Moving Computational Tools for Aortic Disease from the Bench to the Bedside

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• Introduction to Aortic Disease
• Computational Hemodynamics
  • CFD in the Thoracic Aorta
  • Treatment of Boundary Conditions
• TEVAR
  • Predicting post-TEVAR hemodynamics
  • The ascending aorta
• Other project: Hemodynamics and ageing
• Conclusions
Thoracic Aortic Disease

Aortic Aneurysm

Aortic Dissection

BLOOD DYNAMICS ARE CONSIDERABLY AFFECTED
Ingredients for a successful CFD

- **Computer**
- **Geometry/Mesh**
- **Equations/discretization** (incompressible NS)
  - Prospective/retrospective
  - Invasive/non-invasive
  - High-quality/noisy
  - Cheap/Expensive
    - Safe?
- **Boundary conditions** (Dirichlet/Neumann/Robin)
  - Finite Element Method
    - Unsteady
    - Stabilization
Use of computational fluid dynamics studies in predicting aneurysmal degeneration of acute type B aortic dissections by Mills et al.\textsuperscript{22} Zero pressure outlet conditions were assumed for the innominate, left common carotid, left subclavian, and bilateral iliac arteries.

On the Use of \textit{In Vivo} Measured Flow Rates as Boundary Conditions for Image-Based Hemodynamic Models of the Human Aorta: Implications for Indicators of Abnormal Flow

In this study, it is also observed that the BC treatment scheme of imposing the Neumann stress-free condition at every outlet section (S3) does lead to physiologically unrealistic results. Differences between
Outflow boundary conditions problem

Pressure/stress free

Velocity (Dirichlet)

0D lumped model – 3 Element

Windkessel
Available data for parameter estimation

On the choice of outlet boundary conditions for patient-specific analysis of aortic flow using computational fluid dynamics

J. Biomec 2017

Flow in every boundary

Cuff pressure
CONSTRAINED OPTIMIZATION (1987)

FLOW

Target PRESSURE

Estimated PRESSURE
3 Element Windkessel Parameter estimation

CONSTRAINED OPTIMIZATION (2018)

Estimated Pressure

![Diagram of Windkessel model with parameters and estimated pressure graphs.](image)
Results against literature
Results against literature

ERROR = Simulated outflow vs. expected outflow

Flow integral error %

<table>
<thead>
<tr>
<th></th>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC1</td>
<td>100%</td>
<td>150%</td>
<td>120%</td>
</tr>
<tr>
<td>BC2</td>
<td>150%</td>
<td>200%</td>
<td>130%</td>
</tr>
<tr>
<td>BC3</td>
<td>200%</td>
<td>250%</td>
<td>220%</td>
</tr>
</tbody>
</table>

Submitted Int J Num Meth Biom Eng Dec 2017
iCardioCloud experience

21 Patients: data assimilation challenge
• Patient-specific MAKES the difference

• Lumped parameter model is a great trade-off

• Assumptions in input DATA are not bad

• Accomodate noisy and incomplete datasets
Thoracic Endovascular Aorta Repair (TEVAR)
Endoleak: sealing is not perfect
Predicting post-TEVAR hemodynamics

**STEP 1**
- Medical image processing
- Stent-graft modeling
- Virtual deployment

**STEP 2**
- Cylinder mapping on the stent-graft
- CFD mesh generation

**STEP 3**
- CFD analysis of blood flow
- Post-processing

+ =
Predicting post-TEVAR hemodynamics

STEP 1

Medical image processing

Virtual deployment

Stent-graft modeling

Medtronic Valiant 28-24-150

Medtronic Valiant 26-26-100
STEP 2

Cylinder mapping on the stent-graft → CFD mesh generation

Predicting post-TEVAR hemodynamics

Virtual interventions for image-based blood flow computation

Guanglei Xiong, Gilwoo Choi, Charles A. Taylor
STEP 3

CFD analysis of blood flow → Post-processing

Systolic peak

Predicting post-TEVAR hemodynamics

Submitted Comp Fluids Dec 2017
Take Home Messages

- Detailed CFD mesh reconstruction
- Proximal and distal apposition well predicted
- Post-operative hemodynamics well represented
- **Limitation:** not yet able to predict post-op boundary conditions
A systematic review of primary endovascular repair of the ascending aorta

The ascending aorta represents the final frontier of endovascular therapy. Use of endovascular stent grafts ascending aortic diseases are being successfully treated by endovascular technologies. For optimal outcomes, patient selection is critical to align aortic anatomy with the limited device sizing options, and it should be reserved for patients at high surgical risk. (J Vasc Surg 2018;67:332-42)
Case study

- 88yo
- Not suitable for Open Surgery
Device selection and deployment

Stainless Steel + Dacron

Nitinol + Dacron
1 bare ring (proximal)

Nitinol + Dacron
2 bare rings
Virtual TEVAR can help surgery planning in the Ascending Aorta.
What is the impact of ageing in hemodynamics?
Atherogenic TAWSS < 0.4 Pa

Atheprotective TAWSS > 1.5 Pa
Other: Ageing and hemodynamics

Submitted JACC Feb 2018
Thesis Conclusions

• Strong Engineering-Medical Collaboration

• *Systematically* performed CFD in the aorta

• Integrate predictive tools for TEVAR and decision-making

• Numerical results with clinical impact