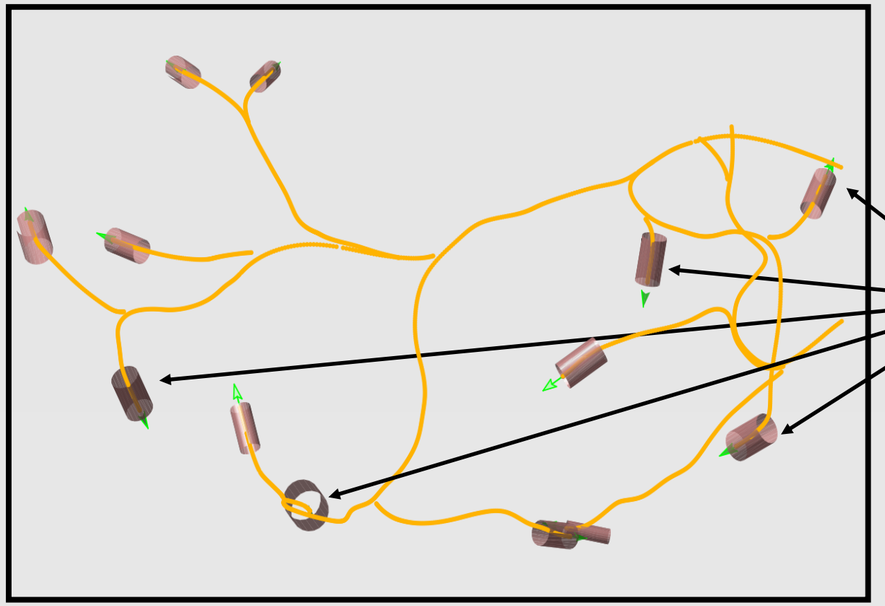
3D Microsphere Distribution





Outlet i:
- Diameter $ø_i$
- Ni microspheres arranged in vessel cylinder

Y-90 Dose Kernel: Use GATE Dose Actor

```
#=====================================================
# GEOMETRY
#=====================================================
/control/execute  geometry.mac

#=====================================================
# PHYSICS
#=====================================================
/control/execute  physic.mac

#=====================================================
# DETECTORS
#=====================================================
/control/execute  actorBeta.mac

#=====================================================
# INITIALISATION
#=====================================================
/gate/run/initialize

#=====================================================
# SOURCE :
#=====================================================
/control/execute   betasource.mac
```

- Sphere, voxel number and total space calculated to match that of desired voxel size
- 364 μm for microspheres

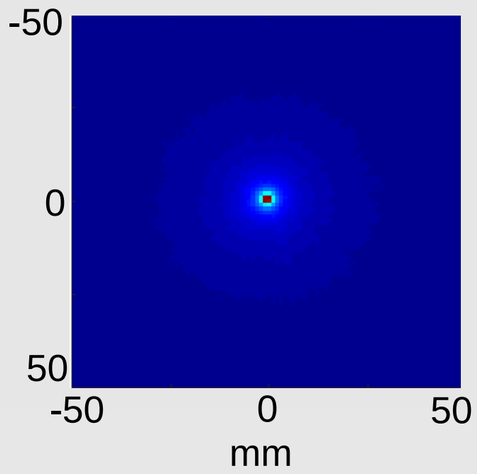
- ^{90}Y: beta isotropic point source defined by energy spectrum
- Collect ~5 10^5 -10^6 events in 280 x 280 x 280 kernel matrix

Dose Kernel Calculation

Cumulative activity (MBq.s)

⊗

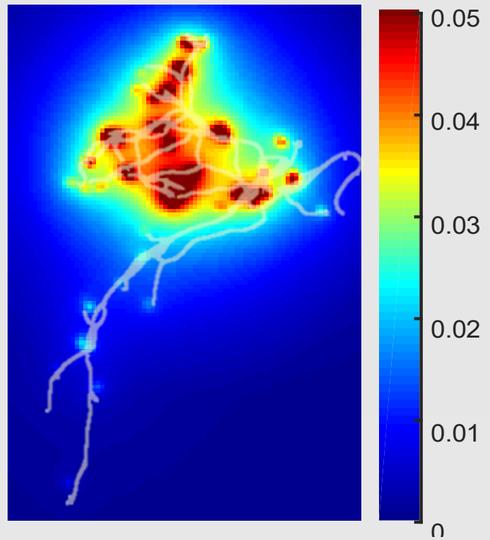
Gy / MBq.s



GATE/Geant4

=

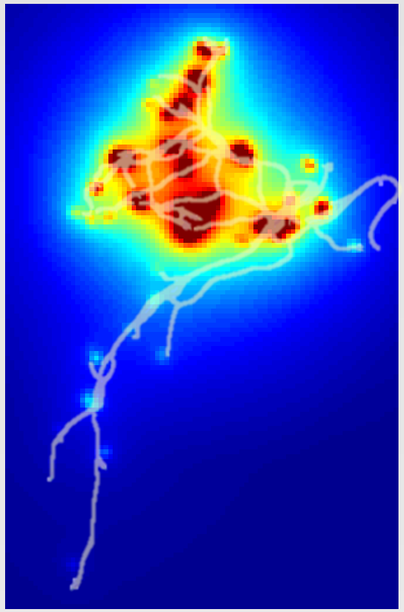
Gy



- Highly heterogenous dose distribution between segments
- Predicted total dose 125 Gy, consistent with physician reported dose with MIRD 137 Gy

3D Dose distribution Predicted by CFD

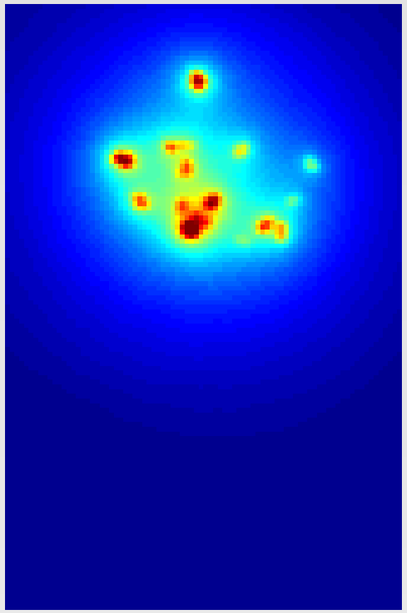
Total dose



125 Gy

=

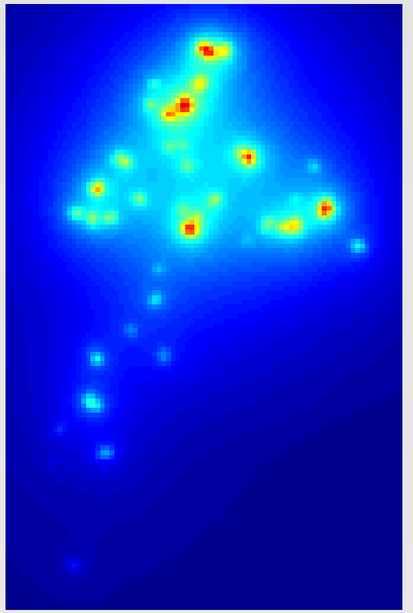
Selective injection



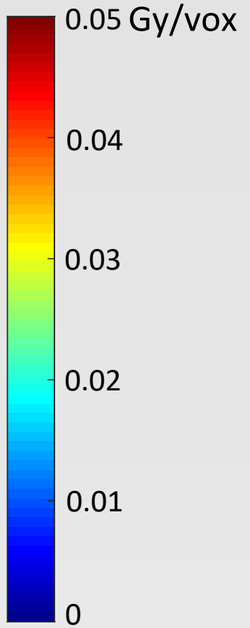
58 Gy (48 Gy to tumor)

+

Lobar injection



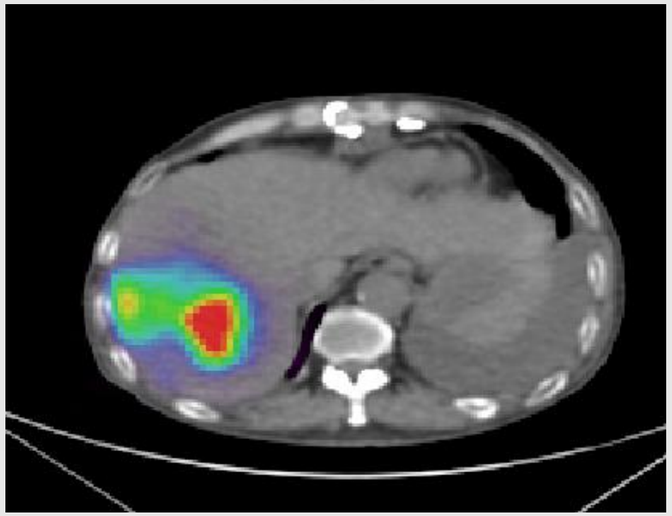
67 Gy (10 Gy to tumor)



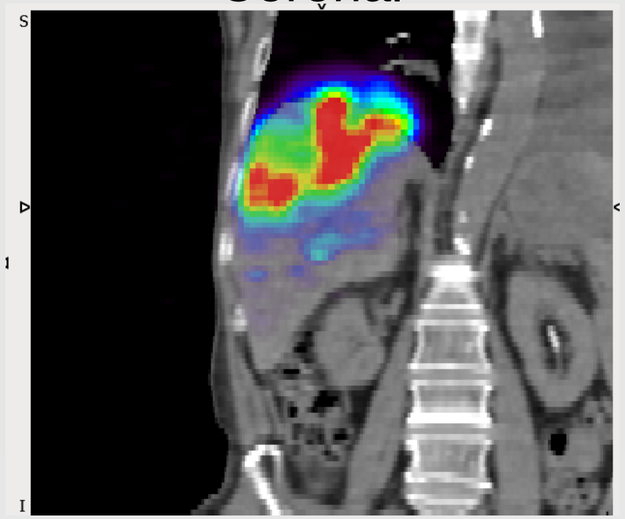
CFD-predicted dosimetry allows to separate multiple injections
→ can optimize number of injections, site, activity

Y-90 PET for Dose Verification

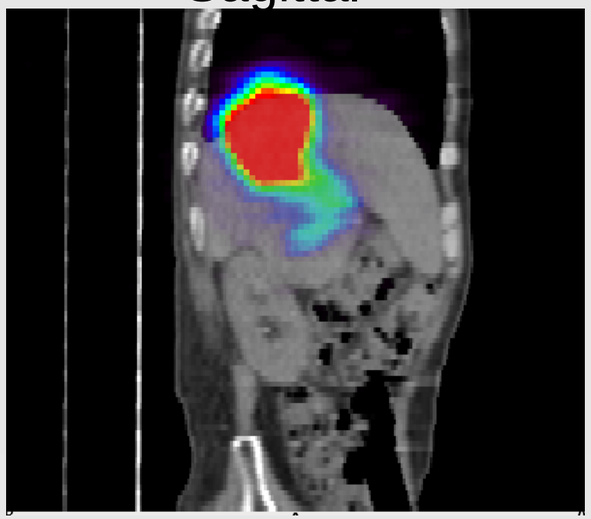
Axial

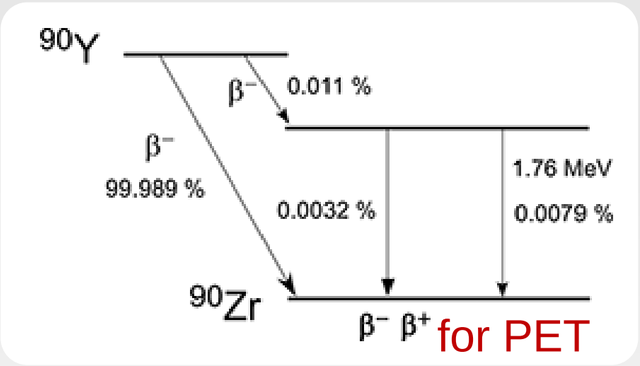


Coronal



Sagittal





Activity distribution **measured** post-treatment is consistent with CFD-**predicted** dose distribution

Conclusions

- Developed proof of concept dosimetry tool for personalized treatment planning
- Promising results, next step is validation
- Ultimate goal is a flexible tool for Interventional Radiologists to determine best injection site and activity **pre-treatment based on dosimetry**

Acknowledgments

Department of Biomedical Engineering
Amirtaha Taebi, Ph.D.
Simon Cherry, Ph.D.
MIPET group
Katya Mikhaylova, Ph.D.

Department of Mechanical Engineering
Yuki Tsuzuki
Ralph Aldredge, Ph.D.
Anthony Wexler, Ph.D.

Department of Radiation Oncology
Stanley Benedict, Ph.D.

Department of Radiology
Catherine Vu, M.D.
Bahman Roudsari, MD, Ph.D.
Ramsey Badawi, Ph.D.
Denise Caudle, CNMT
Michael Rusnak, CNMT
Benjamin Spencer, Ph.D.

Funding