Computational Modeling in Pulmonary Hypertension

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No Disclosures
ENGINEERING  Cardiovascular Biomechanics Computation Lab

- PI: Alison Marsden, PhD
- 12 Students, Postdocs, Staff
- Pediatrics, Bioengineering Departments
- Member of Bio-X, CVI, ICME interdisciplinary programs
- Hospital access next door
Predictive Simulations in Medicine

\[ \rho \frac{\partial \vec{v}}{\partial t} + \rho \vec{v} \cdot \nabla \vec{v} = -\nabla p + \nabla \cdot \tau + \vec{f} \]
\[ \nabla \cdot \vec{v} = 0 \]

Navier-Stokes in 3D domain

We have not yet leveraged the full power of predictive computations in clinical medicine
Patient-Specific Modeling

1. MRI
2. Pathlines
3. Segmentation
4. Solid
5. Mesh
6. Boundary Conditions
7. Simulation

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Emerging Paradigms for CV Simulation

- Virtual surgery and treatment planning
- Personalized Medicine
- Test novel surgical concepts
- Prediction of postsurgical conditions
- Fundamental disease mechanisms
- Vascular Growth and Remodeling
- Mechanobiology
- Patient risk stratification
- Augmenting clinical imaging
New Directions in CV Simulation

- Physiologic Models
- Fluid Structure Interaction
- Uncertainty Quantification
- Machine Learning for Image Segmentation
- Shape Optimization
- Incorporation of Biologic Response

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Physiologic Modeling

Lumped Parameter Model

Velocity Profile at Inlet

Esmaily-Moghadam, Vignon-Clementel, Figliola, Marsden. JCP 2012.

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Electrical Circuit Analogy

\[ \Delta P = RQ \]

\[ Q = C \frac{dP}{dt} \]

\[ \Delta P = L \frac{dQ}{dt} \]

\[ Q = \frac{|Q| + Q}{2} \]

\[ P = A(t) E(V - V_0) + P_0 \left( e^{K(V-V_0)} - 1 \right) \]
Multiscale Modeling

Virtual Surgery for Stage II: Hemi-Fontan vs. Glenn

Investigate how different surgical options can impact resulting physiology, without actually trying them on the patient.
Changes in local hemodynamics

3D Velocity Field

Glenn

HF

HF with 50% Stenosis

HF with 85% Stenosis

3D Pressure Field

Glenn

HF

HF with 50% Stenosis

HF with 85% Stenosis

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Physiology Implications

PV Loop

Left Pulmonary Flow

L. Pulm. Artery Pressure

Junction Loss as % of Pulmonary Loss

Junction Loss as % of Ventricular Output

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Pulmonary Hypertension

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Wall Shear Stress

• What are the forces acting on the vessel wall in PH patients?

• WSS: Amount of force on wall caused by flow going past

\[ \tau = \mu \frac{du}{dy} \]
WSS in PH Patients

Figure 3: Summary of time-averaged wall shear stress (WSS) results for all subjects. Mean WSS color maps (left panel) for two representative age- and sex-matched (top) normal subjects and (bottom) PAH patients. Mean WSS was lower in the proximal arteries of the PAH patients than in those of the normal subjects. Mean WSS averaged over the area of 10-mm circumferential strips taken at the LPA and RPA (proximal) and distal locations was significantly different between the two populations (right panel).

Tang et al., Pulmonary Circulation, 2012
WSS in PH Patients

Kheyfets et al., Pulmonary Circulation, 2015
WSS in PAH patients

FIG. 6. Systolic WSS (averaged across the circumference of the vessel lumen) as a function of disease state, vessel diameter (D), peak flow rate (Qmax), and measurement location. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Barker et al., Mag Res Med, 2014

Truong et al., JCMR, 2013
Team Science

Engineers

Surgeons

Radiologists

Cardiologists

Biologists

www.simvascular.org

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