Machine-Learning-Enhanced Patient-Specific Models for the Blood Flow in Human Femoral Artery

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Abstract: This paper introduces machine-learning-enhanced models for simulated data derived from numerical models for the human femoral artery constructed using MRI scans available in repositories. The quantile loss function is used to identify the most-reliable predictor model for deriving the blood flow characteristics for the constructed patient-specific model.

Keywords: Machine-Learning models, Numerical model, Blood flow, Femoral artery, Patient-specific model.

1. INTRODUCTION & OBJECTIVES

The femoral artery is one of the large arteries in the human body situated in the thigh and is the leading blood supplier to it and the legs. It includes the common femoral artery bifurcated into the superficial and deep femoral arteries. Since catheters can be directed from this point to anywhere in the arterial system, this artery is a frequent site of access in angiography and a puncture point for catheter access. Moreover, it is a critical access point for pre-and post-operative evaluations of patients with peripheral vascular diseases. Thus, we propose characterizing the blood flow through numerical models constructed for patient-specific data. For this, we imported MRI images of the femoral artery from the repositories and constructed a model for it in COMSOL software. Appropriate mathematical models for describing the blood flow problem were identified, and we performed simulations to derive the flow characteristics. This data is taken forward for further analysis using machine-learning algorithms to derive an enhanced model for predicting the flow characteristics in the patient-specific scenario.

Research Objectives:

To develop and validate a numerical model for the patient-specific femoral artery.

- Simulate the model for different flow conditions.
- Compute appropriate physical quantities and validate using the clinical results.

To predict flow characteristics using ML algorithms.

- Develop ML models that best fit the simulated data.
- Compute the metrics and quantile loss function on the train and test datasets to identify the most reliable ML prediction model.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

In light of the clinical data on the dimensions of the components of the femoral artery, we inferred that the blood could be described as a Newtonian fluid in the common Femoral artery and as Newtonian or a non-Newtonian fluid in the bifurcated segments. As a first step, our study identified a precise mathematical model for the blood in these arteries by validating the simulated results of target variables, wall shear stress, and average blood velocity with clinical observations.

A notable point of this study is that the features and target variables of one segment of the artery form the set of features of the latter, thus resulting in multicollinearity among the features in the daughter components. Although this phenomenon is quite common in studies related to the stock market, epidemiological, observational, or retrospective studies, in which there could be a relationship between the features leading to multicollinearity, in our work, it resulted from the geometry and the physics governing the problem. Thus, we worked on understanding the effect of these correlated features on the target variables using regularized techniques, such as Lasso, Ridge, and Elastic Net regression models, ensemble models like decision tree regressor, and boosting algorithms.

ML-Enhance Model is constructed in the next step, where we computed the quantile loss function to identify the best regressor model for predicting the target variables and computed their confidence (quantile) intervals.

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