Combined estimation of cross-sectional area, flow rate and Pulse Wave Velocity using Physics-Informed Neural Networks with 1D hemodynamic model data

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Background: The characterization of blood flow dynamics inside human vessels is essential for the personalised prediction and monitoring of cardiovascular risk. However, accuracy is limited by the difficulty in the estimation of parameters of clinical relevance such as the Pulse Wave Velocity (PWV). The aim of this work is to use Physics-Informed Neural Networks (PINNs) to simultaneously predict the propagation of nonlinear cross-sectional area and flow rate waves inside arterial vessels as well as to estimate the PWV using a cost-effective PINN-based one-dimensional (1D) blood flow model (Figure 1).

Methods: We use a first-order finite-volume Riemann solver to compute the ground truth solution of cross-sectional area $a(x,t)$, flow rate $q(x,t)$ and pressure $p(x,t)$ inside an elastic artery, given a predefined value of the PWV. We then developed a PINN using initial, boundary and vessel midpoint data to estimate the real value of PWV, as well as area and flow rate values. Regarding the neural network hyperparameter selection, we choose $\alpha = 0.001$ for the Adam optimizer and 10 layers of 10 neurons each with activation function $tanh$.

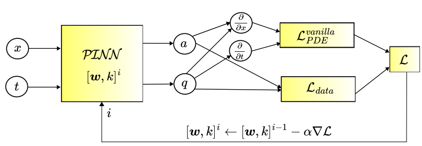

Figure 1: Chart-flow of inverse vanilla PINN using 1D vascular model.

Results: Results reveal that, when departing from *in-silico* data derived from the 1D hemodynamic model, highly precise estimates of the PWV (errors of $4\% \pm 2.5\%$) and accurate area and flow rate wave propagation predictions (errors of $\pm 2\%$) can be obtained.

Conclusions: We conclude that using only blood flow velocity data pertaining exclusively to one virtual single sensor affixed to the vessel's midpoint, it is possible to obtain accurate estimates of the PWV, as opposed to previous approaches that require extensive 3D flow simulation data and the prior knowledge of the PWV.