CFD-BASED SYNTHETIC DATA GENERATION FOR MACHINE LEARNING BASED PRESSURE DROP ASSESSMENT IN AORTIC STENOSIS

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Introduction

Aortic stenosis occurs when the aortic valve does not fully open during systole, which reduces and partially blocks blood flow to the systemic circulation. The type of treatment depends on the functional severity of the stenosis, which is assessed based on the trans-valvular peak pressure drop. Clinically, the pressure drop is routinely estimated analytically, which may lead to sub-optimal results since certain hemodynamic aspects are not fully captured (pressure recovery, turbulence) [1]. A promising solution is based on the use of a machine learning (ML) model to estimate the pressure drop based on patient-specific characteristics. Although an ML-based solution could provide the desired results in real-time, training an accurate model requires a large database of invasively measured pressure drops, which is difficult and costly to set up.

Methods

Our approach is to train the ML model with ground truth values computed using a high-fidelity computational fluid dynamics (CFD) model. The first step is to create a parameterizable anatomical model of the aortic valve. A large number of meshes is then generated based on this anatomical model. The difference between inlet and outlet pressure is calculated after performing simulations for various aorta and valve dimensions, and inlet flow values, all set based on population level characteristics. Thus, a dataset that maps valve and blood flow characteristics to pressure drop is obtained. The open-source CFD software OpenFOAM was employed for the dataset generation.

Results

A preliminary dataset of 105 cases was generated, with each sample containing different combinations for the adjustable parameters. These parameters are the vessel diameter (D), the average velocity of blood flow (U) and the percentage area reduction (Ar). A constraint was added to the sampling process to guarantee that the chosen combinations were realistic from a physiological standpoint: the blood flow at the inlet must be at least 50ml/s and not exceed 650ml/s [1]. For each case, a steady-state simulation corresponding to peak systole was run. The mean absolute difference between the predicted pressure drop and the analytically-derived value was computed to validate the results. The mean difference of 3.99 mmHg suggests that the blood flow characteristics are successfully captured during the simulations. As expected, the largest differences are obtained for cases with higher area reduction, when the circular area assumed in the formula does not apply to the actual geometry.

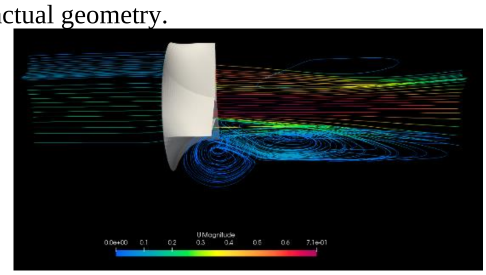

Figure 1: Velocity ParaView visualization.

The correlation matrix computed for the dataset indicates that the blood velocity parameter appears to have the most significant impact on the pressure drop. This information is vital when optimizing the sampling process, leading to a synthetic dataset that closely matches the distribution of real-life data.

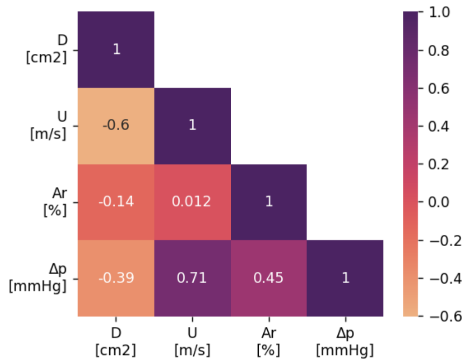

Figure 2: Correlation matrix of the generated dataset.

Discussion

Synthetic datasets are often used as an alternative to real-world data in machine learning applications. Medical data can be costly to obtain and sometimes require invasive procedures to be performed, making the generation of synthetic data an appealing alternative. By using the approach detailed herein, large datasets can be generated, enabling ML model training for pressure drop estimation in aortic stenosis.

References

1. Hoeijmakers, M. et al., J Biomech Eng. 2022 Mar 1; 144(3):031010. doi: 10.1115/1.4052459..

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