Computational analysis of coronary artery bypass graft configurations

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Introduction

Coronary artery bypass grafting (CABG)

- Vessel from elsewhere in body used to bypass blockage in coronary circulation
- Internal thoracic artery (ITA) best option – runs through thoracic cavity parallel to spine; divided into left and right (LITA/RITA)
- Coronary arteries and ITAs have distinct, segment-specific, material properties

Long-term success of CABG

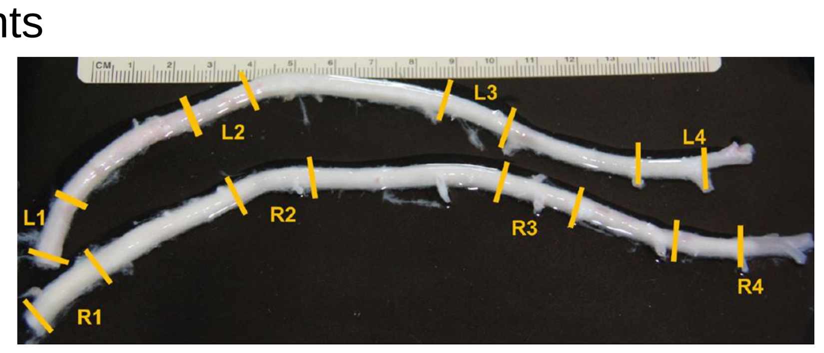
- Dependent upon match of donor and recipient vessel
- If vessels are too different in size, histology, etc. poor clinical outcomes
- Long-term inflammatory response → disease state

Can we use fluid and solid finite element analyses to determine ideal combinations of coronary and thoracic arteries for CABG?

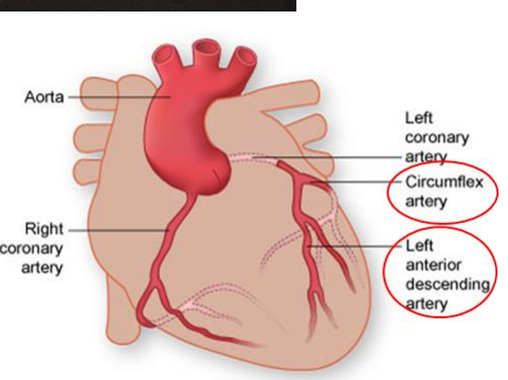
Methods

Modeled combinations of 4 coronary artery segments and 8 ITA segments

- Used FEBio[1] – finite element analysis engine
- Thoracic artery: divided LITA and RITA each into 4 segments



- Coronary artery: proximal & distal left anterior descending artery (PLAD/DLAD), right coronary artery (RCA), and left circumflex artery (LCX)



Two main components of modeling pipeline

- Solid mechanics: find stresses on vessels before and after anastomosis and reperfusion
- Fluid dynamics: model blood flow through the connected vessels

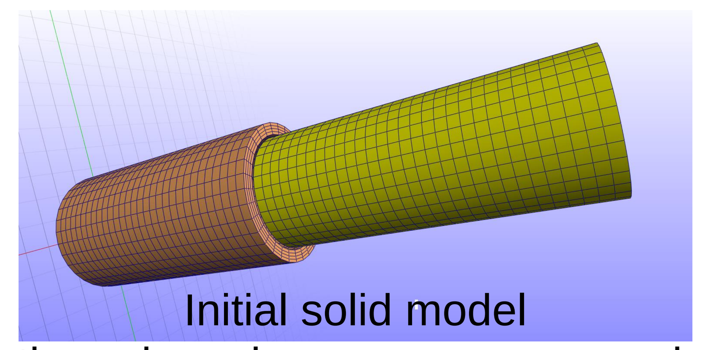
Solid mechanics

- Model vessels as Holzapfel-Gasser-Ogden material[2]
- Parameter(s) of interest: Spatial measurements of 1st & 2nd principal stresses

Fluid dynamics

- Model blood as Carreau fluid[3]
- Body-weight scaled blood velocity from literature[4]
- Parameters of interest: fluid velocity, fluid shear stress, pressure gradient

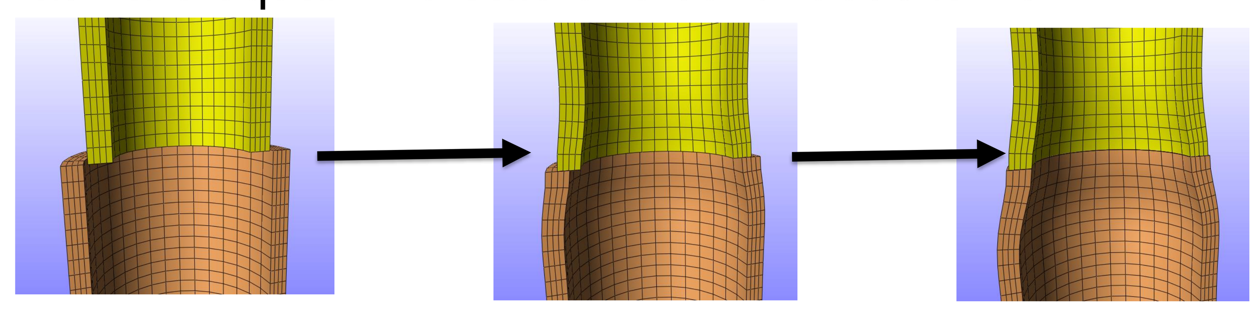
Solid Mechanics



← thoracic end coronary end →

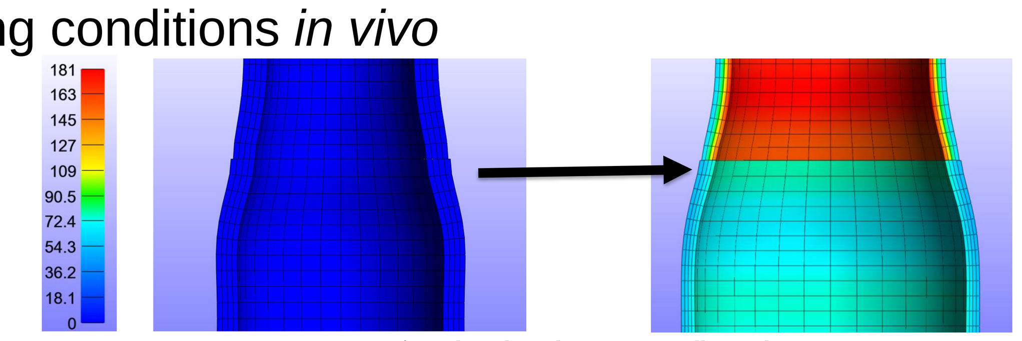
Tapering step

- Constrict thoracic artery and dilate coronary artery until internal radii are equal → create one continuous lumen



Inflation step

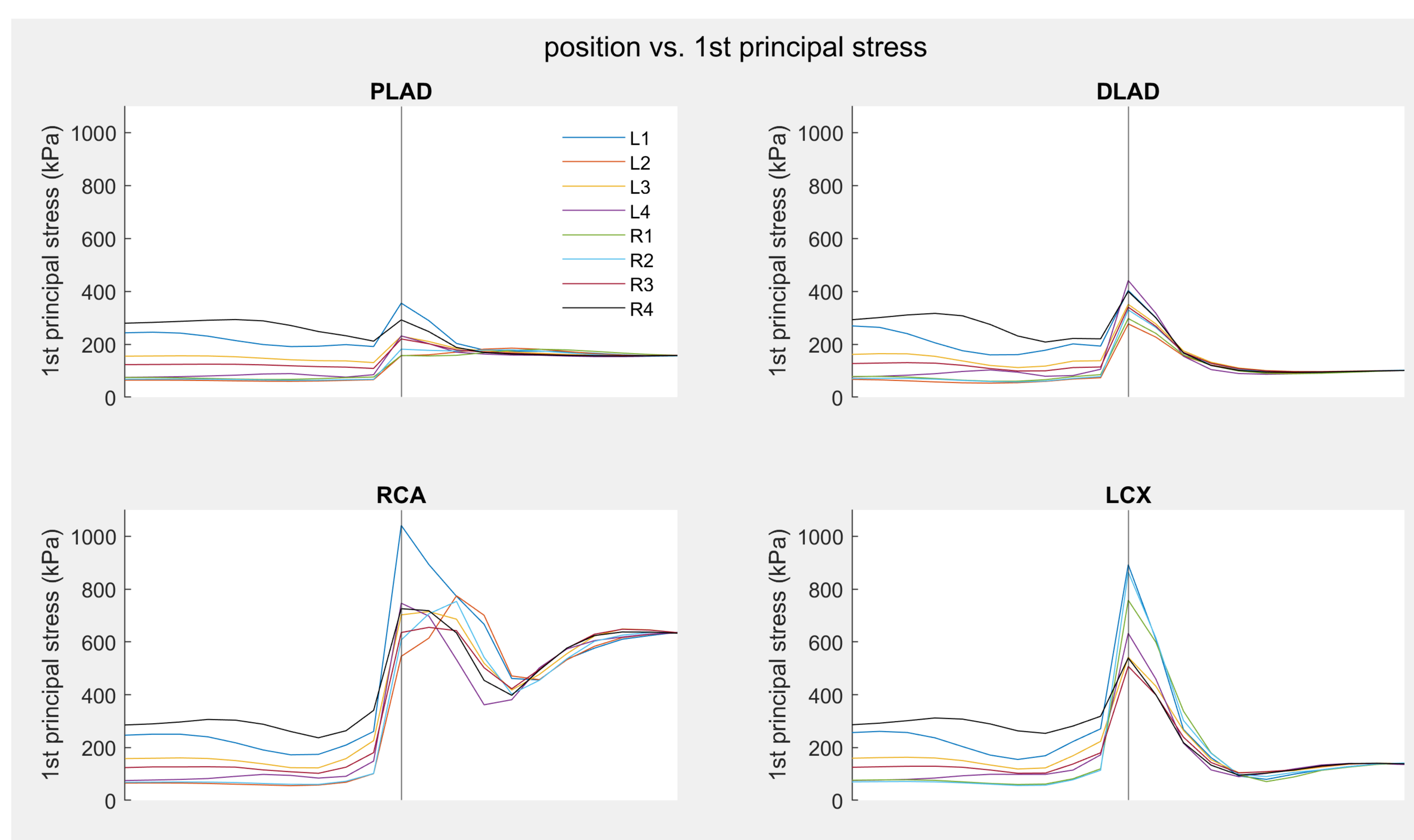
- Apply mean blood pressure to connected arteries to simulate loading conditions *in vivo*



1st principal stress (kPa)

1st principal stress

- Find stress on the inside of the vessel wall after inflation



Vertical indicates anastomosis site. Internal wall of thoracic artery to left of center line; internal wall of coronary artery to right of center line.

Conclusions

Combinations of RCA and LCX result in higher peak stress

- <u>RCA</u>: L2/R2 minimize 1st principal; L3/R3 minimize fluid shear
- <u>LCX</u>: R4 best combination, minimizes both stresses

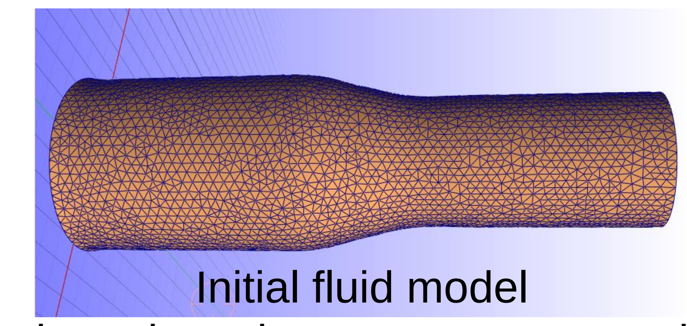
PLAD and DLAD – generally lower peaks of stress

- L2 and R1 minimize 1st principal stress

Future work

- Model a more realistic anastomotic geometry
- Consider fluid-solid interactions within the model

Computational Fluid Dynamics

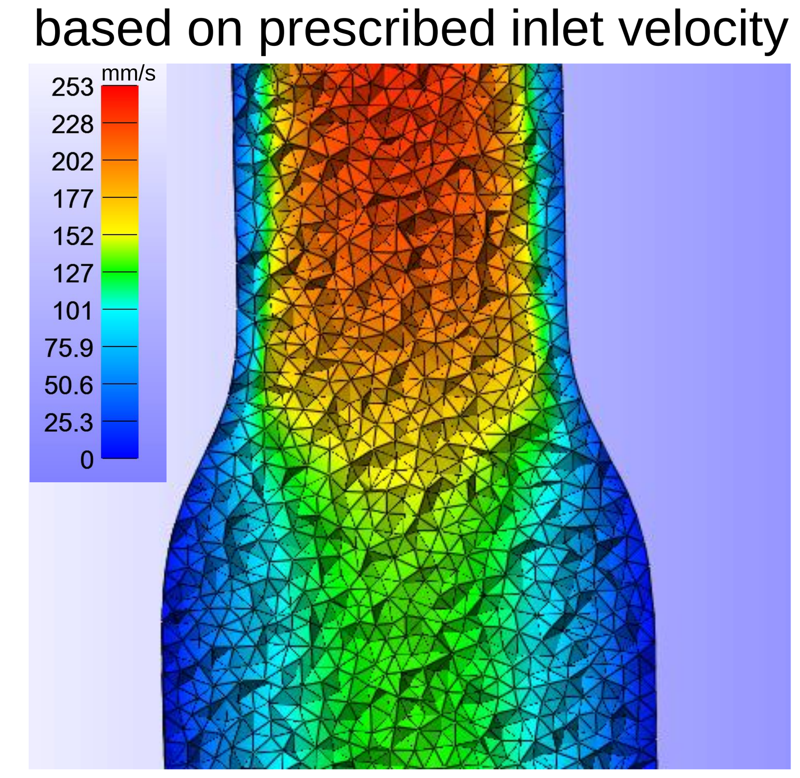


← thoracic end coronary end →

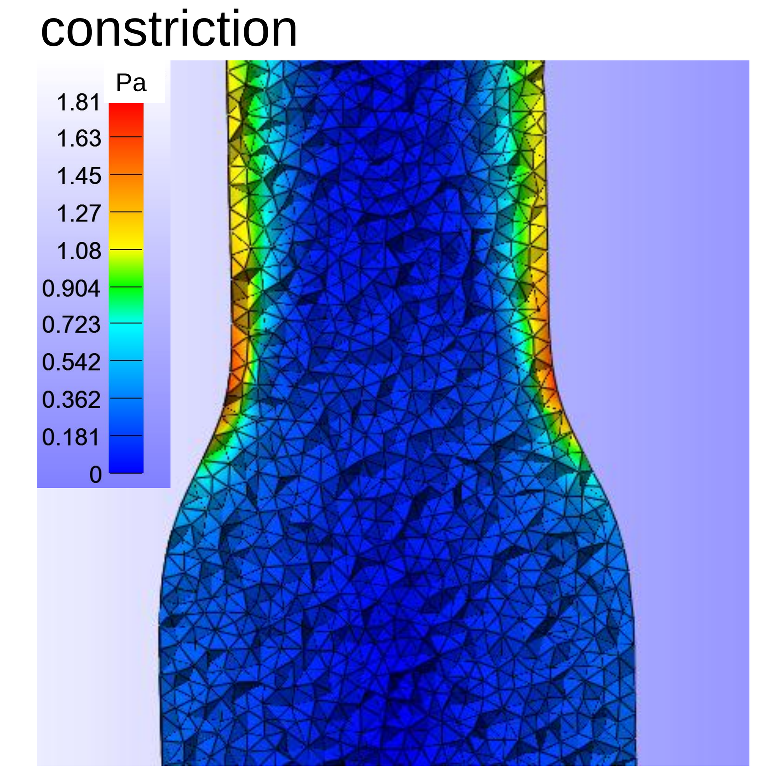
Fluid flow modeling

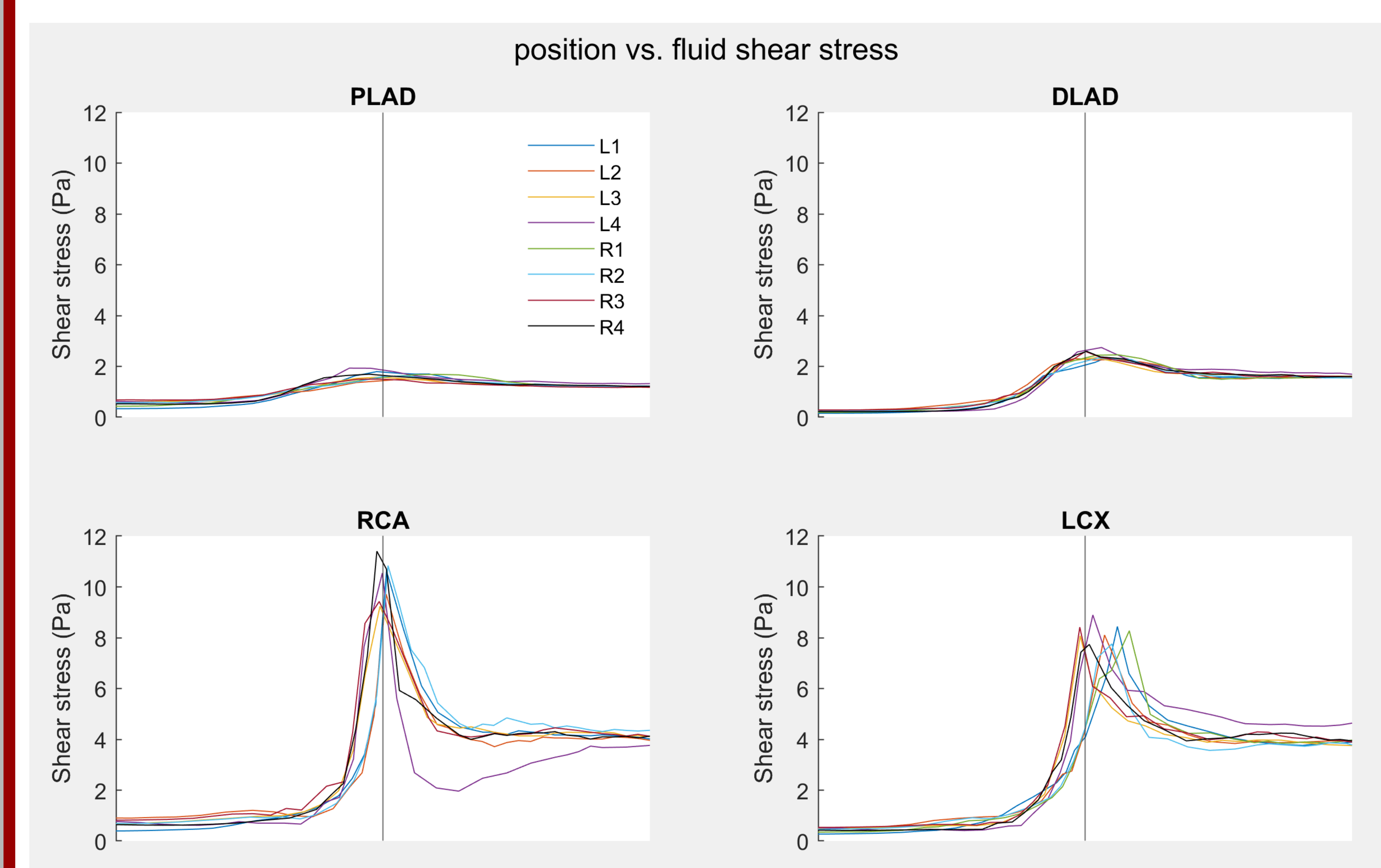
- Blood flows from thoracic inlet to coronary outlet
- Geometry for CFD created from deformed geometry generated in solid mechanics analysis

Fluid velocity at the coronary outlet based on prescribed inlet velocity



Fluid shear stress around the constriction





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