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An AI-ready Vascular Model Repository for Modeling and Simulation in Cardiovascular Disease

Principal Investigator

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NOT-OD-21-094 AI-Readiness: Closeout meeting — Oct 31st - Nov 1st

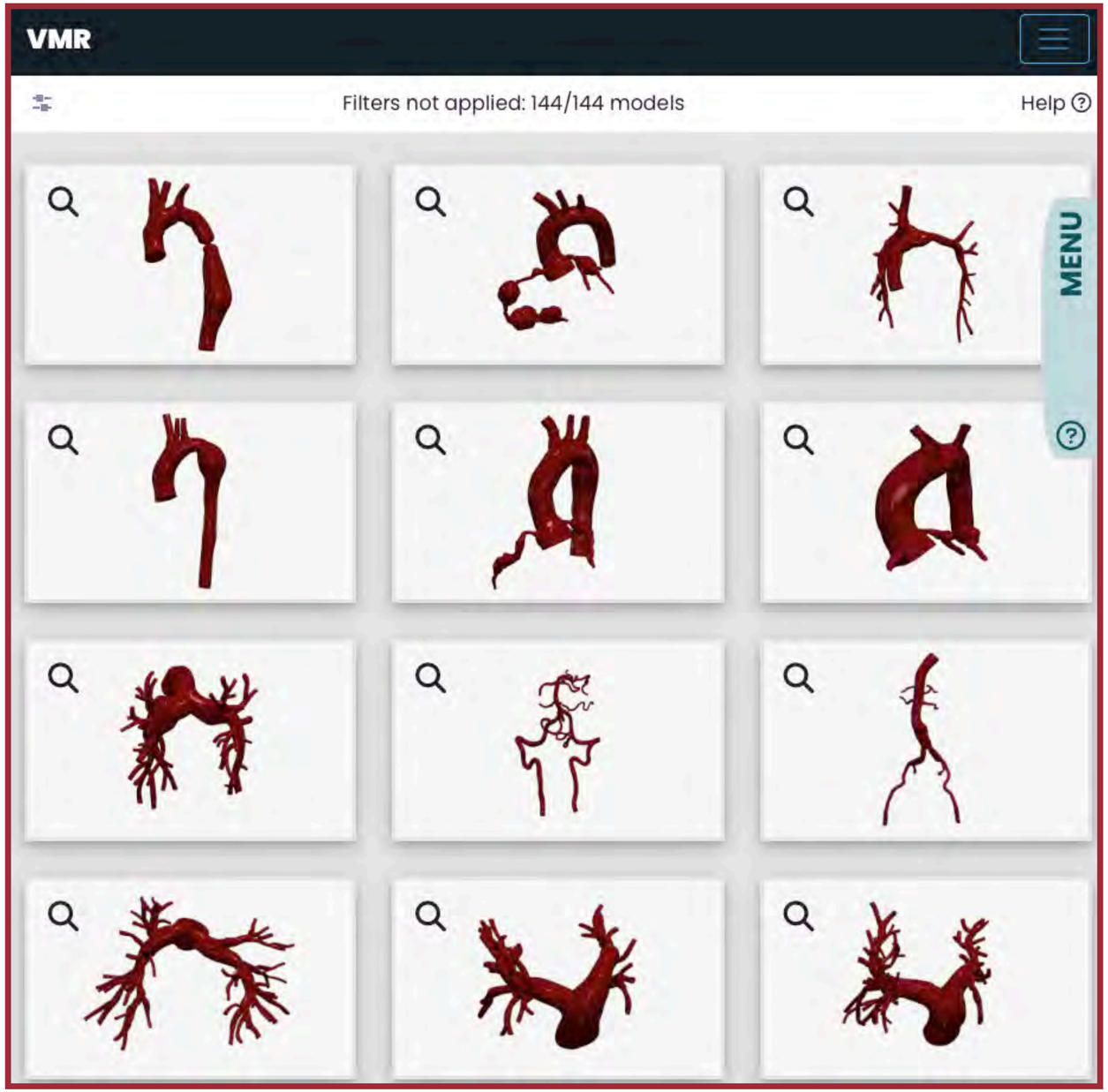
Goals of the project

- Create publicly available platform to **share cardiovascular models and simulations.**
- Understand **strengths and limitations** of available reduced order models.
- Train machine learning algorithms to **automate 3D model generation** and **simulation accuracy.**

The Vascular Model Repository (VMR) by the numbers

- Available at www.vascularmodel.com
- 144 SimVascular* projects
- 111 simulation results
- More than 5500 downloads
- 3000 users worldwide

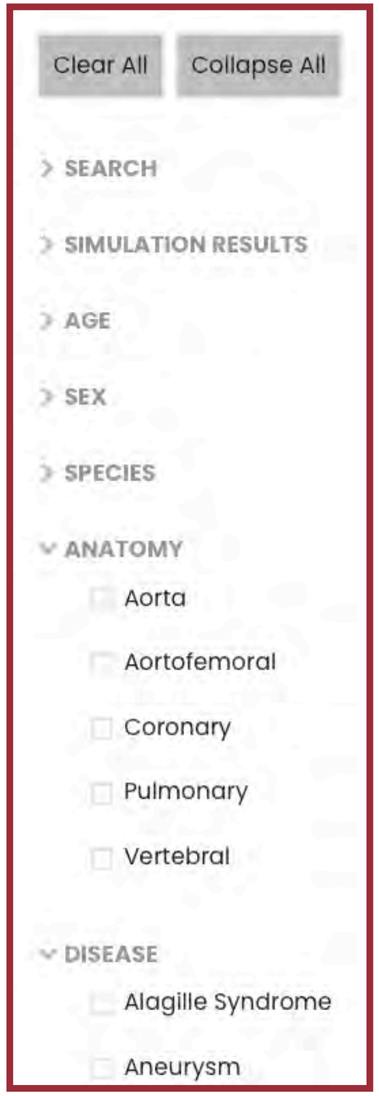
COUNTRY	USERS
United States	1.3K
China	504
Italy	142
India	134
United Kingdom	111
Germany	90
Canada	74



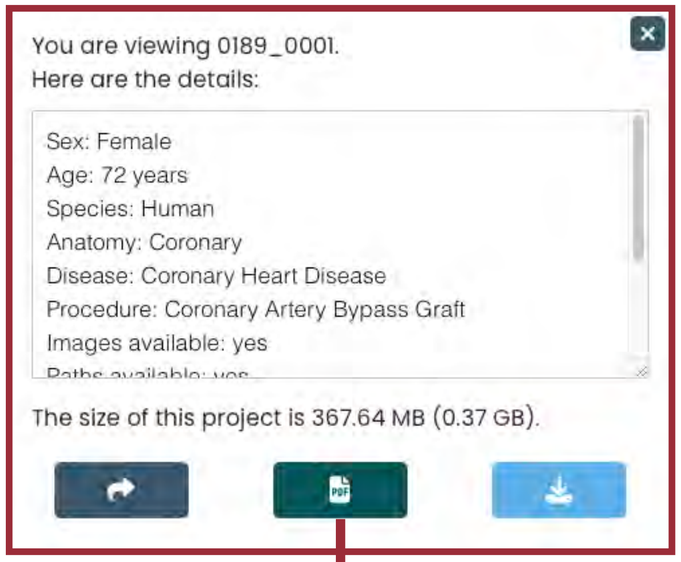
[*] http://simvascular.github.io

Improved website

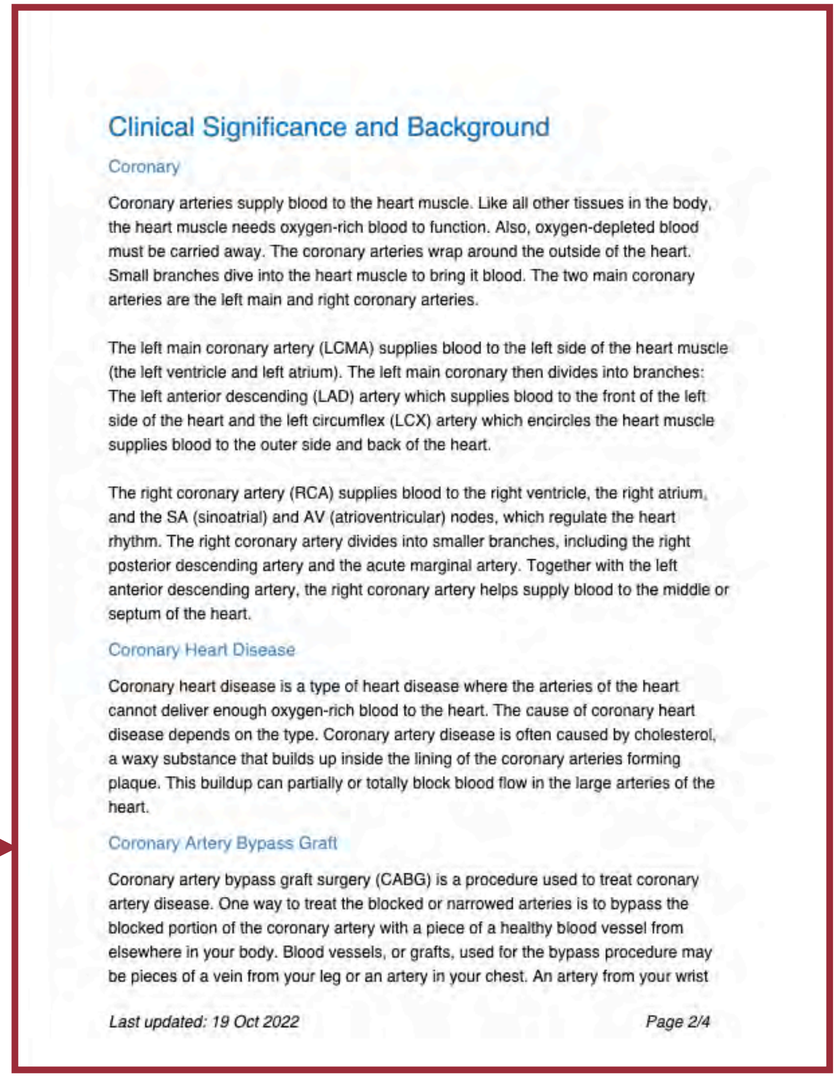
Filters to speed up query of relevant cardiovascular models



Patient information readily available online



PDF specification document with patient-specific information



Clinical Significance and Background

Coronary

Coronary arteries supply blood to the heart muscle. Like all other tissues in the body, the heart muscle needs oxygen-rich blood to function. Also, oxygen-depleted blood must be carried away. The coronary arteries wrap around the outside of the heart. Small branches dive into the heart muscle to bring it blood. The two main coronary arteries are the left main and right coronary arteries.

The left main coronary artery (LCMA) supplies blood to the left side of the heart muscle (the left ventricle and left atrium). The left main coronary then divides into branches: The left anterior descending (LAD) artery which supplies blood to the front of the left side of the heart and the left circumflex (LCX) artery which encircles the heart muscle supplies blood to the outer side and back of the heart.

The right coronary artery (RCA) supplies blood to the right ventricle, the right atrium, and the SA (sinoatrial) and AV (atrioventricular) nodes, which regulate the heart rhythm. The right coronary artery divides into smaller branches, including the right posterior descending artery and the acute marginal artery. Together with the left anterior descending artery, the right coronary artery helps supply blood to the middle or septum of the heart.

Coronary Heart Disease

Coronary heart disease is a type of heart disease where the arteries of the heart cannot deliver enough oxygen-rich blood to the heart. The cause of coronary heart disease depends on the type. Coronary artery disease is often caused by cholesterol, a waxy substance that builds up inside the lining of the coronary arteries forming plaque. This buildup can partially or totally block blood flow in the large arteries of the heart.

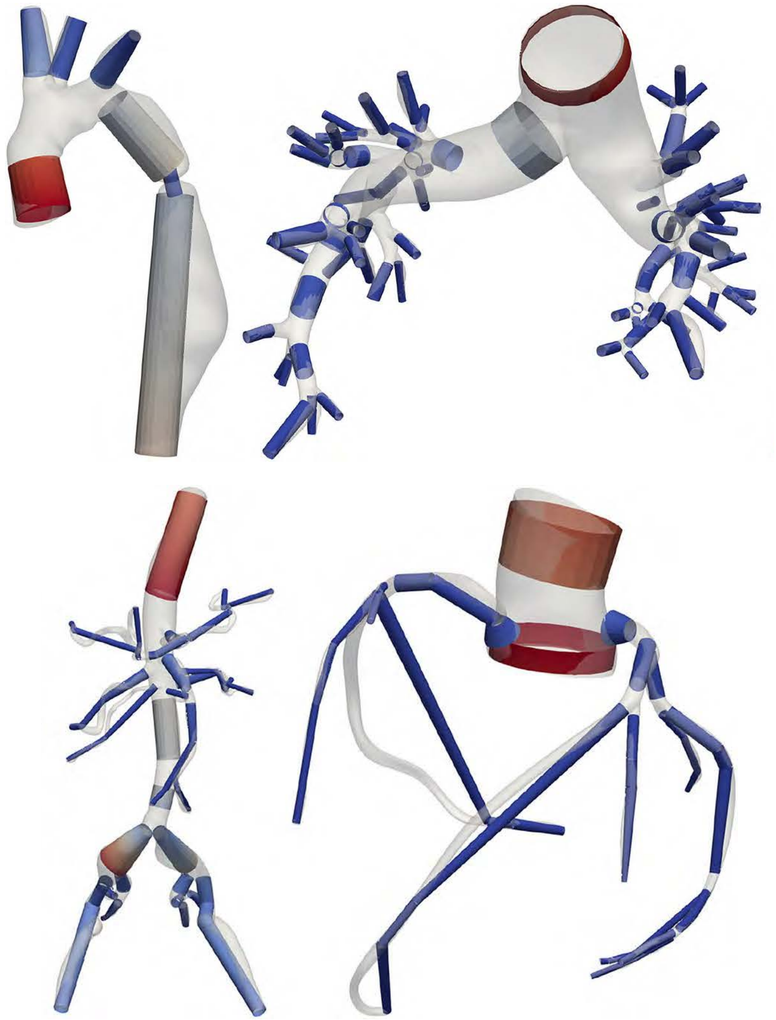
Coronary Artery Bypass Graft

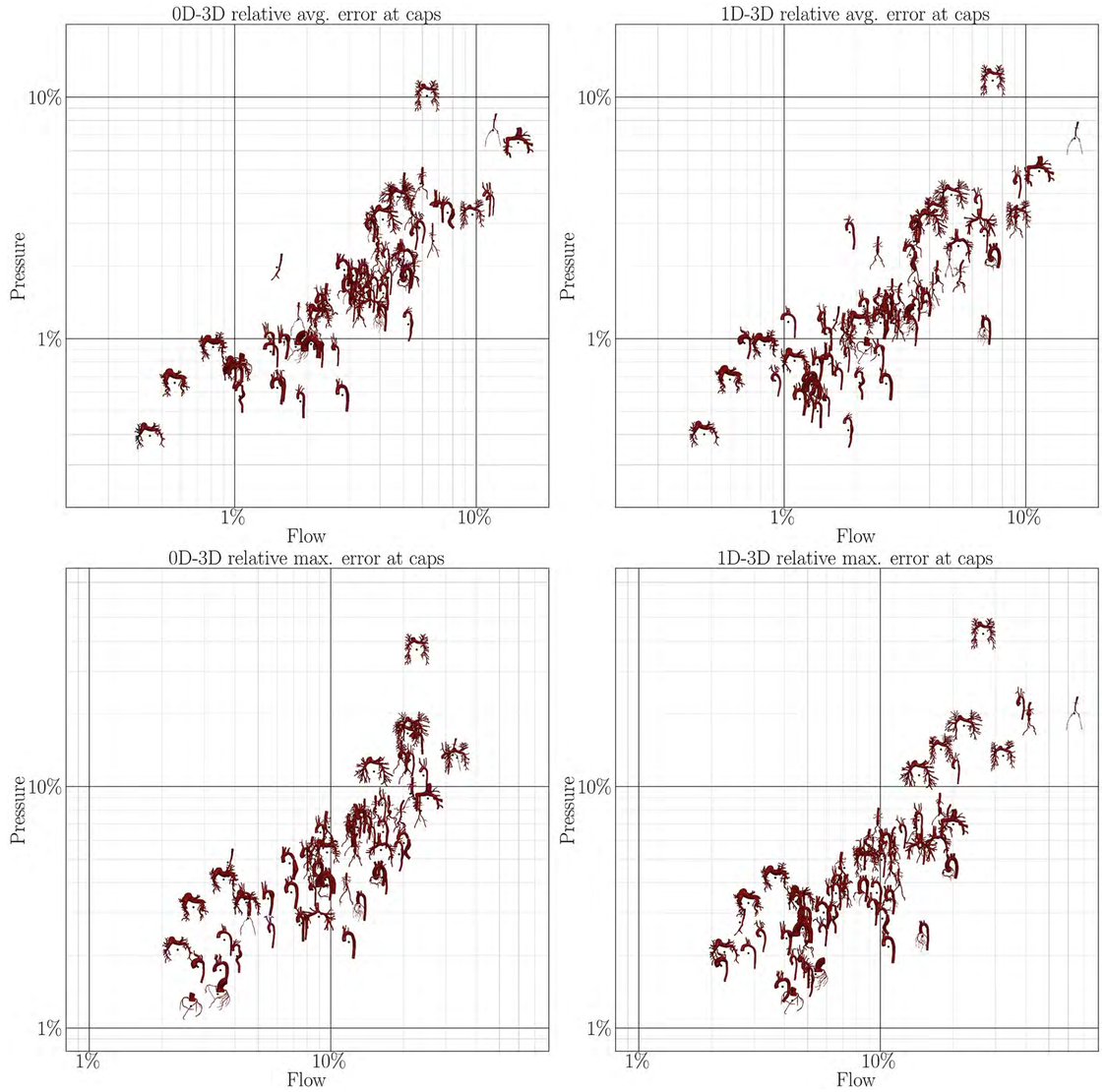
Coronary artery bypass graft surgery (CABG) is a procedure used to treat coronary artery disease. One way to treat the blocked or narrowed arteries is to bypass the blocked portion of the coronary artery with a piece of a healthy blood vessel from elsewhere in your body. Blood vessels, or grafts, used for the bypass procedure may be pieces of a vein from your leg or an artery in your chest. An artery from your wrist

Last updated: 19 Oct 2022 *Page 2/4*

Application: validation of reduced order models

We used models in the VMR to validate 0D and 1D reduced order models against 3D simulations.



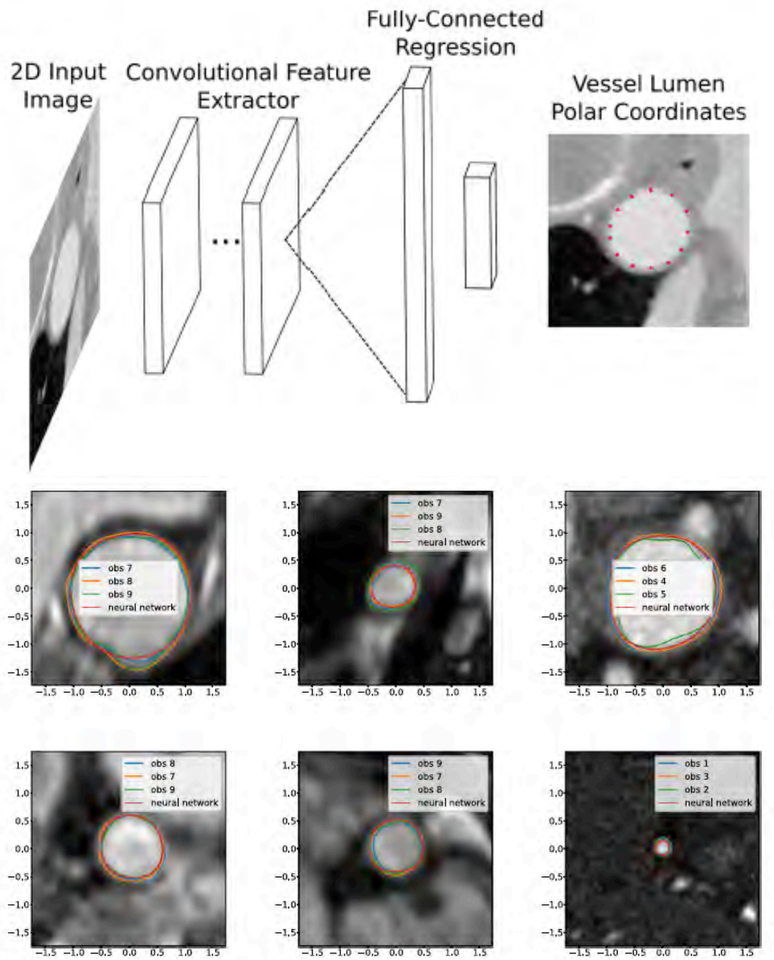


Pfaller et al. Automated generation of 0D and 1D reduced-order models of patient-specific blood flow. Int J Numer Meth Biomed Engng (2022).

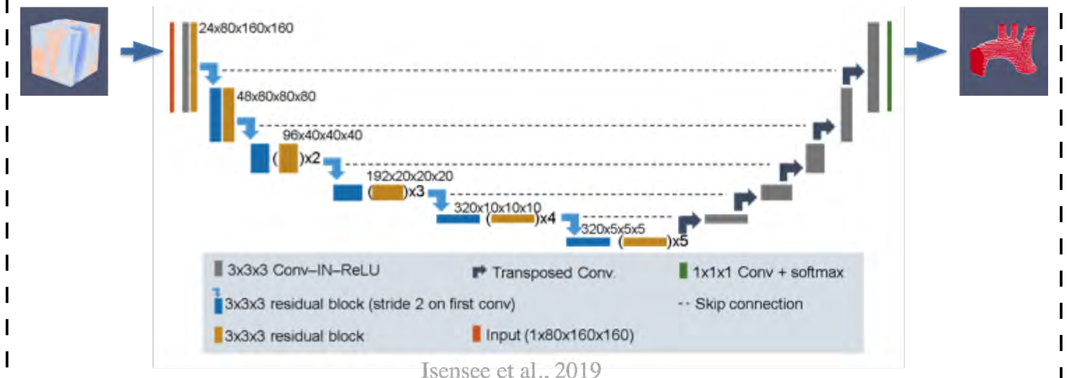
Application: data-driven segmentation

Segmentation is one of the bottlenecks of the pipeline in cardiovascular simulations. We want to train machine learning models on the VMR to automate this step.

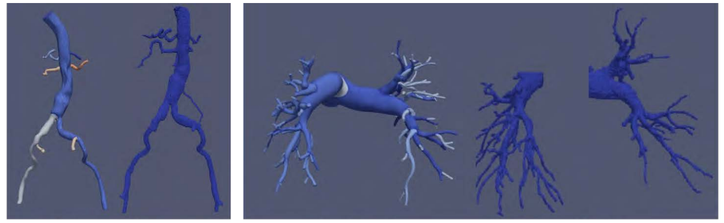
Convolutional networks for 2D segmentation*



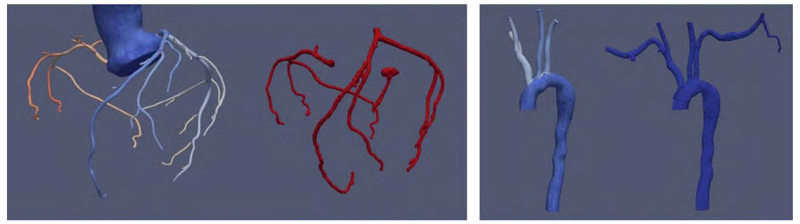
Neural network-based 3D segmentation



Isensee et al., 2019



Ground Truth Prediction Ground Truth Prediction



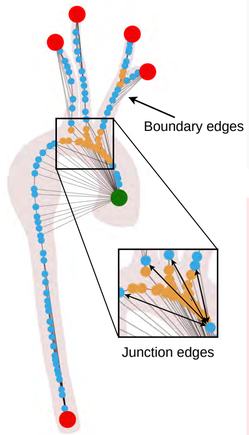
Ground Truth Prediction Ground Truth Prediction

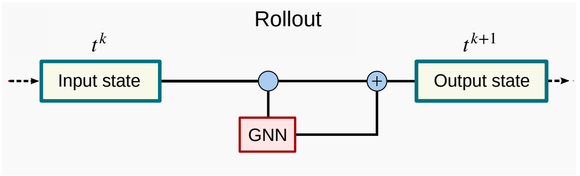
[*] Maher et al. Neural Network Vessel Lumen Regression for Automated Lumen Cross-Section Segmentation in Cardiovascular Image-Based Modeling. Cardiovascular Engineering and Technology (2020).

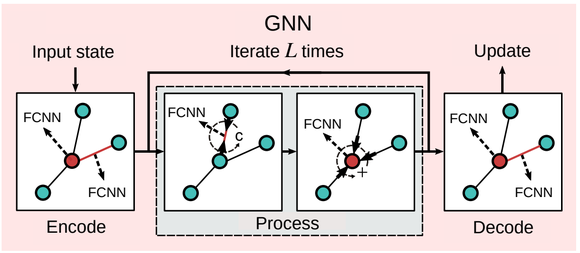
Application: data-driven reduced order models

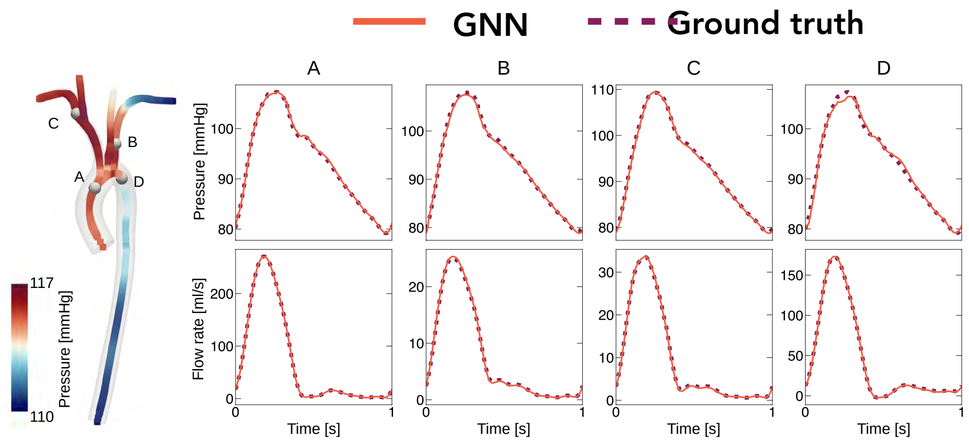
Reduced order models are efficient in solving average quantities (pressure and flow rate) but are sometimes inaccurate due to the underlying physical assumptions. We want to train accurate and efficient data-driven reduced order models using the VMR.

1D models based on graph neural networks*

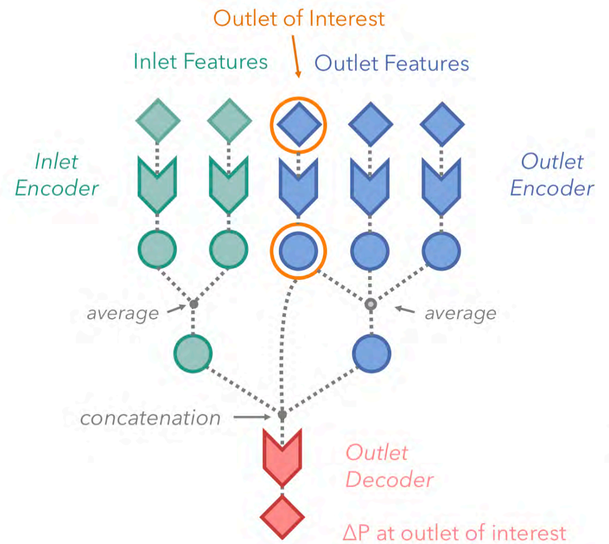


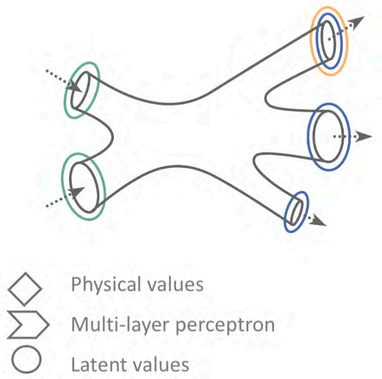






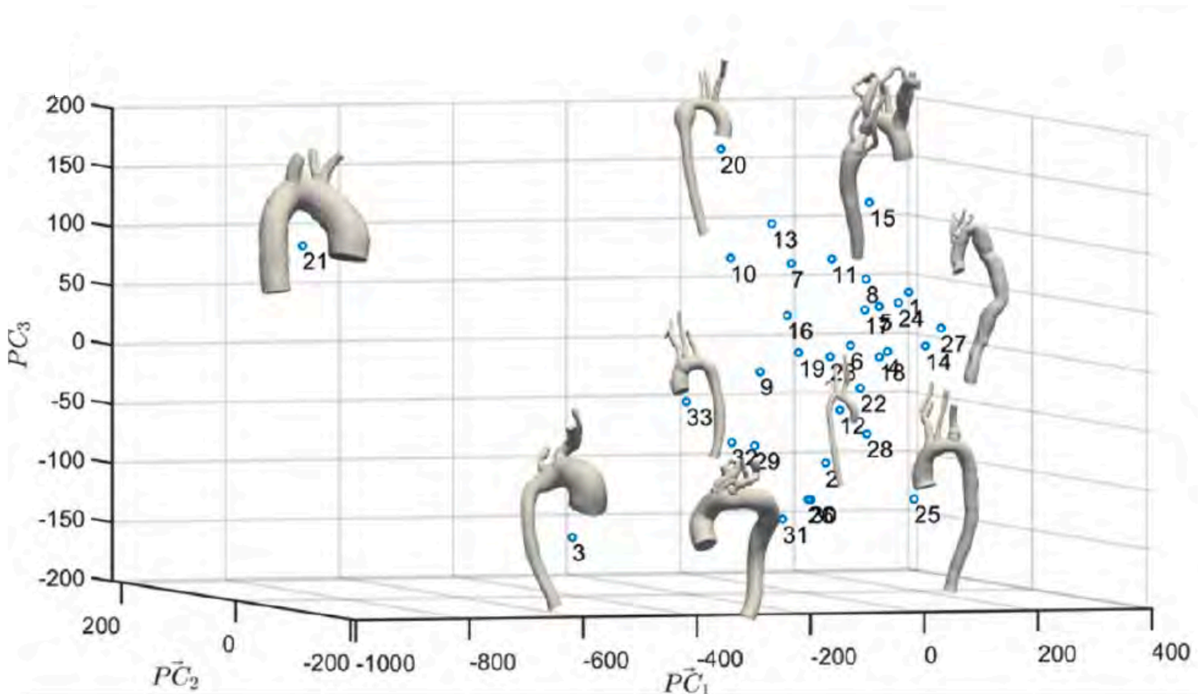
Data-driven junction models



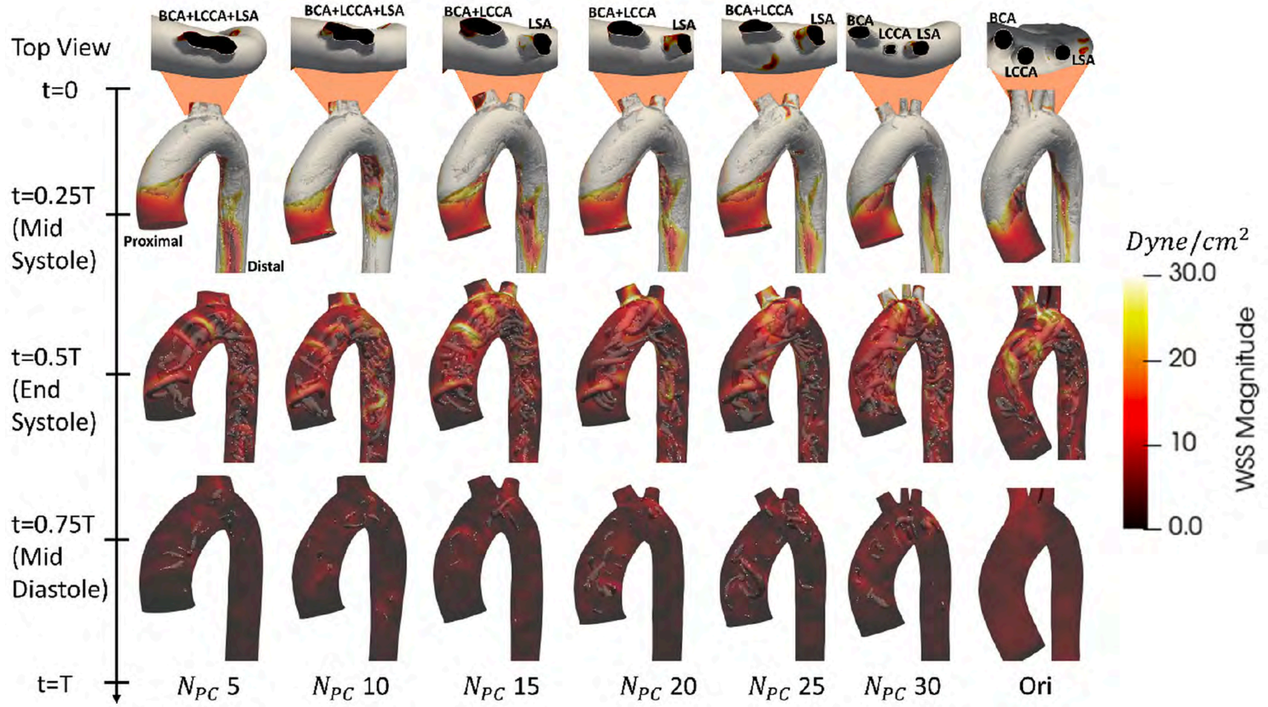


[*] Pegolotti et al. *Learning Reduced-Order Models for cardiovascular simulations with Graph Neural Networks*. Submitted to Learning on Graphs 2022.

Application: shape analysis of thoracic aorta



33 aorta models (24 taken from the Vascular Model Repository) were used to perform PCA-based Statistical Shape Modeling



Statistical models were used to study the effects of branch modeling on Wall Shear Stress approximation

Wiputra, et al. Statistical shape representation of the thoracic aorta: accounting for major branches of the aortic arch. Computer Methods in Biomechanics and Biomedical Engineering (2022).

Next steps

- Continue **increasing the number of models** in the Vascular Model Repository.
- Implement semi-automated process to **accept submissions** from other research groups.
- Final goal: employ machine learning and artificial intelligence to enable **fast and reliable use of cardiovascular simulations** in the clinic.

References

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Wilson NM, Ortiz AK, Johnson AB. T*he vascular model repository: a public resource of medical imaging data and blood flow simulation results.* Journal of medical devices. 2013 Dec 1;7(4). https://pubmed.ncbi.nlm.nih.gov/24895523/

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