A Data Driven Approach to Predicting Hemodynamic Factors of Coronary Stenosis Severity

DUC MINH TRAN, MINH TUAN NGUYEN, SANG-WOOK LEE
School of Mechanical Engineering
University of Ulsan
93 Daehak-ro, Namgu, Ulsan
REPUBLIC OF KOREA
leesw@ulsan.ac.kr

Abstract: - In this study, a data driven approach to predicting hemodynamics based diagnostic factors for ischemic severity of stenotic lesion of coronary by a machine learning technique was proposed. For a training dataset, we generated total 1,116 coronary vessel models with various geometric features of a stenosis and conducted 3D-0D coupled blood flow dynamics simulations. We employed a fully connected deep neural network model with four hidden layers and a sigmoidal activation function. This novel approach produced a promising outcome for near-real time assessment of coronary lesion severity with reasonable accuracy.

Key-Words: - Coronary circulation, Stenosis severity, Computational fluid dynamics, Machine learning, Hemodynamic factor, Geometric features, Physiological index

1 Introduction

The lack of accurate diagnostic measure of coronary lesion severity causes clinical decision making difficult. Morphology based marker of stenotic lesion significance, mainly, the constriction rate of a vessel was revealed to have limited accuracy [1].

Recently, remarkable progress of computing power and image processing techniques facilitate non-invasive functional evaluation using multi-scale computational fluid dynamics (CFD). However, CFD simulation requires generally more than a few hour-computing time even in high performance parallel cluster.

Itu et al. [2] introduced a reduced-order model (1D) for patient-specific coronary blood flow dynamics and demonstrated at least two order of magnitude faster performance compared to 3D CFD model. In addition, they developed machine learning (ML) algorithm to evaluate the fractional flow reserve (FFR) by training the model with the database from the 1D model computations [3].

In this study, we propose a new ML based approach with 3D CFD models to predicting hemodynamic factor for coronary stenosis severity.

2 Method

2.1 Stenotic Coronary Model

We generated total 1,116 vessel models consisting of synthetically designed straight conduits with various geometric parameters of a stenosis. Details of geometric parameters and aortic pressure conditions considered in this study were presented in Table 1. Three different mean aortic pressures were also considered as an input parameter because the cardiac pressure has significant effect on coronary flow dynamics.

Table 1. Geometric parameter values considered for training model

Feature	Description	Values			
$\%DS$	stenotic degree	40	50	60	70
L_s	total length	1.0D	2.0D	3.0D	4.0D
L_i	entrance length	0.25D	0.5D	1.0D	-
L_o	exit length	0.25D	0.5D	1.0D	-
ϵ	eccentricity	0	10	40	-
P_{mean}	mean aortic pressure	85	95	105	-

2.2 Computational Fluid Dynamics and Machine Learning Algorithm

Computational fluid dynamics simulations for the stenotic vessel models were performed to obtain the hemodynamic information necessary for training the ML algorithm [4]. To accommodate the specific time-varying pressure-flow characteristics of coronary flow, 0D lumped parameter modelling techniques for coronary circulation were coupled.

The ML model was developed by TensorFlow software [5]. We used a fully connected network model with four hidden layers. The input layer has six neurons corresponds to the geometric parameters of stenosis and aortic pressure. Each hidden layer has 256, 64, 16 and 4 neurons, with a sigmoidal activation function.

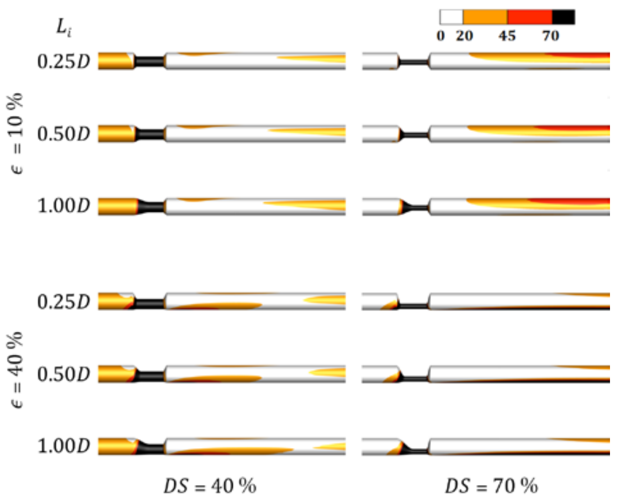

Fig.1. Comparison of wall shear stress distribution at different stenosis degree and eccentricity

3 Results and Discussion

Fig. 1 shows the distribution of wall shear stress (WSS) according to different stenosis degree and eccentricity. Fig. 2 presented comparisons of fractional flow reserve (FFR) values at different stenosis degree and entrance length.

We validated the developed ML model with FFR factor from randomly selected testing set. FFR_{ML} and FFR_{CFD} were compared and it produces excellent correlation (R = 0.9998, P < 0.001).

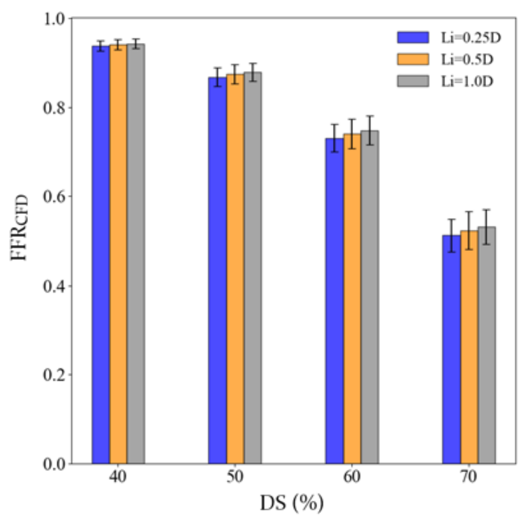

Fig. 2. Comparison of FFR values according to different stenosis degrees and entrance lengths

The ML predicted FFR value (FFR_{ML}) for patient-specific models was compared with invasively measured FFR ($FFR_{Invasive}$) showed fairly good correlation (R = 0.727, P < 0.001) and diagnostic accuracy. The training and the prediction time in FFR_{ML} were about one and a half hours and less than a second, respectively.

4 Conclusion

We demonstrated the development of a near-real time ML algorithm for prediction of hemodynamic parameters for coronary lesion severity based on CFD simulation dataset with synthetically generated stenotic coronary models. This may be useful for fast assessment of coronary lesion severity in routine clinical procedure. To improve the accuracy, further study with larger database will be necessary.

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