Simulating Blood Flow in the Pulmonary Artery using Physics-Informed Neural Networks

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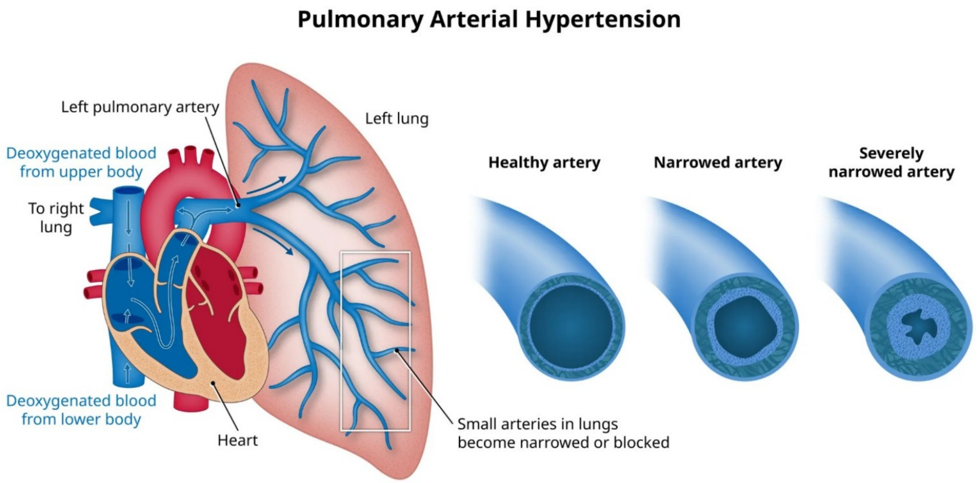
What is Pulmonary Arterial Hypertension (PAH)?

- Rare, progressive, mPAP > 20 mmHg at rest
- Late diagnosis: 2 to 3 years, 4 to 6 physicians
- Structural alterations of the vascular wall
- **Highly invasive evaluation**

Subject-specific computational models:

- **Non-invasive**
- In silico experimentation
- Gain prediction capabilities



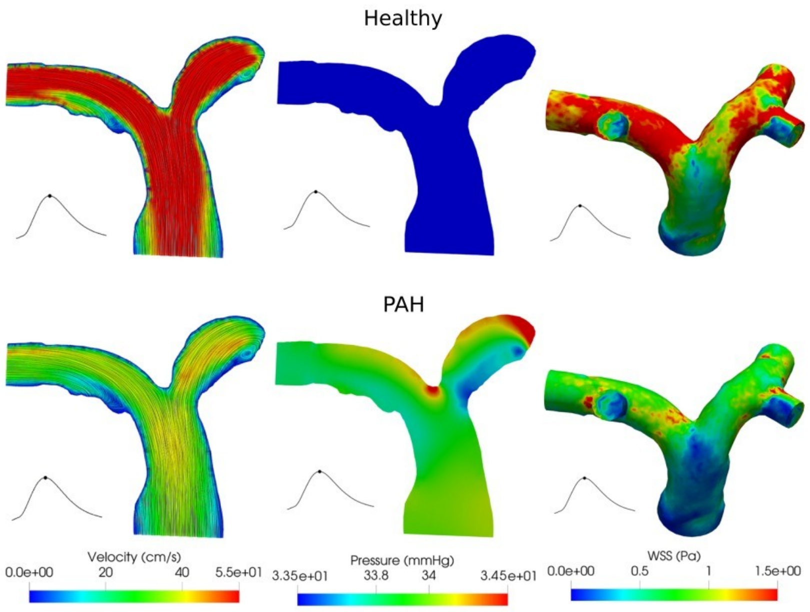
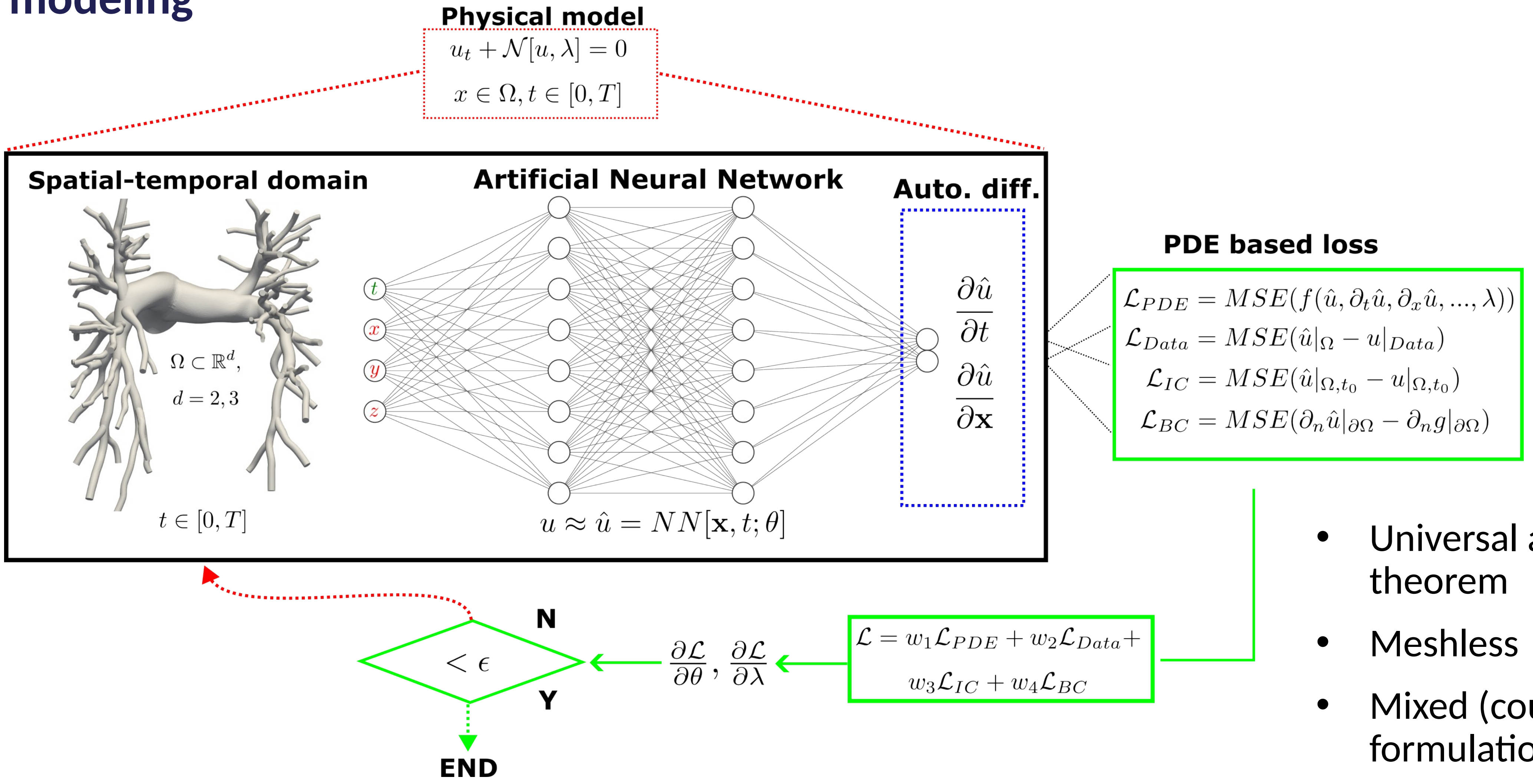


Fig. 10 Systolic peak ($t = 1.9$ s). Left: Velocity field. Center: Pressure field. Right: WSS field. Test VI

ESC/ERS Guidelines 2022; Jorge etal. 2016; Hoeper etal. 2017; Lan etal. 2018

Kong etal. 2019; Marcinno etal 2023; Garay etal. 2023

Physics-Informed neural networks (PINNs) for computational modeling

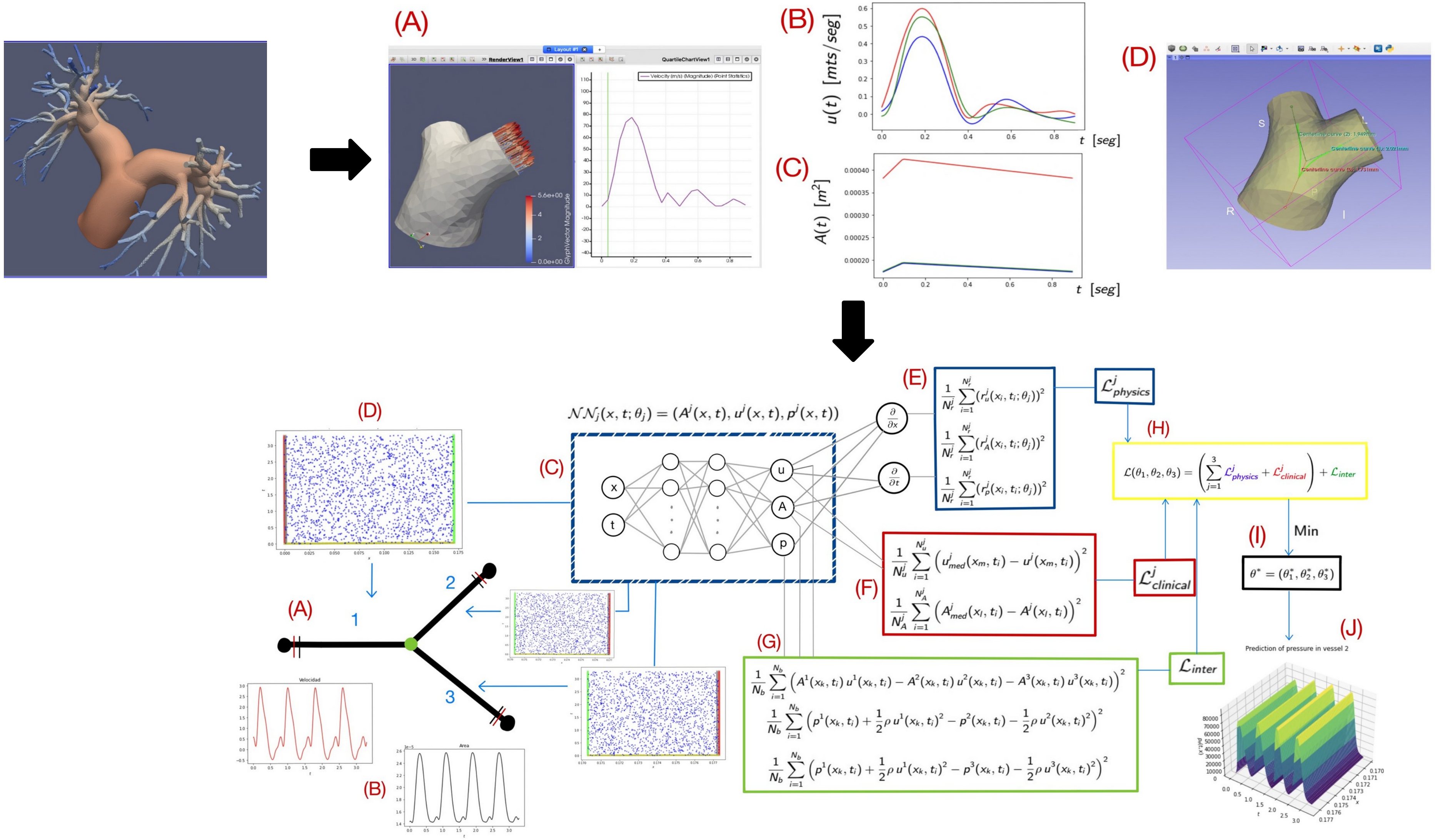


- Universal approximation theorem
- Meshless
- Mixed (coupled) formulations
- Forward and inverse problems

Raissi etal. 2019, Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations.
Karniadakis etal 2021, Physics-informed machine learning

PINNs used in blood flow modeling

Jara 2023. Pulmonary artery blood pressure estimation using PINNs



PINNs used in blood flow modeling

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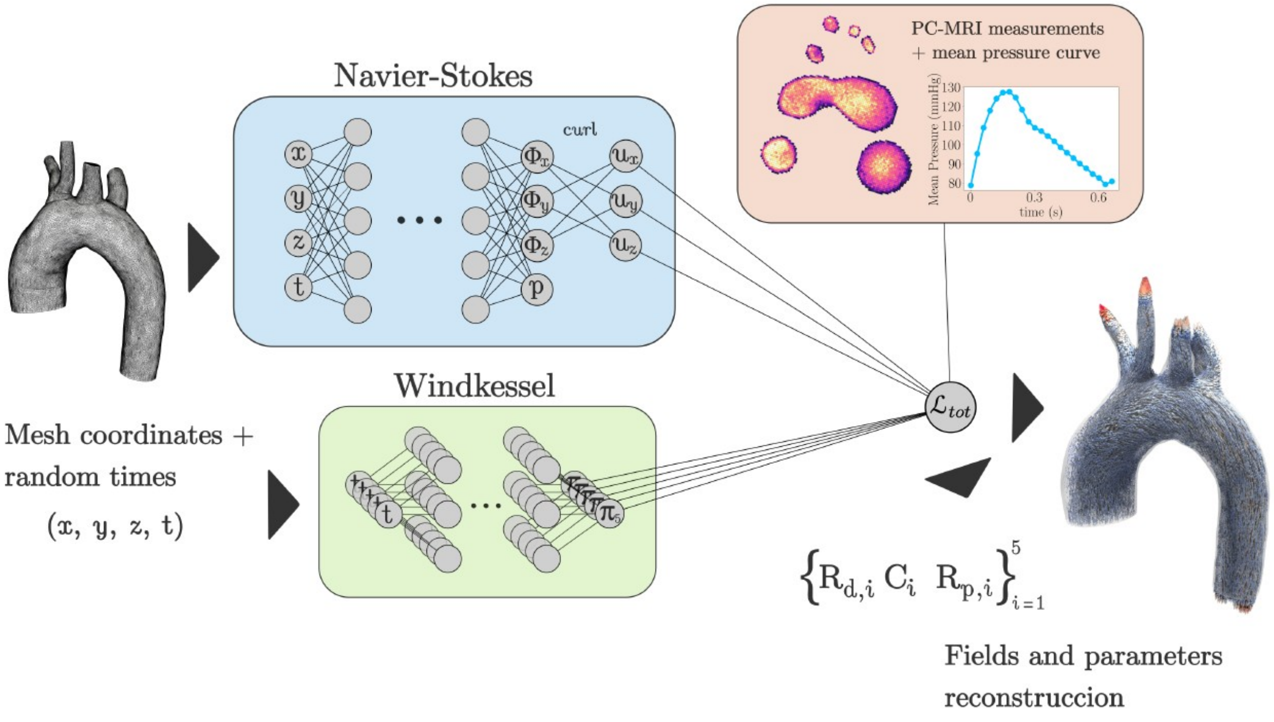
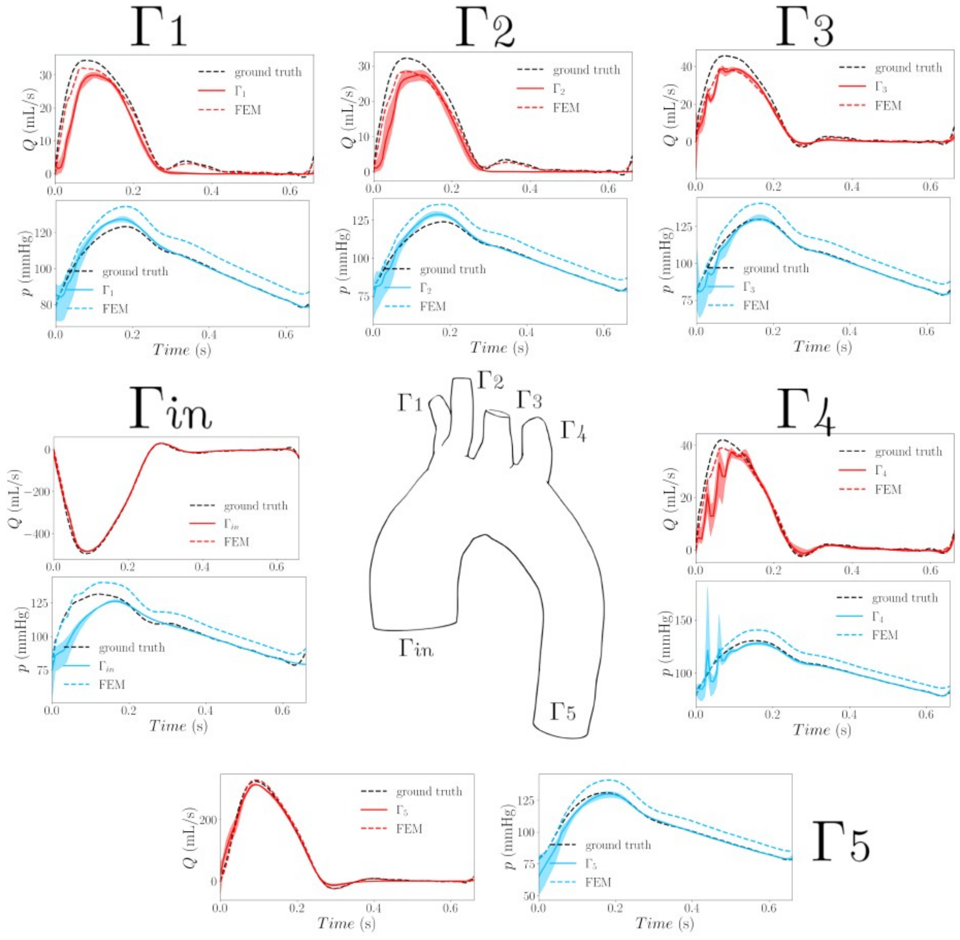
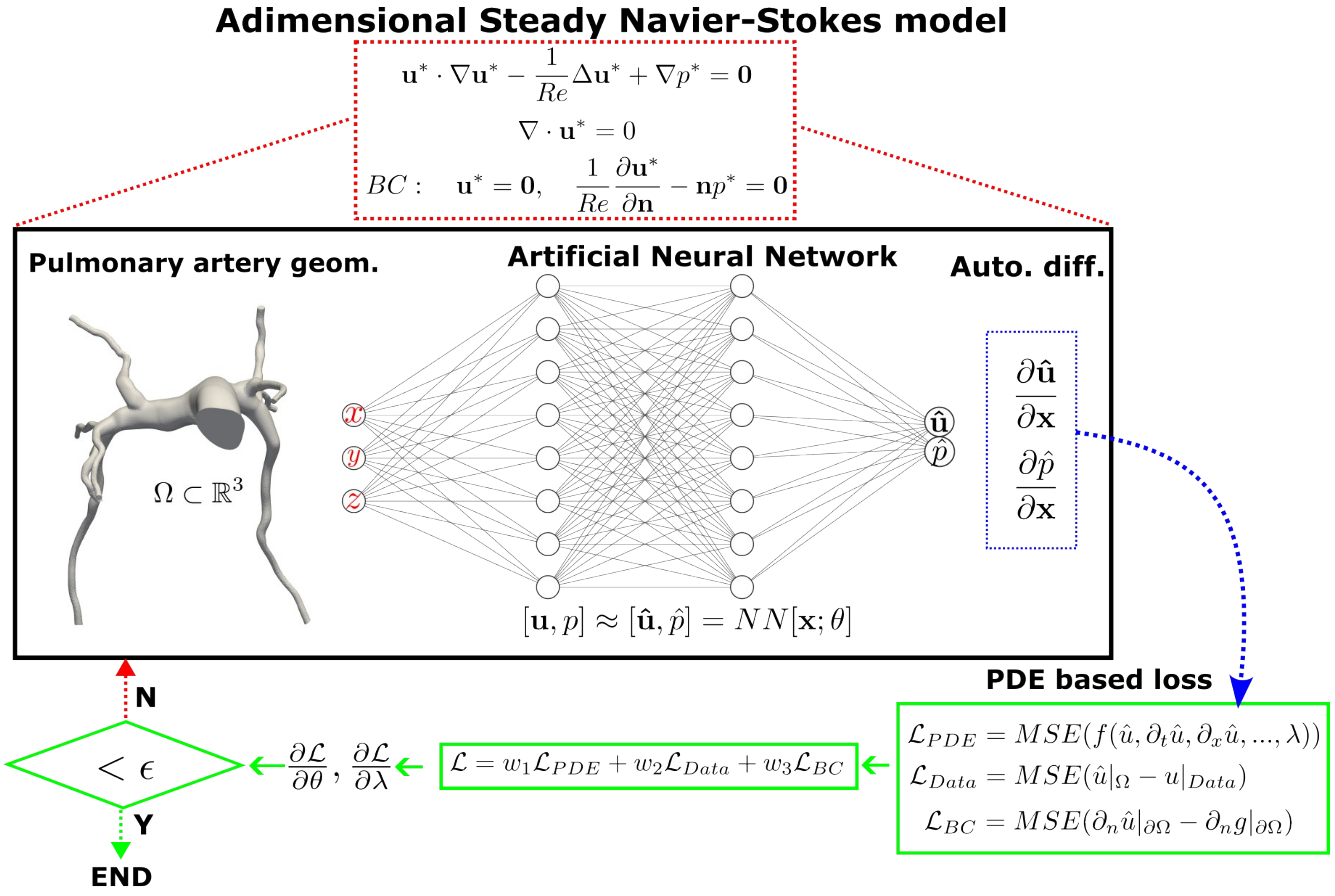
Garay 2023. Physics-informed neural networks for blood flow inverse problems





Other works related to PINNs in blood flown: Sarabian etal. 2022; Dadan Ma 2023

Our approach



Parameters:

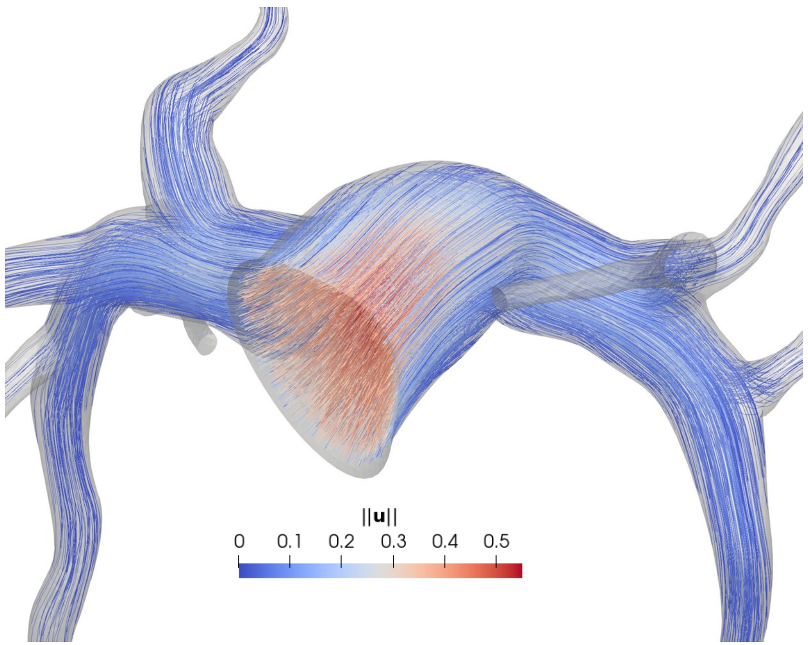
- Density:
- Viscosity:
- Velocity:
- Length:
- Reynolds: 2500

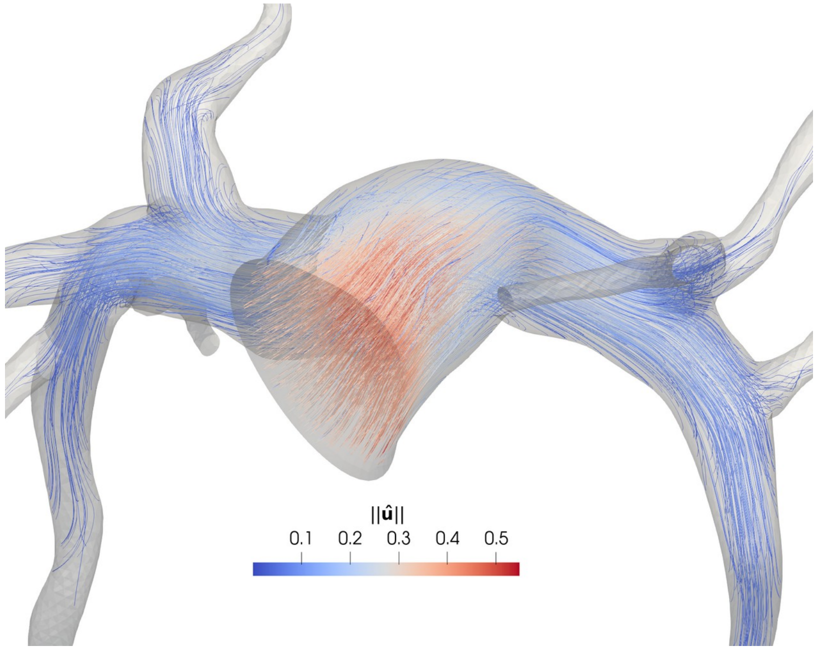
Reference solution (Data):

FEniCS PROJECT

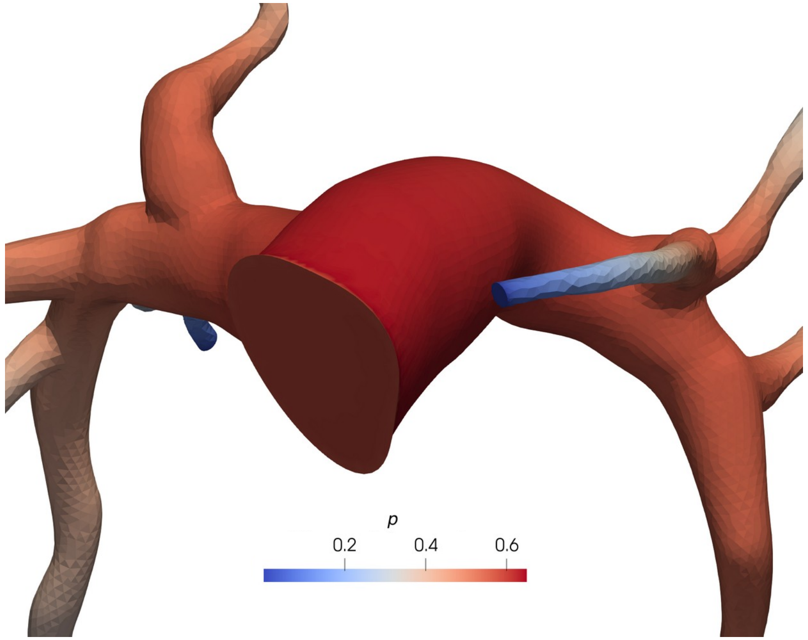
Numerical reference

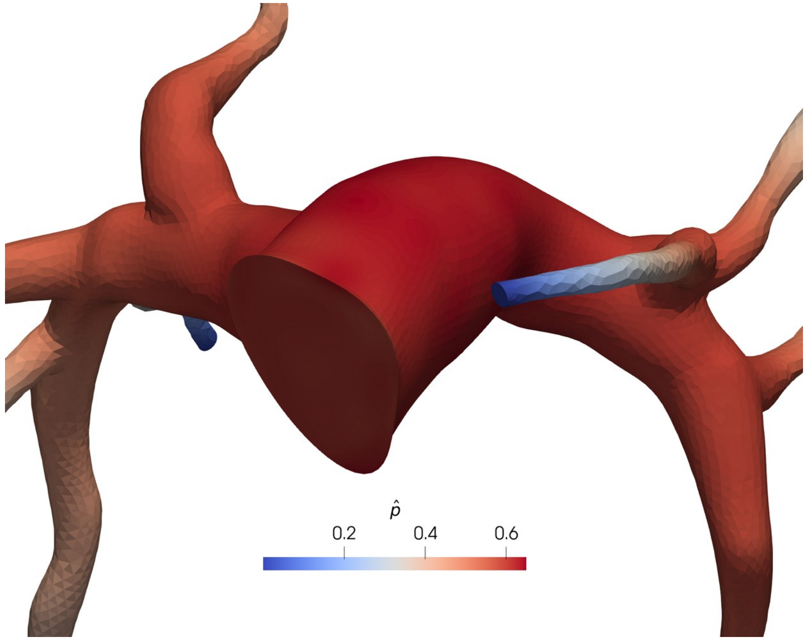
PINN solution





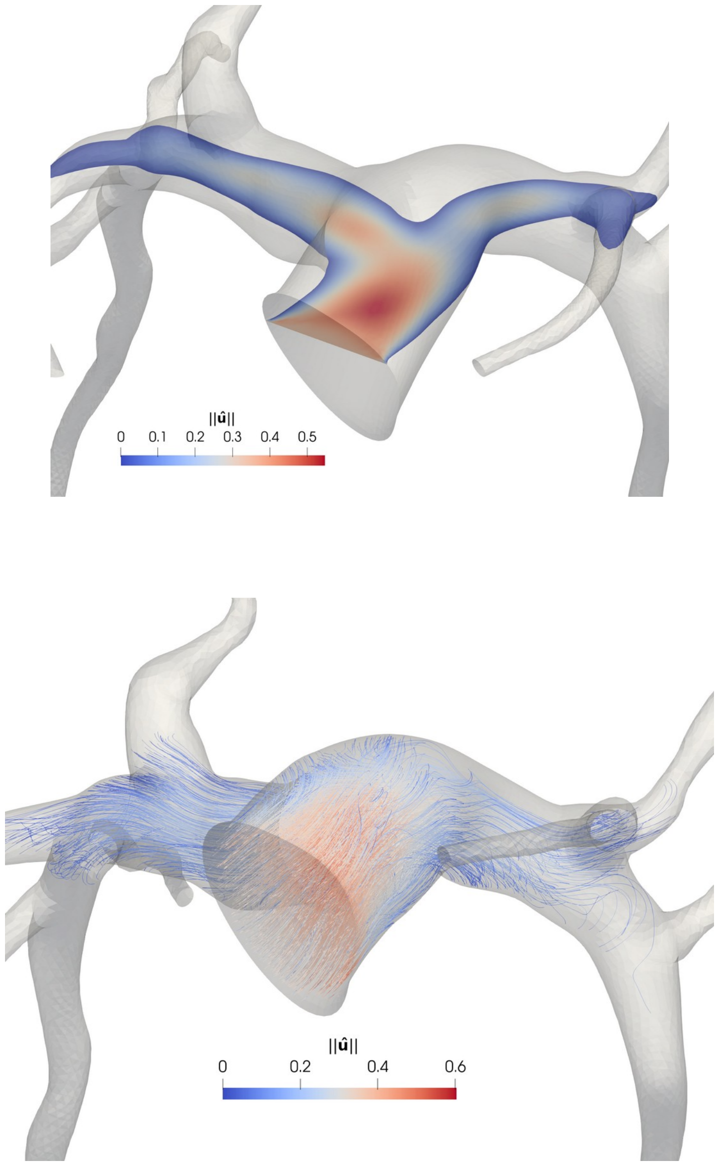
- ModifiedMLP (Wang etal. 2020)
- 10 Hidden layers
- 100 Neuron
- Fourier Features
- 100 Epochs





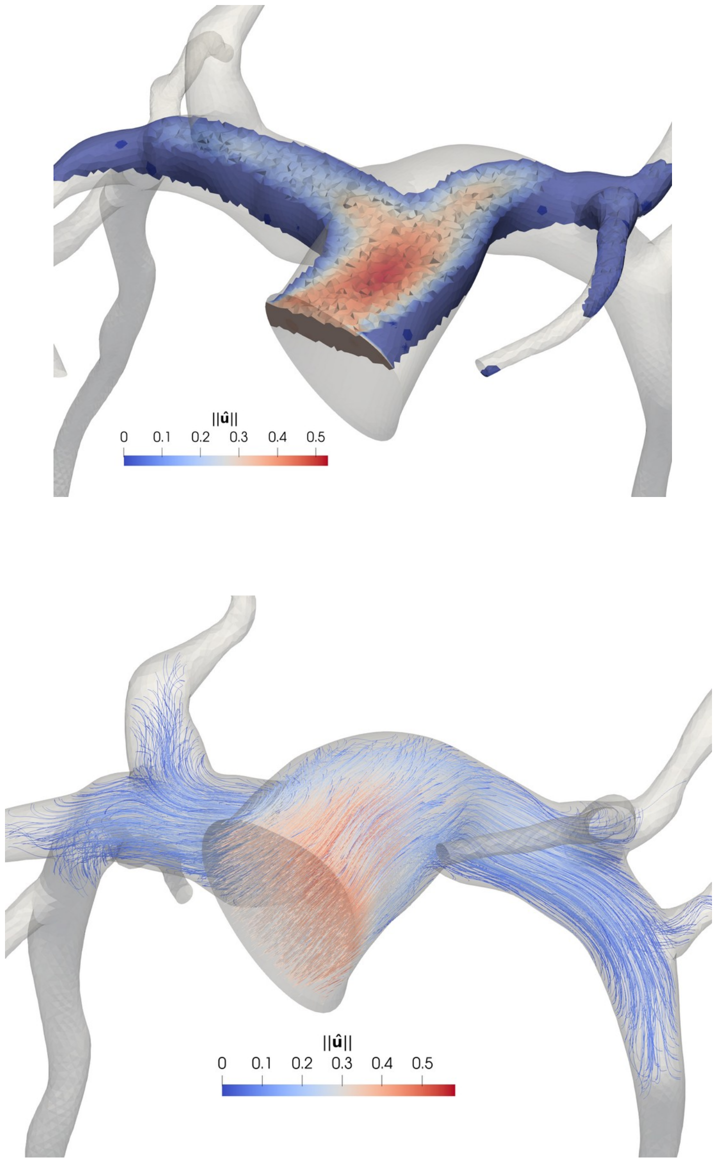
Relative error: 0.04

Simple cut



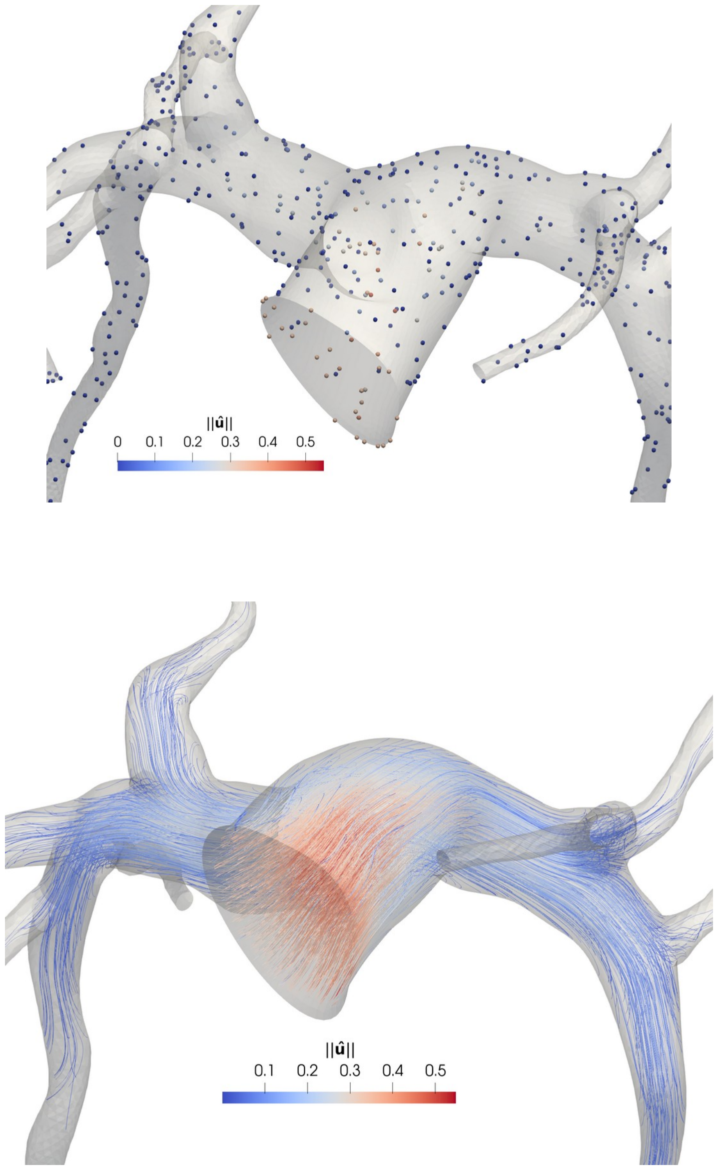
Relative error: 0.11

Chunk



Relative error: 0.09

Random Sampling



Relative error: 0.04

Conclusions:

- Accurate estimation of the blood pressure in the pulmonary artery
- Accurate in high Reynolds numbers
- Accuracy depends on the spatial distribution of the input data

What is next?

- Transient Navier-Stokes
- Use 4D-flow (simulated) data
- Add Windkessel model

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