

# Non-Invasive Young modulus and aortic root flow reconstruction from scarce data using Physics-Informed Neural Networks

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## Abstract

Two clinical scenarios focused on inference of non-measurable cardiovascular signals and parameters within the human arterial system are presented. In the first scenario, we use Physics-Informed Neural Networks (PINNs) constrained with zero-dimensional (0D) hemodynamical models to jointly reconstruct the Young modulus of each of the elastic vessels of a mock arterial circulatory system, from lumen area in-silico data. In the second scenario, we use PINNs to reconstruct the flow rate at the ascending aorta inlet of a healthy adult thoracic network using exclusively an in-vivo pressure signal measured non-invasively with tonometry at the left common carotid artery.

Accurately inferring waveforms and hidden parameters plays a vital role in the physical modeling of dynamic systems, for both predictive as well as system characterization purposes. This becomes particularly important in biomedical contexts, where many physiological quantities cannot be measured directly. In cardiovascular research, one-dimensional (1D) and 0D models simulating the flow of blood through elastic arterial networks have demonstrated strong potential for delivering patient-specific insights that aid in diagnostics and inform intraoperative decisions.

In this work, we use zero-dimensional models (0D), where the variables of the blood flow (flow rate and pressure) are averaged across the longitudinal coordinate along the centerline and depend only on time. 0D models pose some advantages against 1D models, especially with regards to computational efficiency. These models are used to mathematically describe a network of vessels interconnected by junctions and also for formulating the downstream

boundary conditions, referred to as *vascular beds*, which mimic organ vascularity.

In this work, we use 0D models to constrain the loss function of a neural network. At the same time, these networks will also be fed with clinical data corresponding to patient measurements, giving rise to a Physics-Informed Neural Network, dubbed PINN.

PINNs have proven to be powerful algorithms to solve complex ill-posed inverse problems, mainly because of the flexibility of the neural network to incorporate clinical noisy and scarce data and learn physical waveforms and constitutive parameters corresponding to the system of coupled ODEs describing the vascular network.

The loss function of the PINN has the following form:

$$L_{PINN} = L_{ODE} + L_{cycle} + L_{data}$$

where  $L_{ODE}$  is the loss associated to the fulfillment of the physics of the vascular network,  $L_{cycle}$  enforces periodicity across cardiac cycles and  $L_{data}$  ensures the fitting of the available data.

In the first scenario, we reconstruct the stiffness parameters, that is, the Young moduli of all the vessels in a mock experimental circulatory system built and test by authors in [1]. Results of the PINN predictions show high level of accuracy not only for the Young moduli (relative RMSE<5%) but also close agreement with the flow rate and pressure in-vivo measurements (see Figure 1 (upper)).

In the second scenario, we use PINNs to reconstruct the aortic root flow, which cannot be measured by clinicians unless invasive techniques are used, using exclusively a single measurement at the patients left common carotid artery. Results show agreement with in-vivo measurements took by authors in [2] (see Figure 1 (lower)).

## Conclusions

This study sets groundwork on the inference of non-measurable signals and parameters using PINN inverse solvers. Potential applications of this algorithm are vessel ageing diagnosis based on patient-specific vessel Young moduli assessment, as well as cardiac output waveform monitoring during surgical interventions. Future work involves accelerating the algorithm to achieve real-time predictions.

## REFERENCIAS

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