APPLICATION OF MACHINE LEARNING TECHNIQUE IN THE PREDICTION OF THE HEMODYNAMIC PARAMETERS OF AN ATHEROSCLEROTIC PLAQUE

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Introduction

Risk assessments of atherosclerotic plaques require reliable evaluation of changes occurring in hemodynamic parameters during the progression of plaque [1]. Fluid-structure interaction (FSI) modelling is the most reliable method to study hemodynamic parameters [2]. However, FSI modelling is a costly process and yet it is not considered an efficient way in clinical settings. Meanwhile, the machine learning (ML) technique offers a promising method for creating mathematical models with a large decrease in processing costs and increased simplicity [3]. The aim of this study is to develop a tool with which the hemodynamic parameters of an unstable plaque can be assessed both reliably and efficiently and it can assist the practitioner in the vulnerability assessment of plaque. For this purpose, deep neural network algorithms (DNNs) are implemented to develop surrogate models from the corresponding FSI models of plaque. Three separate feed-forward networks are designed to predict the changes in the hemodynamic parameters namely, the maximum of wall shear stress signal (WSS), time-averaged wall shear stress (TAWSS), and the maximum velocity in a cardiac cycle.

Methods

To train the DNNs, a design-of-experiment method is implemented to generate sampling data that are appropriately distributed across the design and analysis space. The current analysis space is made of the geometric risk factors i.e., the stenosis ratio ($25 \leq \%St \leq 70$), the plaque shoulder length ($2.5\,mm \leq l_{plq} \leq 8\,mm$), and the fibrous cap thickness ($0.025\,mm \leq f_c \leq 0.1\,mm$). Then, the corresponding FSI models of data are developed based on a 3-D idealised geometry of negatively remodelled plaque. The surrogate models take the three geometrical parameters as input to predict the intended hemodynamic parameter.

Results

The optimum architectures for DNNs are obtained based on the absolute relative error depicted in Eq.1. Each network is trained 10000 times and the best models are provided in Table 1.

$$RE = abs\left(\frac{\hat{\chi}-\chi}{\chi}\right) \times 100, \qquad (1)$$

In which $\hat{\chi}$ is the predicted value of the desired hemodynamic parameter via DNN and χ is derived from the FSI model. In Figure 1, the effect of changes in the stenosis ratio and the plaque shoulder length on the WSS is obtained via network A and is compared with FSI models.

Network	Output	Maximum RE	Architecture
A	Peak of WSS	3.22 %	(5 5 5)
B	TAWSS	3.46%	(5 5 5)
C	Velocity	3.66%	(3 3 3)

Table 1: Details of the optimum DNNs.

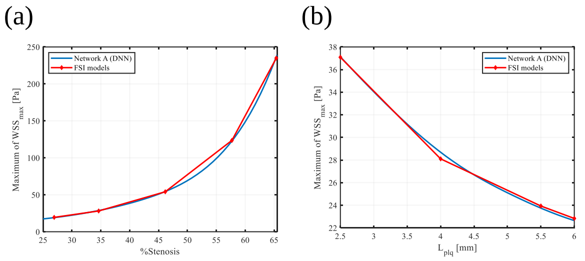

Figure 1: The performance of network A (DNN) versus the FSI models. (a) The effect of stenosis ratio ($l_{plq} = 7\ mm$ and $f_c = 0.045\ mm$). (b) The effect of plaque shoulder length ($\%St = 34.62$ and $f_c = 0.045\ mm$).

Discussions

The networks provided excellent performance with an absolute relative error of less than 4%. According to the results, machine learning techniques can reliably help practitioners in clinical risk assessment procedures.

References

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