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

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12/03/2018

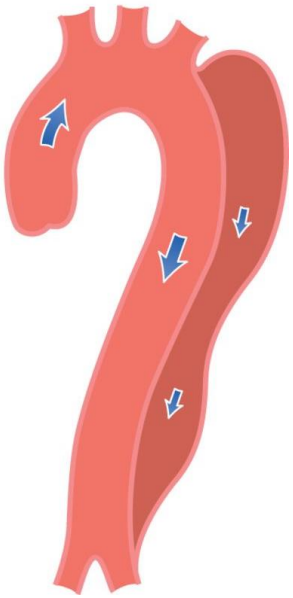
Outline

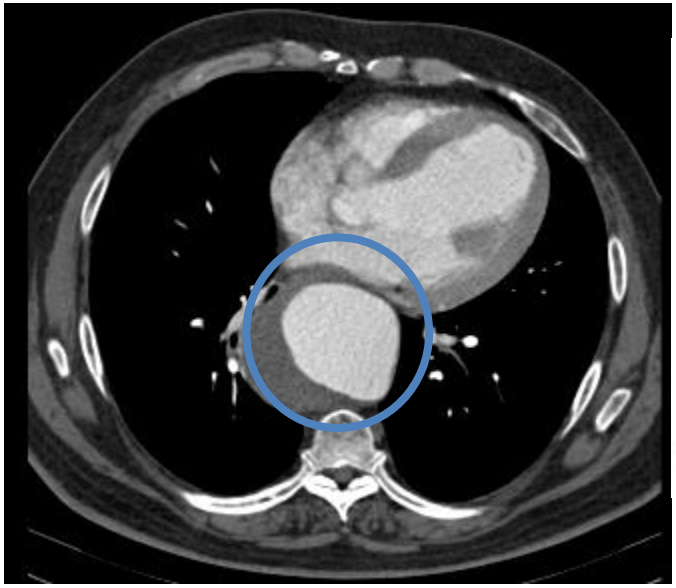
- Introduction to Aortic Disease
- Computational Hemodynamics
  - CFD in the Thoracic Aorta
  - Treatment of Boundary Conditions
- TEVAR
  - Predicting post-TEVAR hemodynamics
  - The ascending aorta
- Other project: Hemodynamics and ageing
- Conclusions

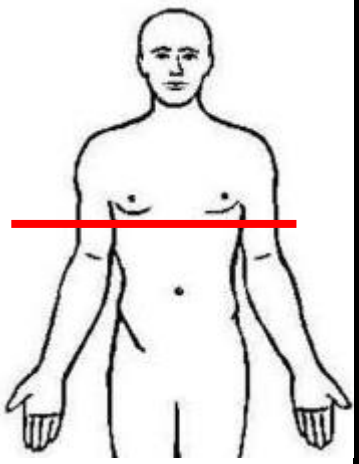
Thoracic Aortic Disease

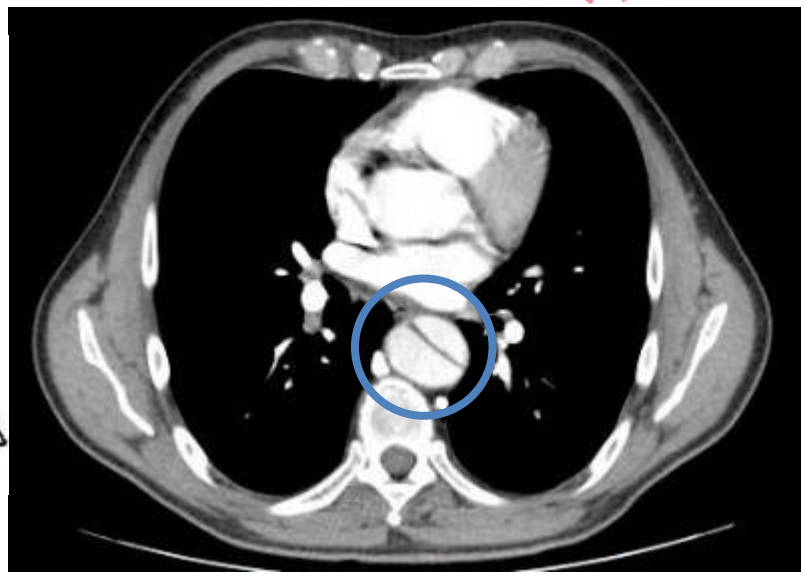
Aortic Aneurysm

Aortic Dissection









BLOOD DYNAMICS ARE CONSIDERABLY AFFECTED

Ingredients for a successful CFD

Computer

Geometry/Mesh

Equations/discretization (incompressible NS)

- Finite Element Method
- Unsteady
- Stabilization

EMORY UNIVERSITY

- **Prospective/retrospective**
- **Invasive/non-invasive**
- **High-quality/noisy**
- **Cheap/Expensive**
- **Safe?**

Boundary conditions (Dirichlet/Neumann/Robin)

Motivation

Use of computational fluid dynamics studies in predicting aneurysmal degeneration of acute type B aortic dissections

JVS 2015

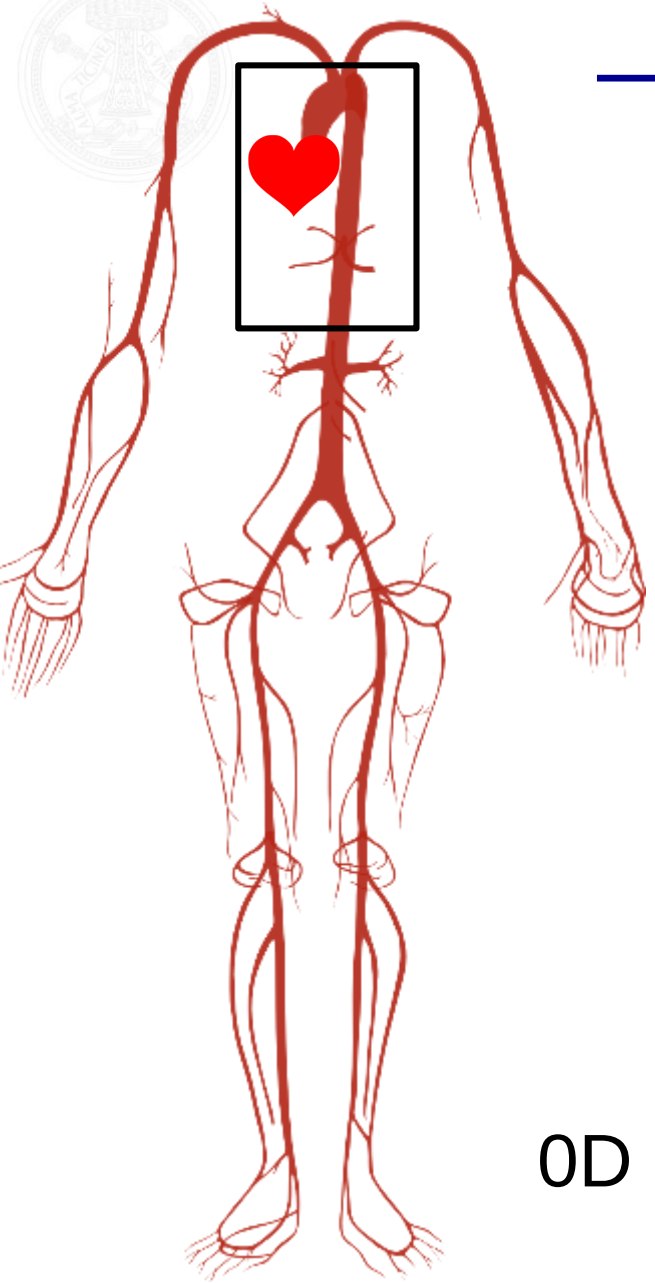
by Mills et al.[22] Zero pressure outlet conditions were assumed for the innominate, left common carotid, left subclavian, and bilateral iliac arteries.

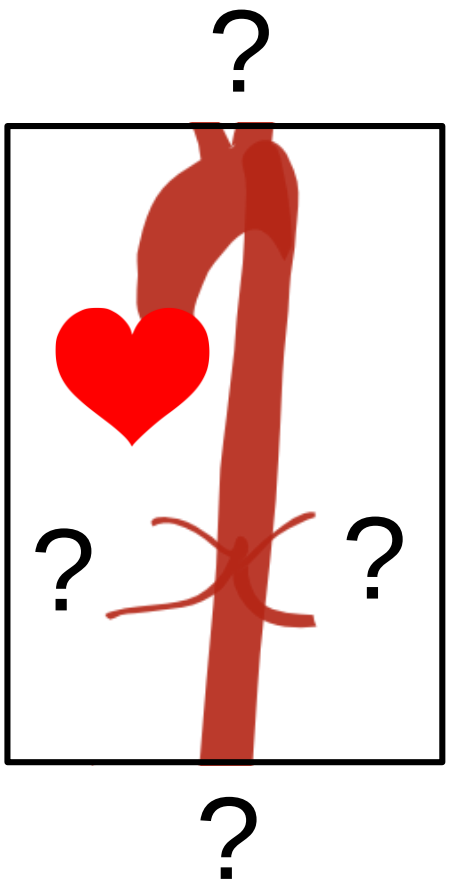
On the Use of *In Vivo* Measured Flow Rates as Boundary Conditions for Image-Based Hemodynamic Models of the Human Aorta: Implications for Indicators of Abnormal Flow

ABME 2012

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

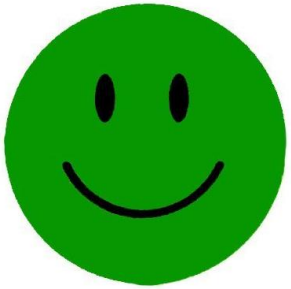




Pressure/stress free

Velocity (Dirichlet)

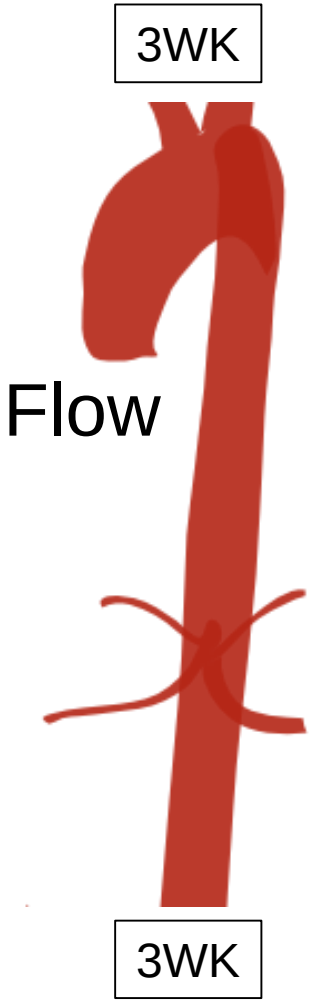
0D lumped model – 3 Element Windkessel



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



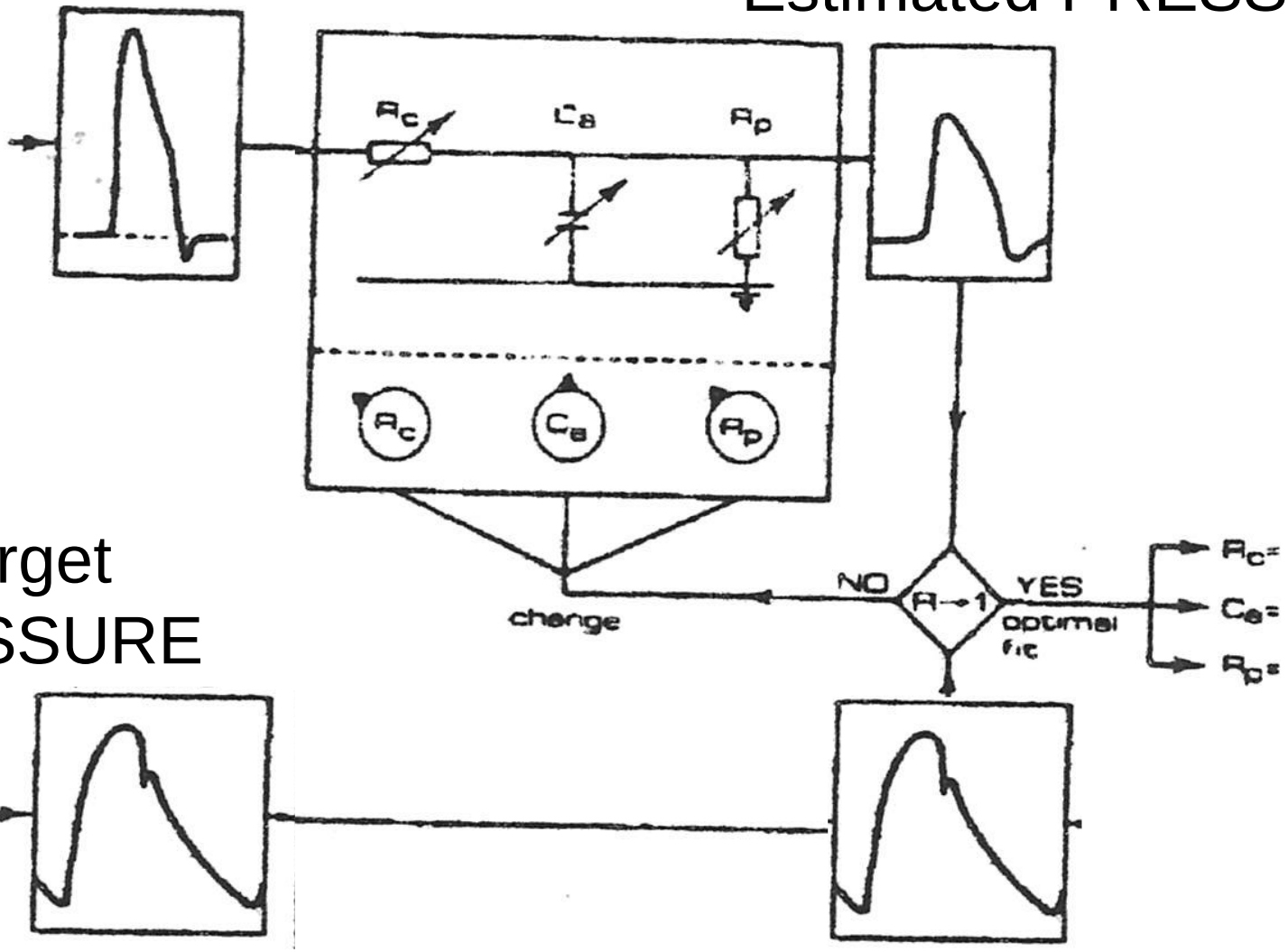
Flow in every boundary

Cuff pressure

CONSTRAINED OPTIMIZATION (1987)

Estimated PRESSURE

FLOW

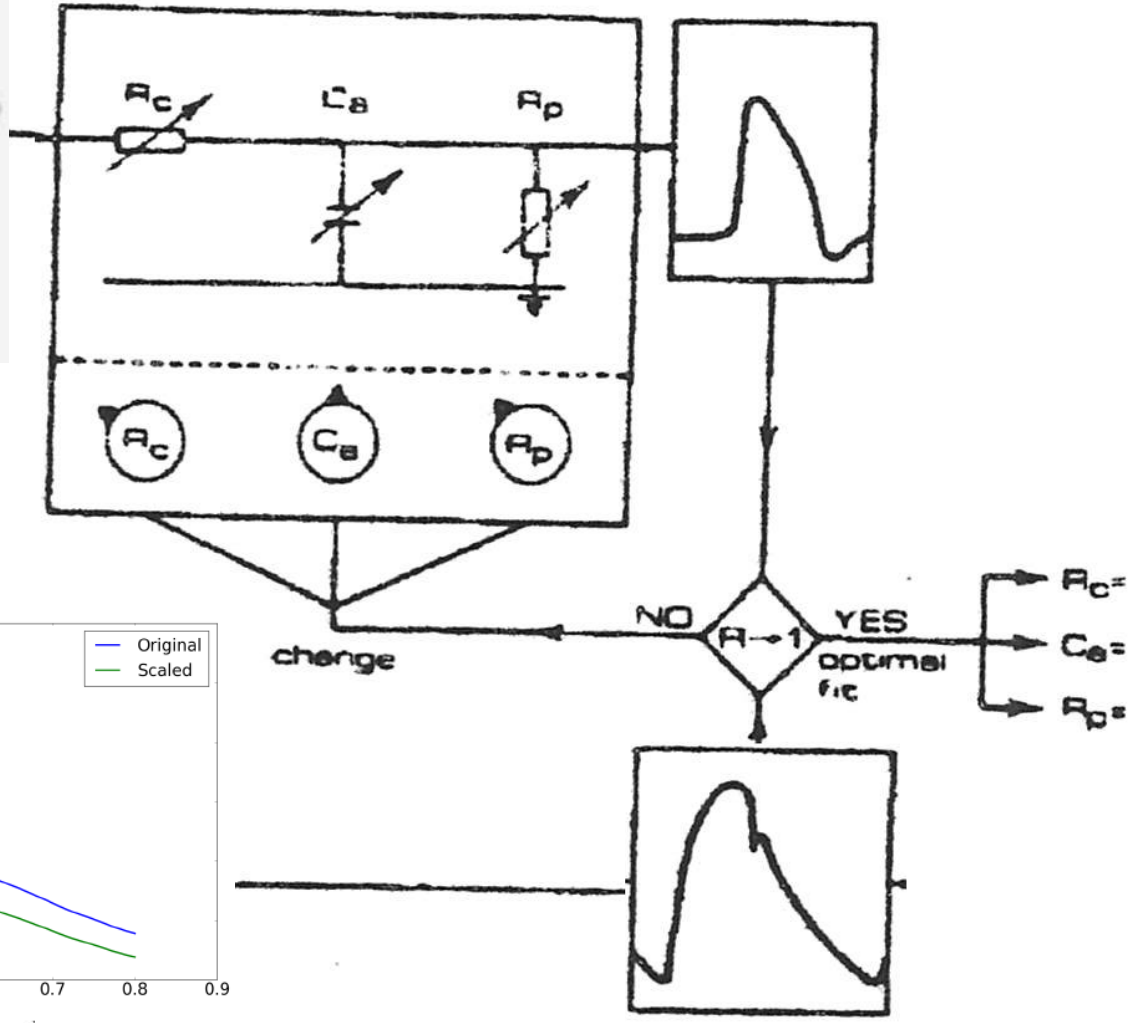


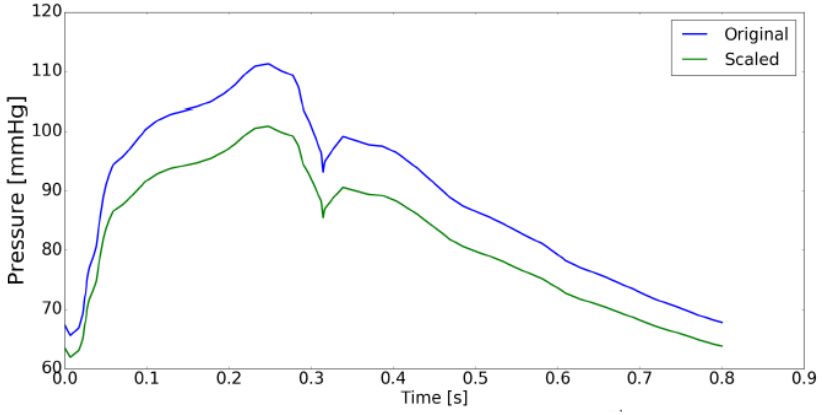
Target PRESSURE

3 Element Windkessel Parameter estimation

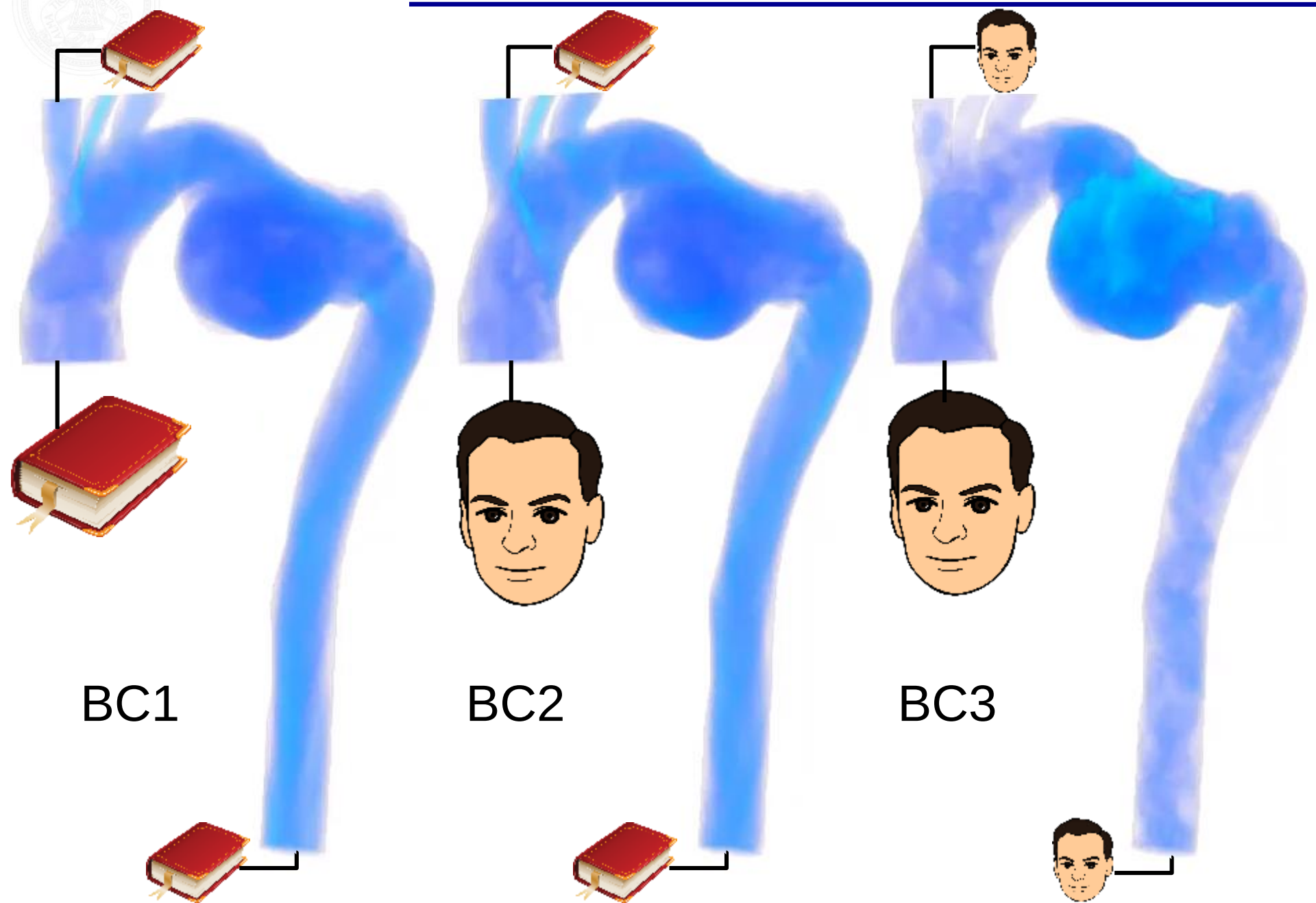
CONSTRAINED OPTIMIZATION (2018)

Estimated Pressure



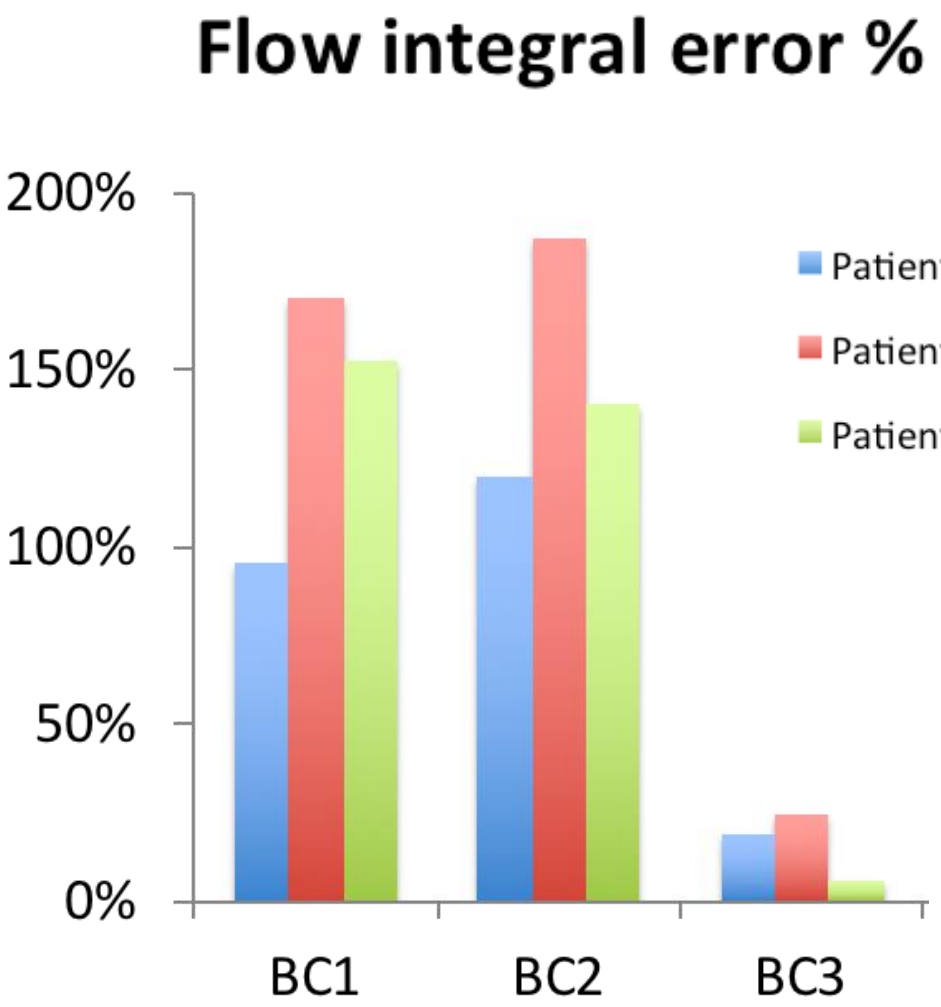


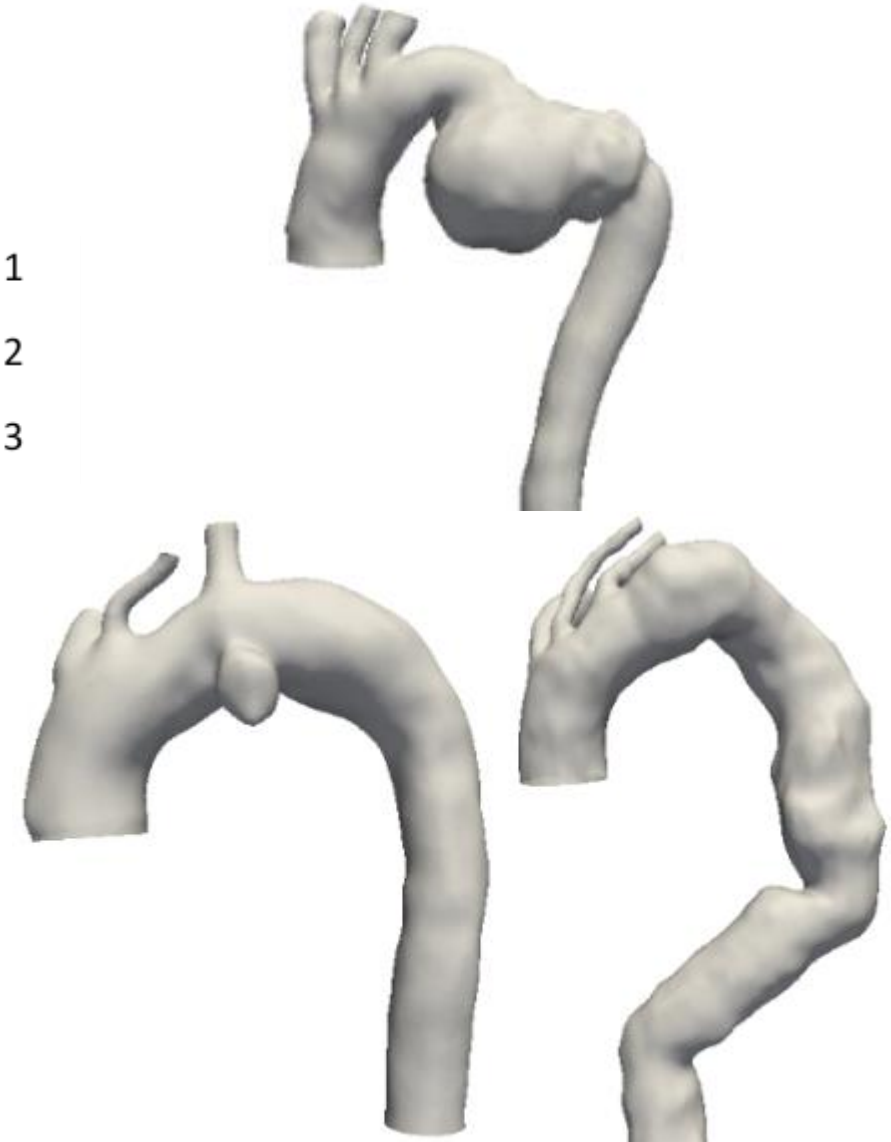
Results against literature



Results against literature

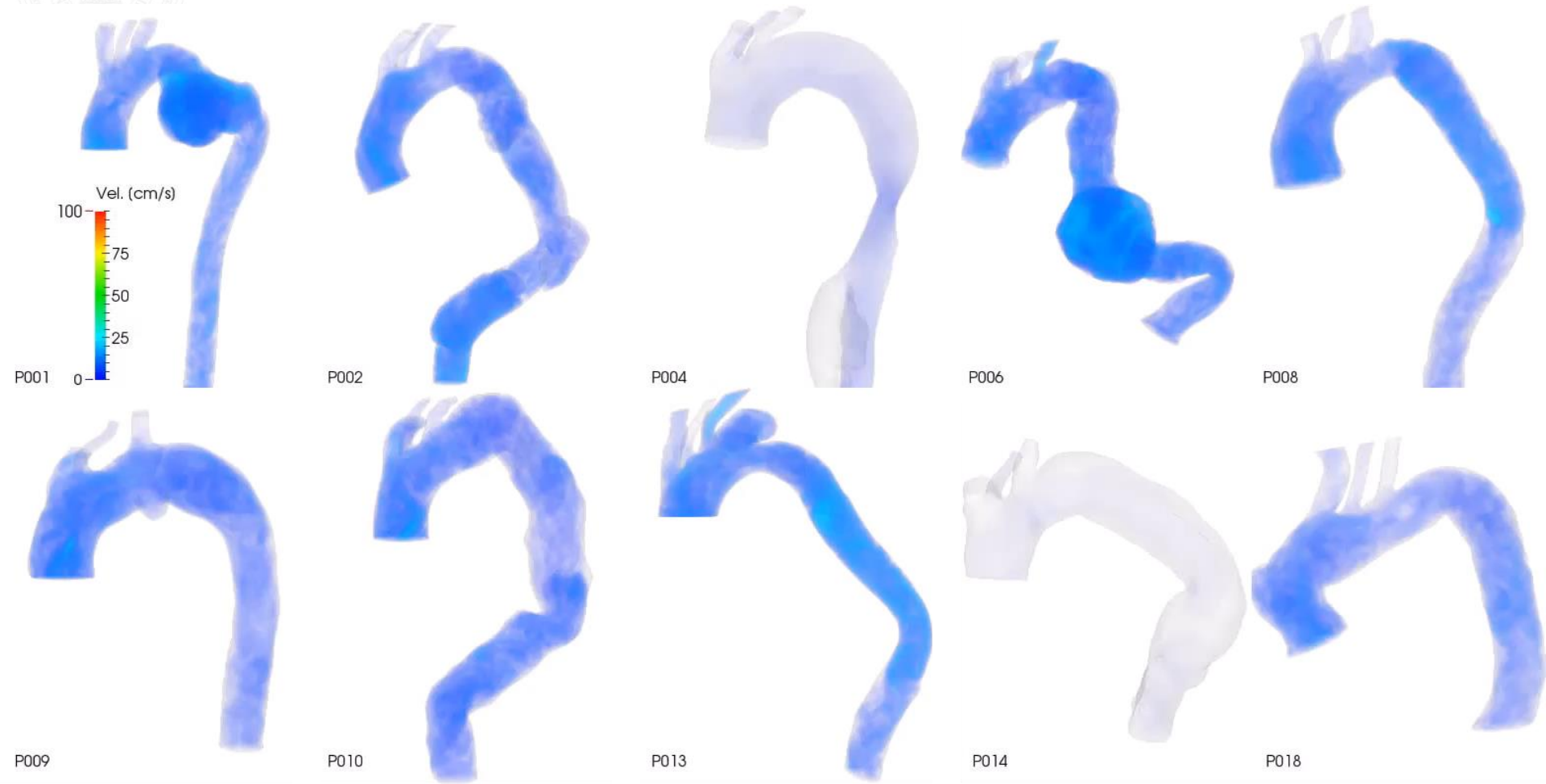
ERROR = Simulated outflow vs. expected outflow





Submited Int J Num Meth Biom Eng Dec 2017

iCardioCloud experience



21 Patients: data assimilation challenge

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Take Home Messages

- 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

TEVAR: what is?

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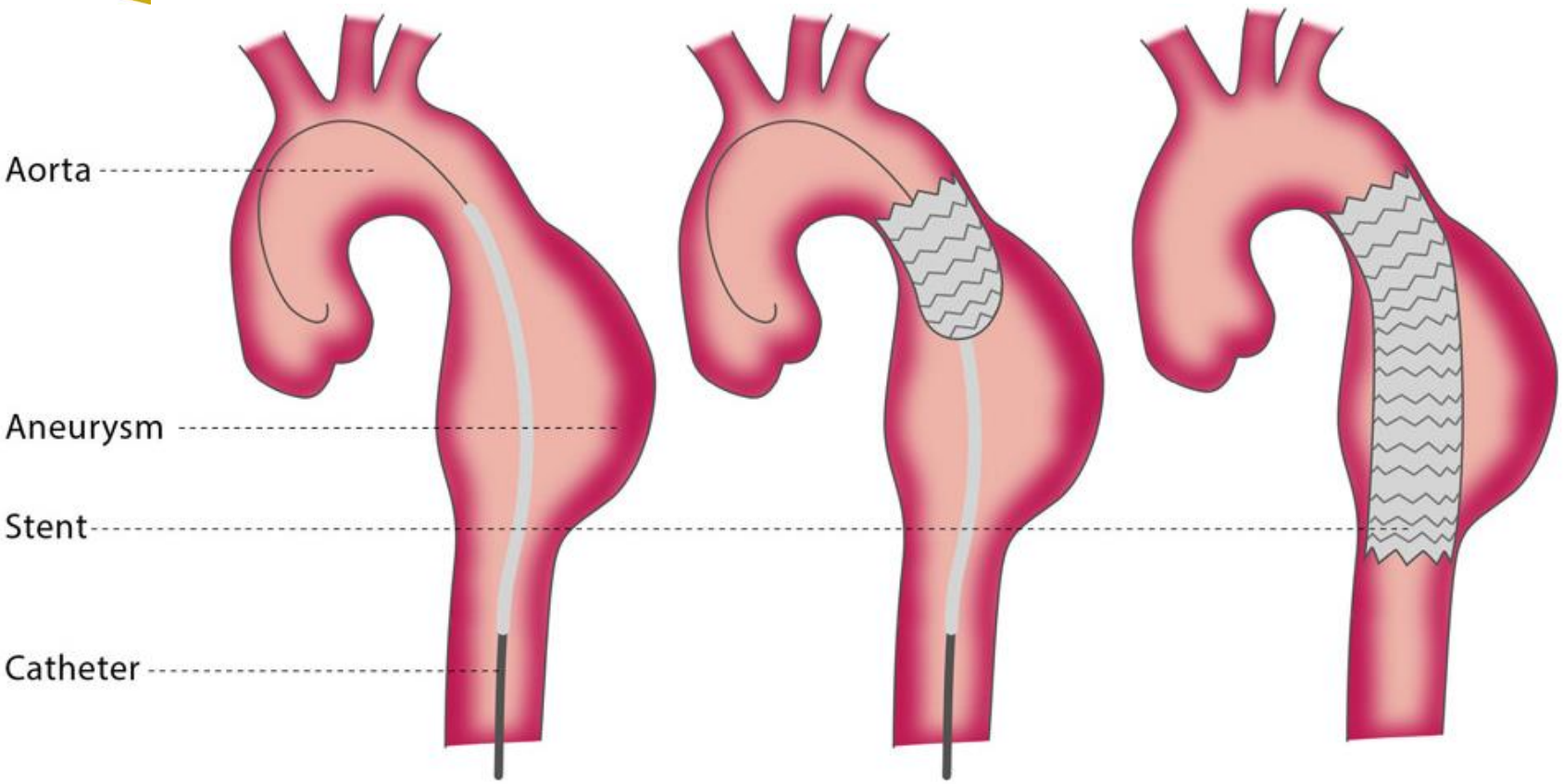
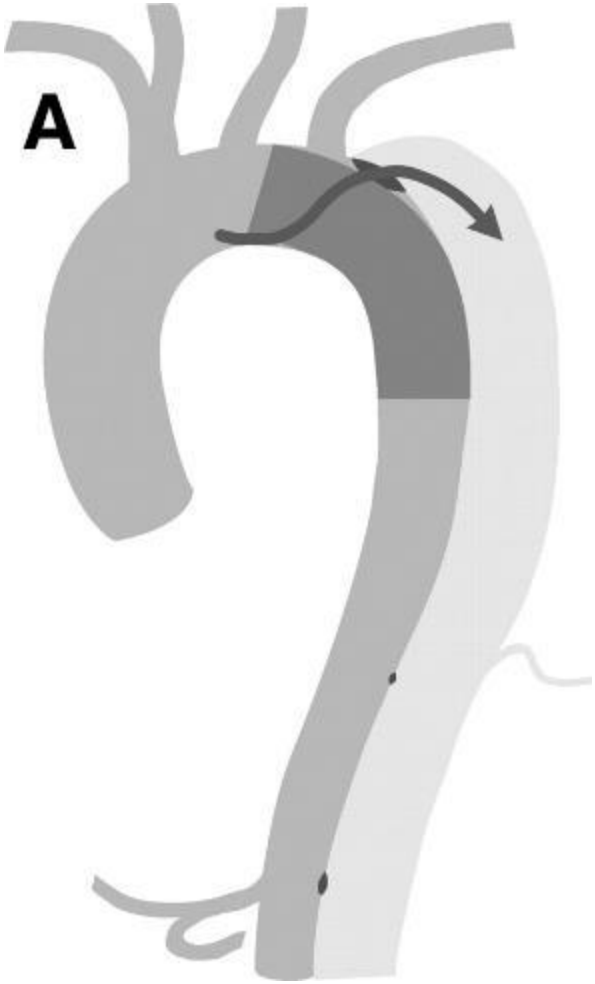
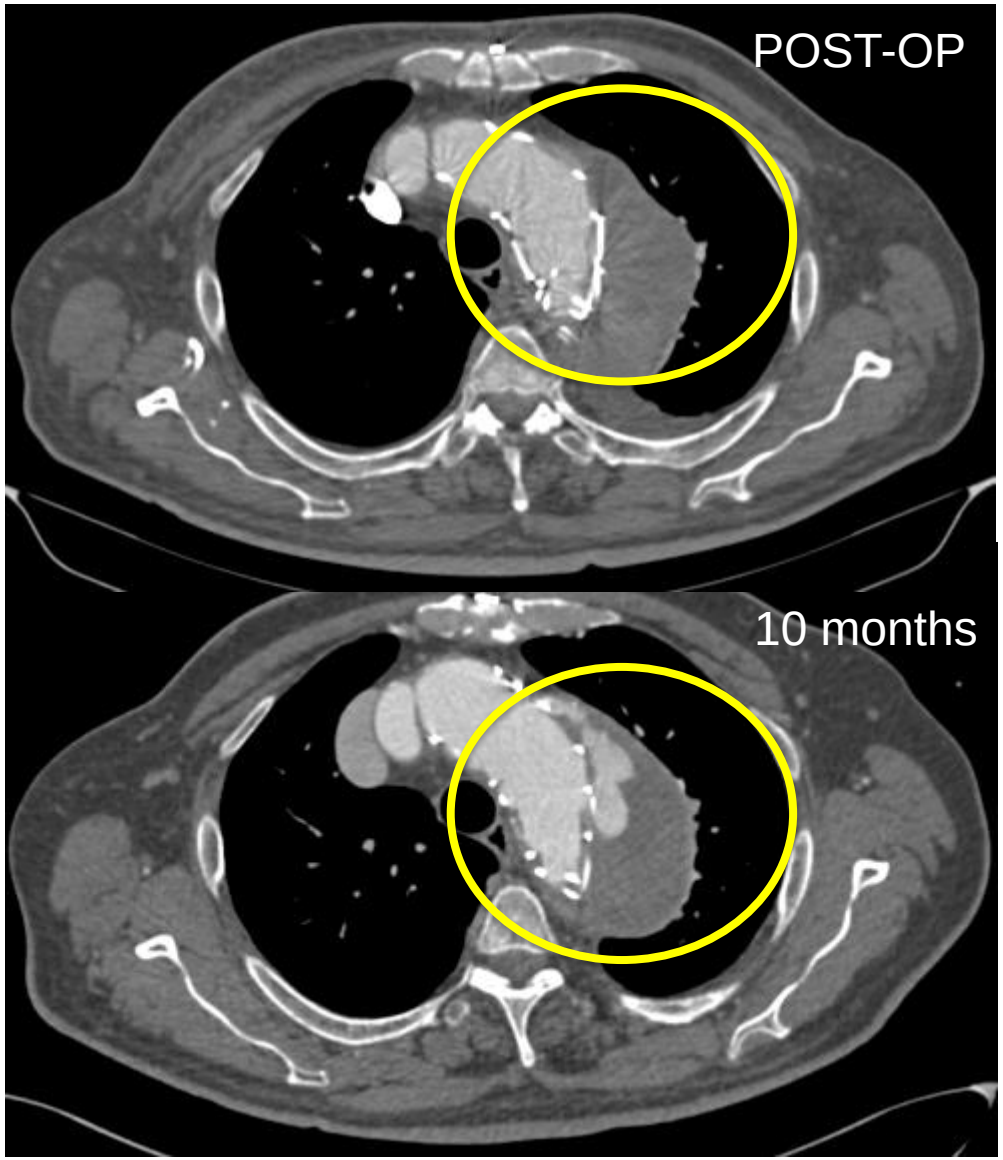
Thoracic **E**ndo**V**ascular **A**orta **R**epair (TEVAR)

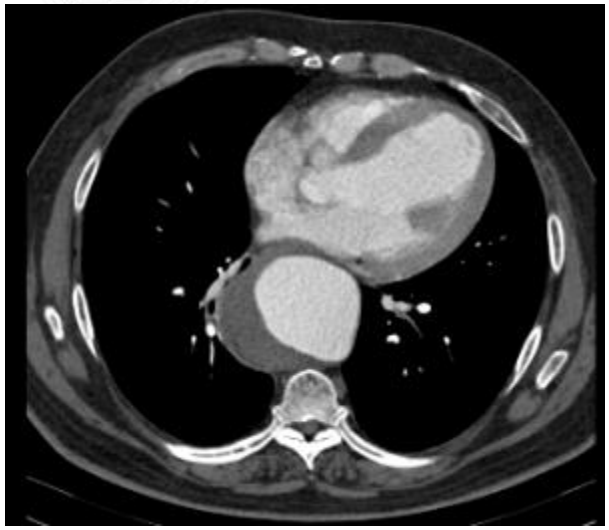


Endoleak: sealing is not perfect





Predicting post-TEVAR hemodynamics



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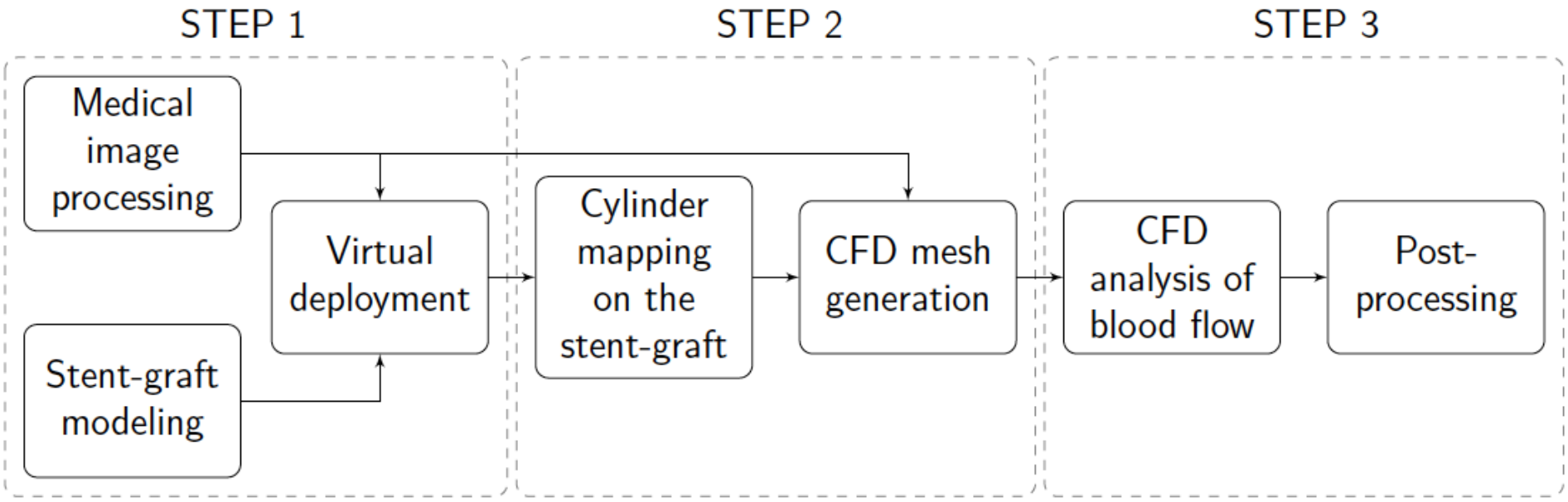

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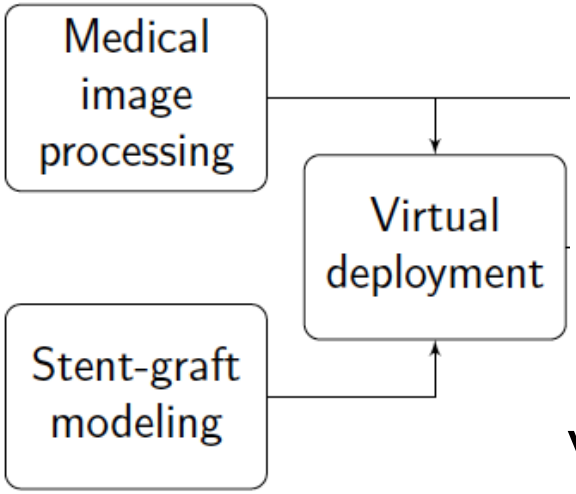
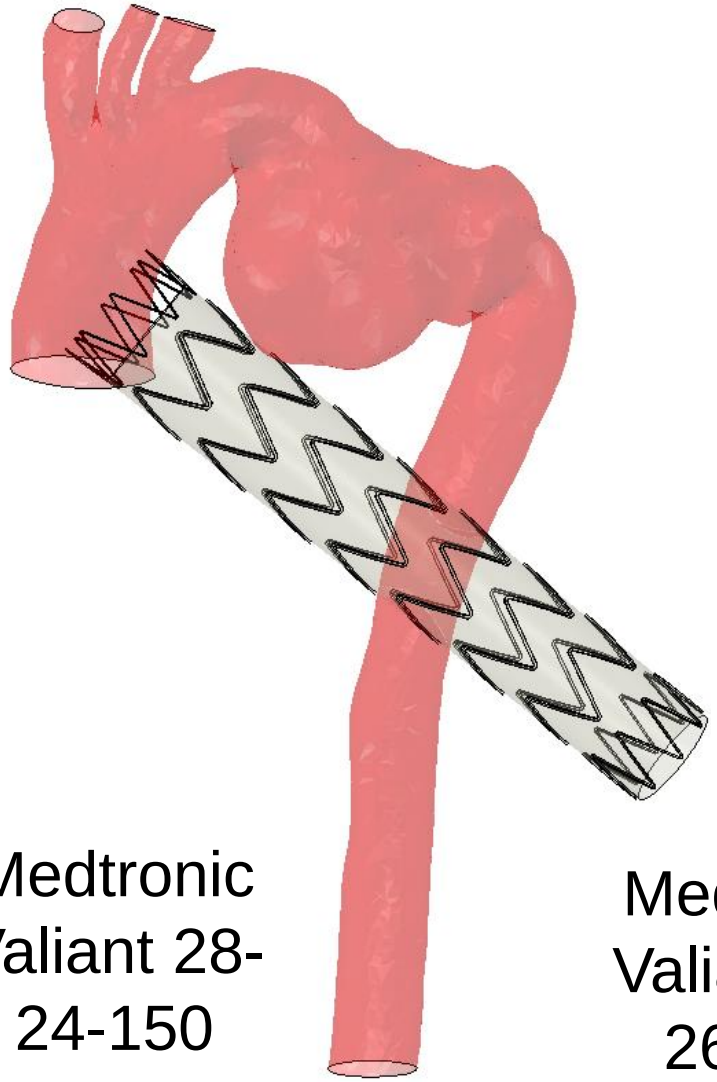
Predicting post-TEVAR hemodynamics

STEP 1



P1



Medtronic Valiant 28-24-150

P2

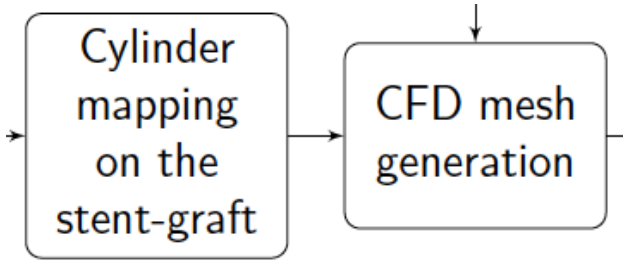
Medtronic Valiant 26-26-100

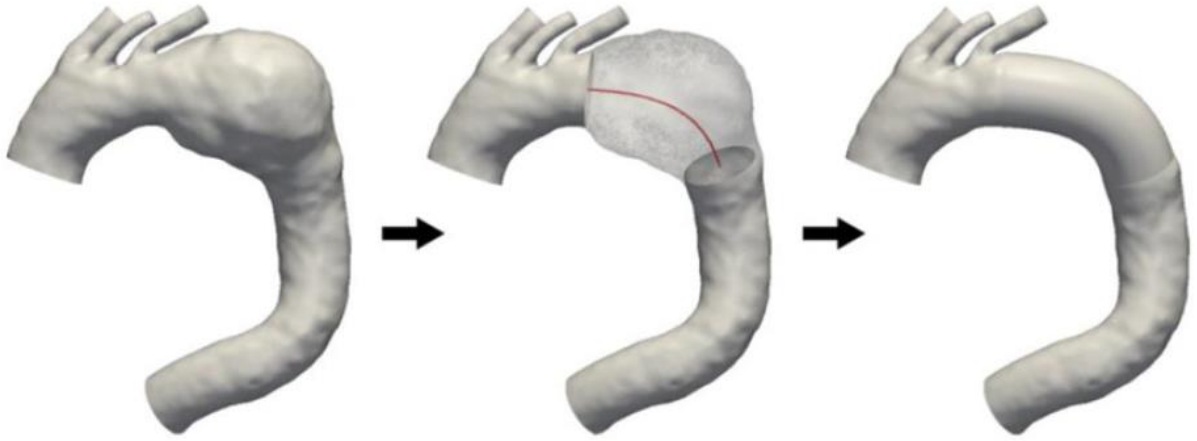
Predicting post-TEVAR hemodynamics

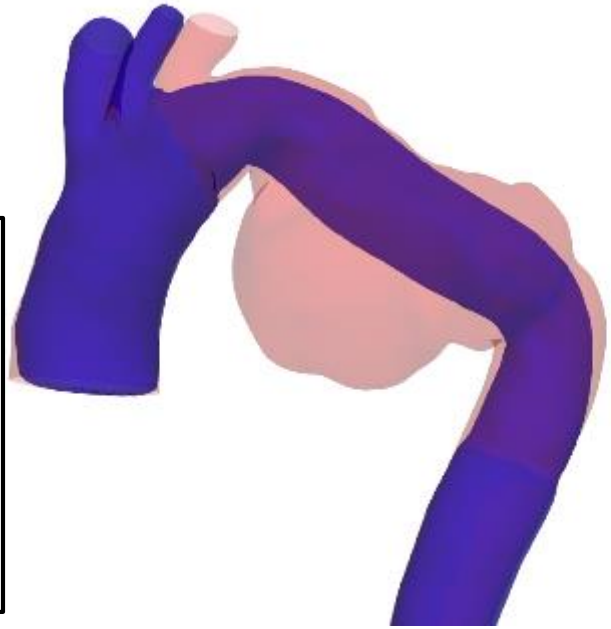
STEP 2

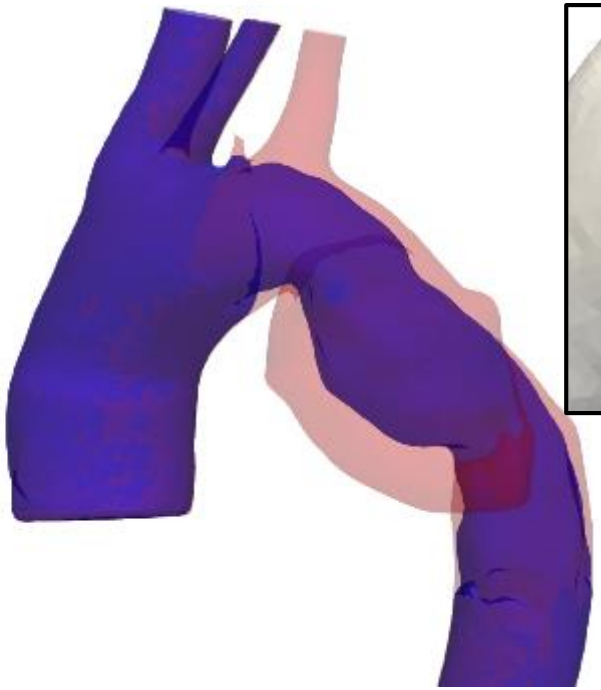
Virtual interventions for image-based blood flow computation

Guanglei Xiong [a,*], Gilwoo Choi [b], Charles A. Taylor [c]









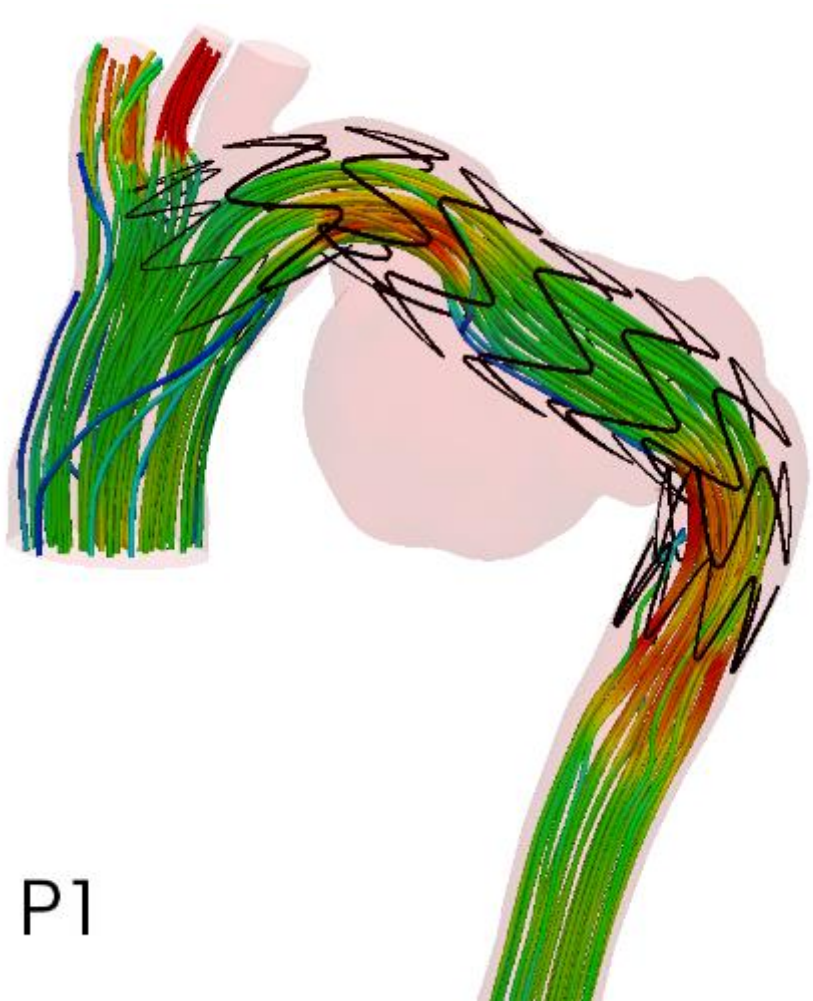
Predicting post-TEVAR hemodynamics

STEP 3

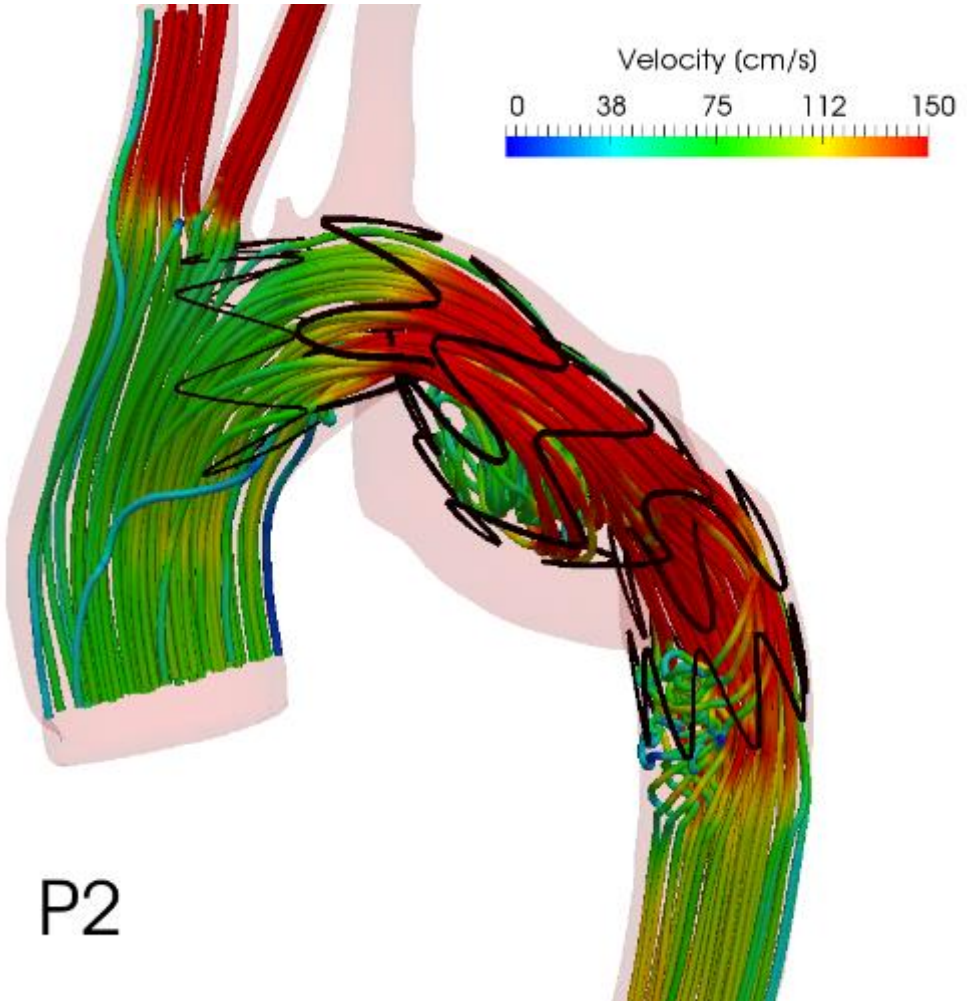
Submitted Comp Fluids Dec 2017

CFD analysis of blood flow → Post-processing

Systolic peak



P1



P2

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

Virtual TEVAR: a current medical need

JVS 2018

From the Society for Vascular Surgery

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.)

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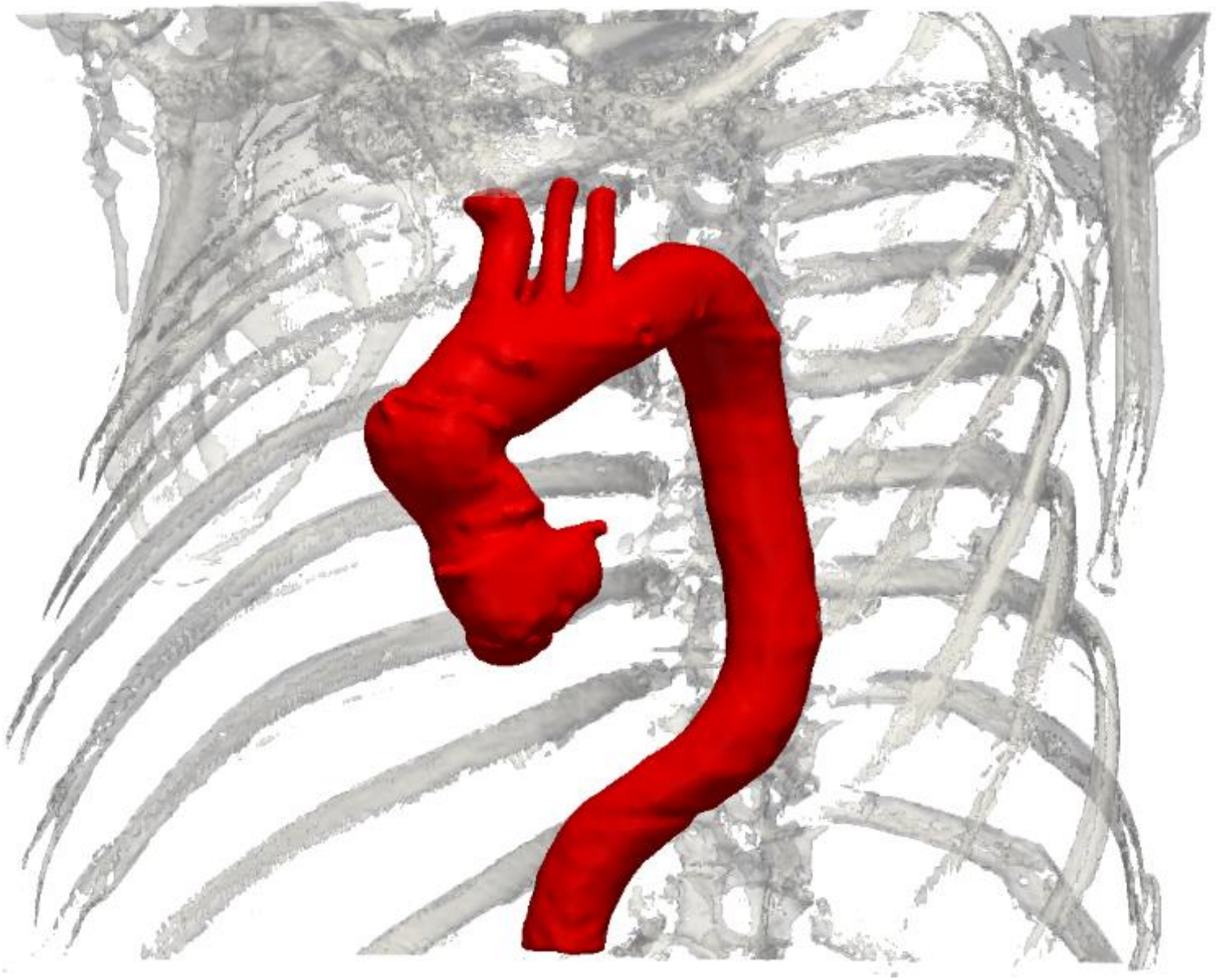
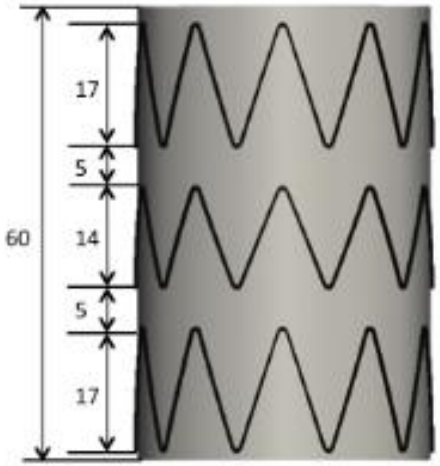
Case study

- 88yo
- Not suitable for Open Surgery

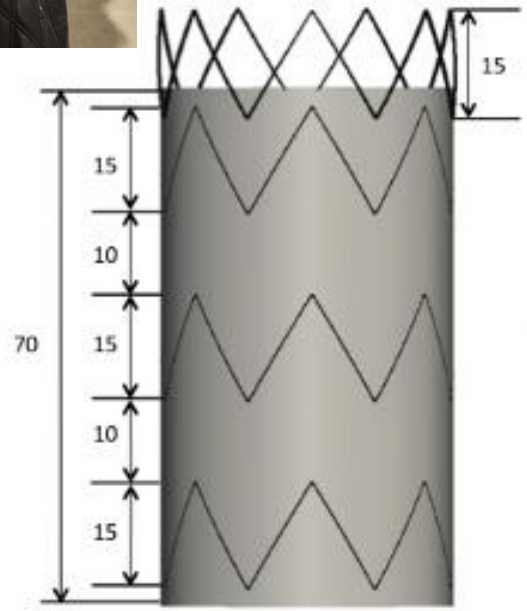


Device selection and deployment



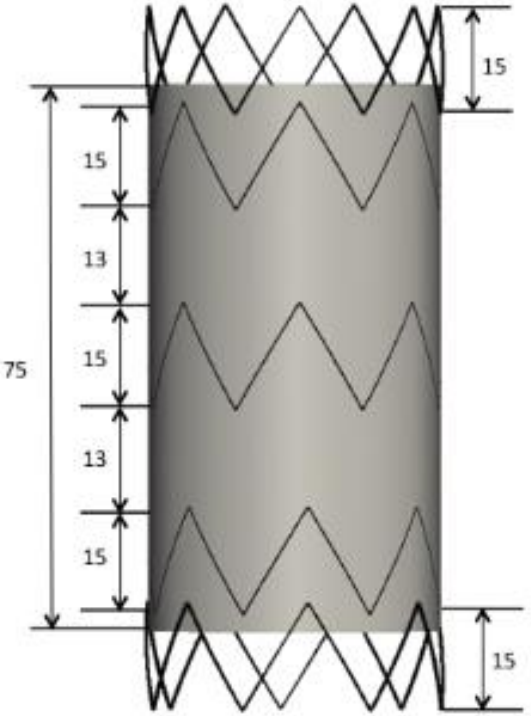
Stainless Steel
+ Dacron

A



Nitinol + Dacron
1 bare ring
(proximal)

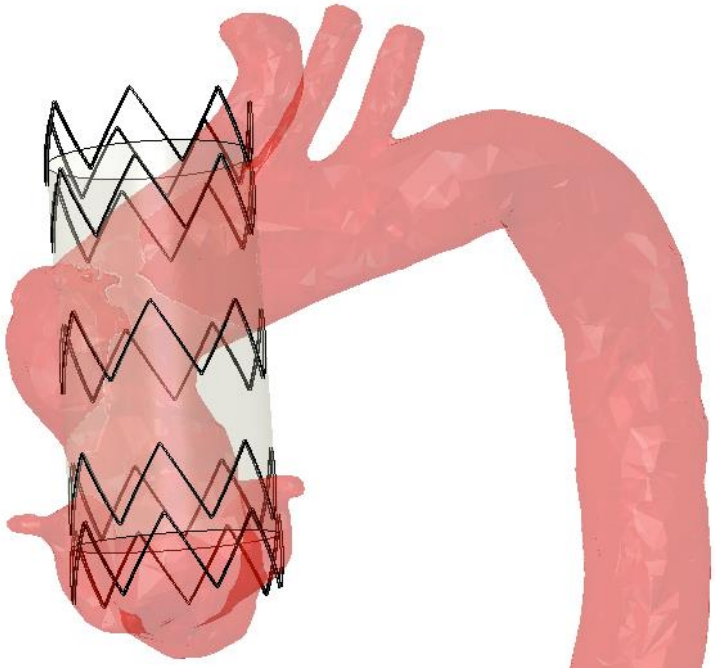
B



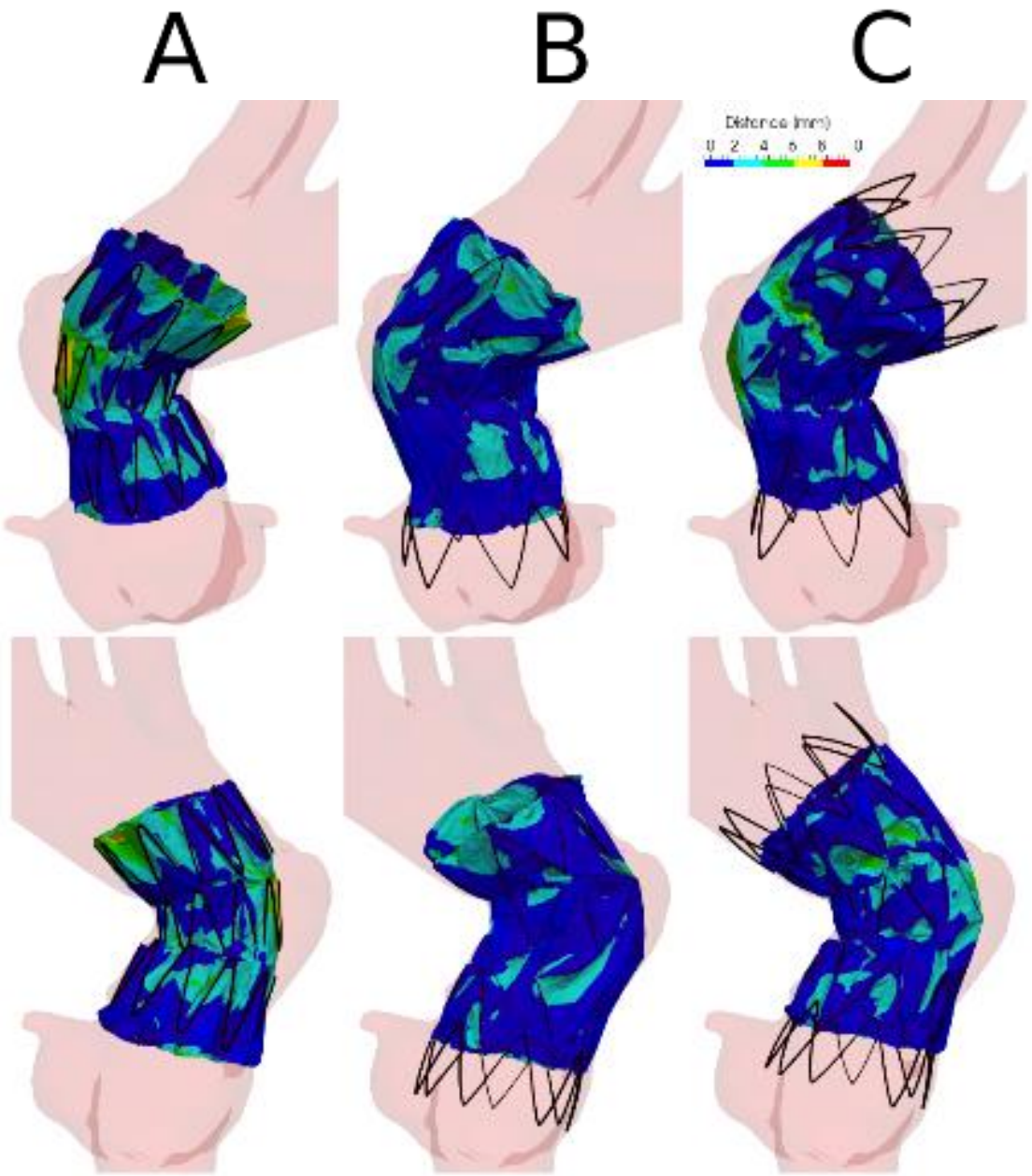
Nitinol + Dacron
2 bare rings

C

Results and Conclusions



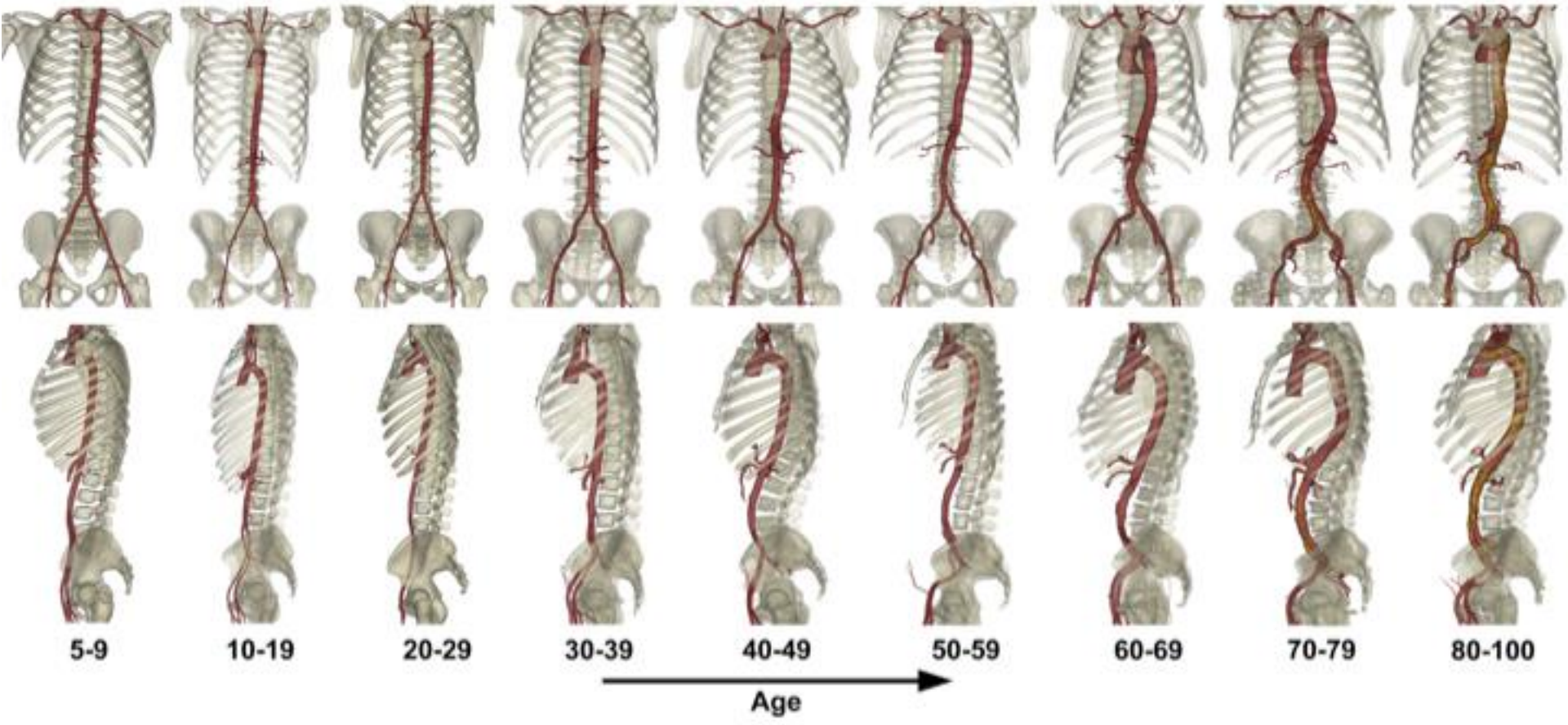
Virtual TEVAR can help surgery planning in the **Ascending Aorta**



University of Nebraska Medical Center

Other: Ageing and hemodynamics

Submitted JACC Feb 2018

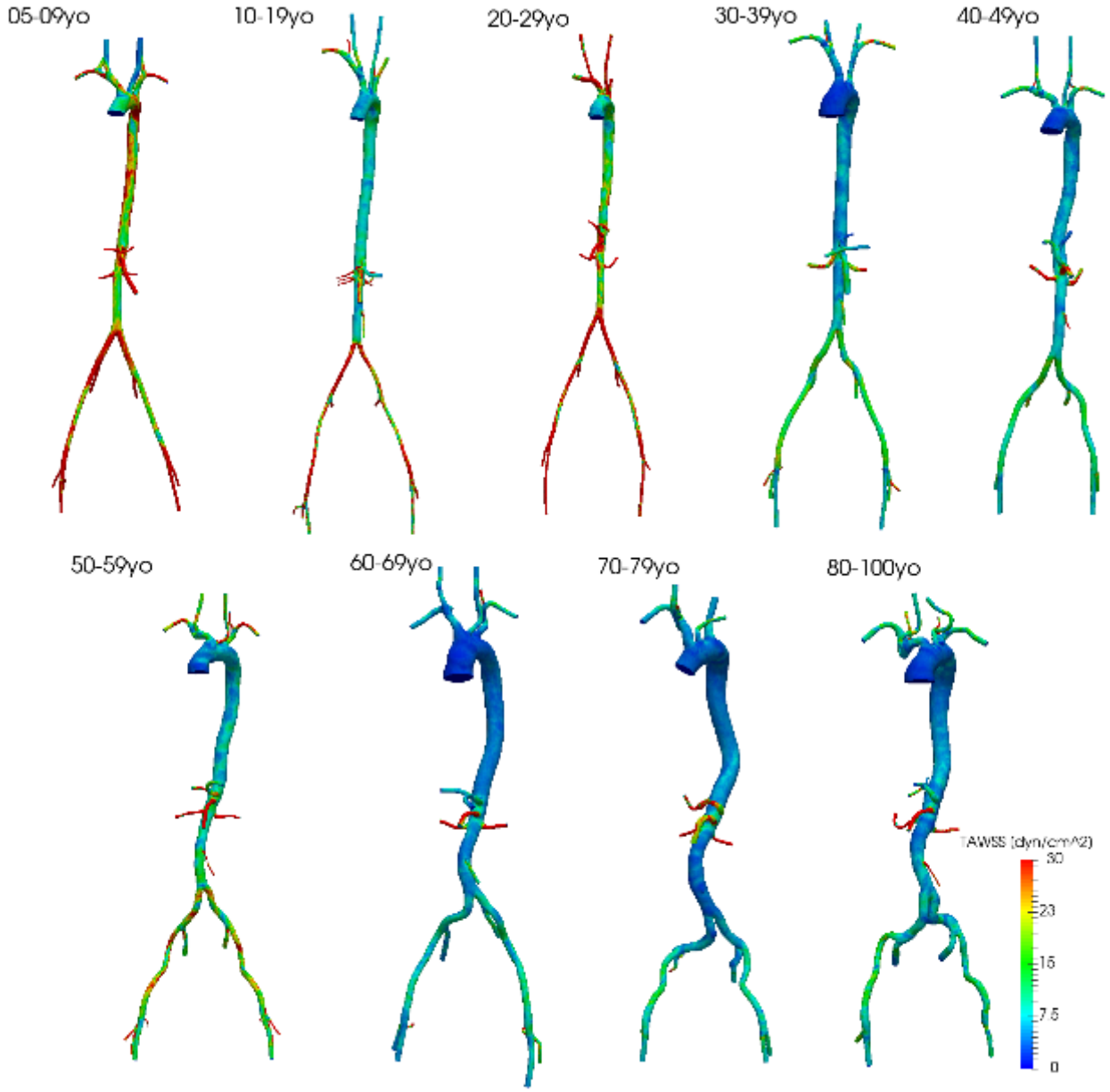


What is the impact of ageing in hemodynamics?

University of Nebraska Medical Center

Other: Ageing and hemodynamics

Submitted JACC Feb 2018



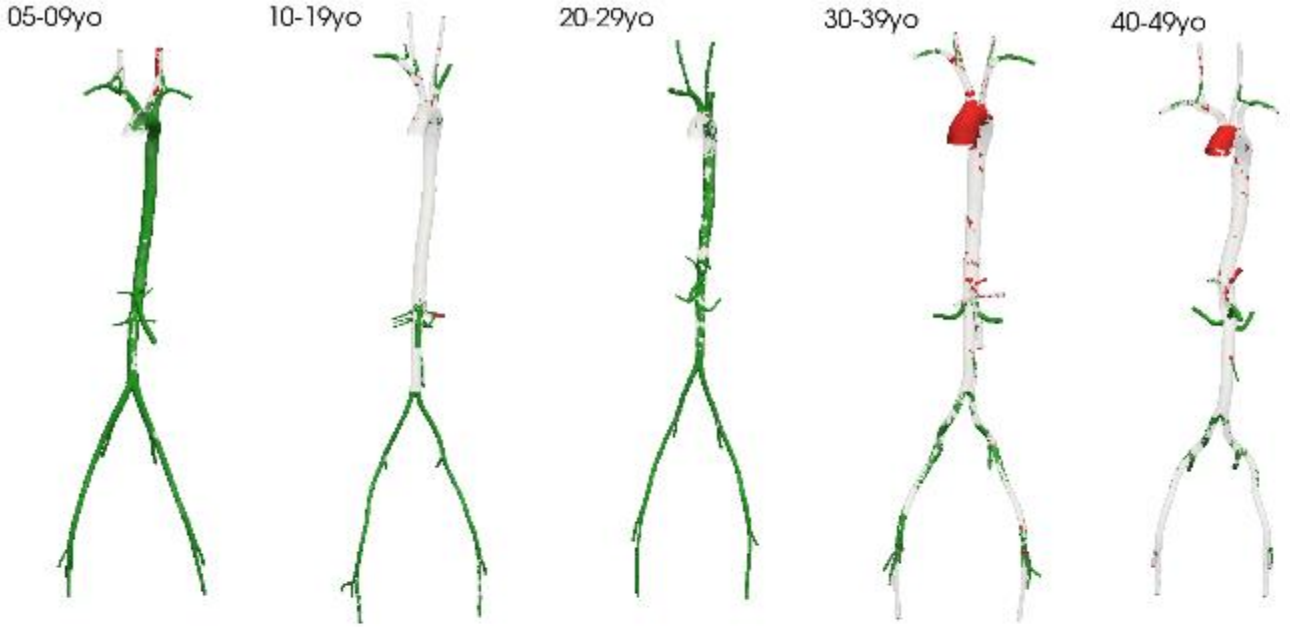
Atherogenic
TAWSS
<0.4 Pa

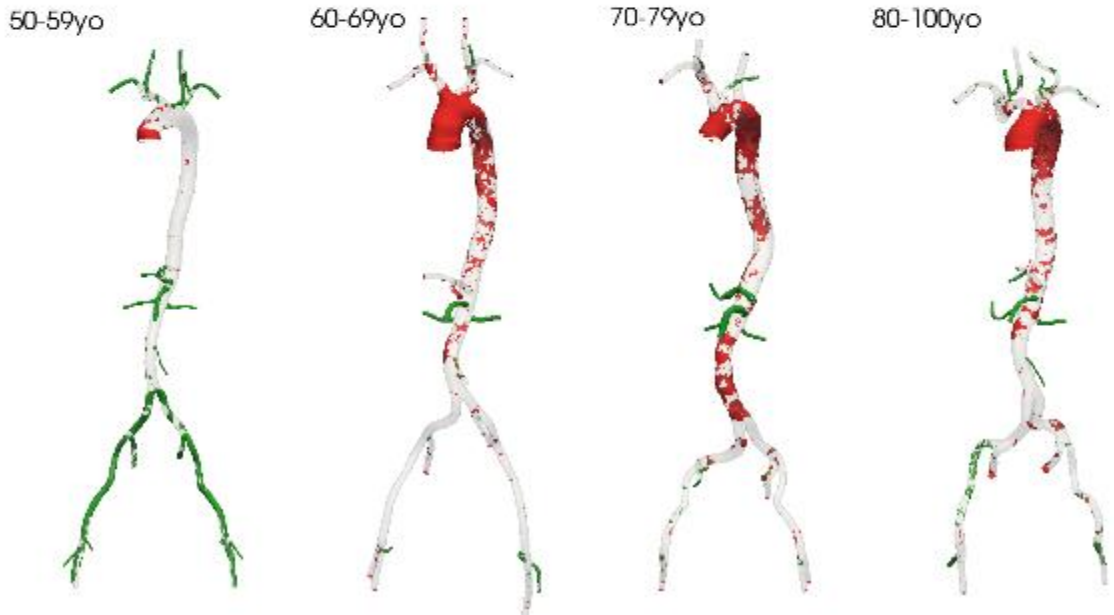
Atheprotective
TAWSS
>1.5 Pa

University of Nebraska Medical Center

Other: Ageing and hemodynamics

Submitted JACC Feb 2018





atheroprotective
atherogenic

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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