머신러닝 알고리즘 기반의 Fractional Flow Reserve 예측

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Fractional Flow Reserve Estimation Based On Machine-Learning Algorithm

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Abstract : The purpose of this paper is to develop an coronary artery analyzing algorithm based on machine-learning technique for clinical needs. To overcome the lack of data number for machine learning algorithm, synthetic blood vessel is analyzed by computational fluid dynamics. Also, real patient data is used in the feedback system to enhance the algorithm. The result have shown high accuracy, although the cases were focused on LAD.

1. Introduction

CFD(Computational Fluid Dynamics) have long been used for diagnosis and treatment of blood vessel related diseases. Most common usage of CFD is to calculate FFR(Fractional Flow Reserve) for making clinical decision [1], or to analyze wall shear for prediction of rupture risk and outcome of stent insertion[2]. Compared to conventional invasive FFR method, this CFD FFR method requires less cost and time.

Yet the cost and time of CFD FFR is insufficient to be fully used in clinical field. The performance of CFD relies on the power of computational resource, and the cost of time for CFD FFR is usually expected to be about 3 hours[3]. Also, the accuracy and calculation time is always in trade-off situation, and therefore decreasing the calculation time blindly might cause the decrease of the accuracy.

To overcome this weakness of CFD FFR, a new method of using ML(Machine Learning) technique is being suggested[4]. Assuming that ML algorithm is operational, the time for calculation is less than a minute and requires less computational power. However, the problem of ML FFR is that it is hard to collect sufficient volume of data required to develop ML algorithm. Because of the complicity of blood vessel and individual difference, the number of data required is estimated to be over 10,000 cases. Obtaining these data from real patients is practically impossible.

The alternative method is to use CFD study of synthetic vessel as the input data for ML algorithm. There are some advantages of using CFD data compared to using clinical data. First, it is able to increase the number of cases almost infinitely. Secondly, the control of variables is easier than clinical vessel. To develop accurate ML algorithm, not only the number of cases but also the diversity of each variables are important, and in synthetic model this can be easily controlled.

In this paper, the prototype of ML FFR algorithm is being developed and tested. Vessels are focused on LAD of coronary artery. Two types of synthetic models are used for the algorithm input data. After developing the algorithm, clinical cases are used as

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feedback system to enhance the accuracy of the algorithm. Finally, the algorithm is tested for actual clinical cases to observe the overall performance.

2. Methods & Results

2.1.Numerical Methods

For the CFD solver, LBM(Lattice Boltzmann Method) is used. LBM has few advantages when simulating blood vessel, including the parallel process to increase calculation speed and lattice grid form for complicated vessel geometry[5].

For the base of ML algorithm, Gaussian Regression model is used. Fig. 2(a) shows the overall flowchart of algorithm developing process. First, the synthetic geometries are created as shown in Fig. 2(b). Then, from these synthetic models, the geometrical features are extracted to be used as input data of ML. CFD is performed on these geometries to obtain FFR, which is also used for input data of ML. After developing an initial version of ML algorithm, the feedback system by experimental FFR is applied.

2.2.Results

First, the accuracy of algorithm itself is tested by comparing predicted response to actual response. Fig. 3. Shows the graph of predicted response versus actual response. Machine learning algorithm itself have shown high accuracy, With R value of 0.98 and Root mean square error of 0.0089.

To test the performance of ML FFR, real geometries and conventional FFR data are collected. Geometries are obtained from OCT image and converted into lattice grid. For each cases, both CFD FFR and ML FFR are performed to compare the result. Fig 3. shows the geometries and results. The accuracy of ML FFR was similar to CFD result.

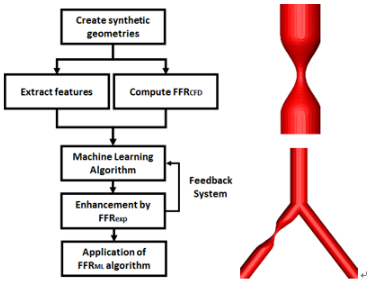
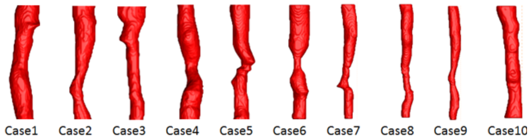


Fig. 1 (Left) Overall flowchart of ML FFR development process. (Right) Two types of base synthetic model (Straight type and Vifurcation type).



Case	stenosis	length	longi	cross	shape	FFR				Error(%)		
						Exact	CFD	ML(synthetic)	ML(enhanced)	CFD	ML(synthetic)	ML(enhanced)
1	72	121	0.34	0.23	0.21	0.728	0.764	0.746	0.765	0.050	0.025	0.051
2	43	99	0.21	0.16	0.43	0.857	0.811	0.834	0.812	0.053	0.056	0.053
3	66	67	0.83	0.82	0.17	0.743	0.674	0.709	0.676	0.092	0.099	0.090
4	73	72	0.24	0.34	0.52	0.823	0.732	0.777	0.731	0.111	0.126	0.112
5	81	100	0.14	0.72	0.32	0.769	0.721	0.743	0.717	0.062	0.072	0.068
6	77	82	0.43	0.25	0.43	0.780	0.764	0.772	0.765	0.020	0.020	0.020
7	79	97	0.34	0.32	0.11	0.790	0.811	0.801	0.812	0.027	0.027	0.027
8	86	101	0.21	0.71	0.84	0.750	0.674	0.713	0.676	0.101	0.110	0.099
9	64	78	0.44	0.24	0.72	0.860	0.732	0.795	0.731	0.149	0.176	0.150
10	55	115	0.72	0.31	0.61	0.910	0.721	0.813	0.717	0.208	0.268	0.212

Average error: CFD=8.72% ML(synthetic)=9.79% ML(enhanced)=8.82%

Fig. 1 (Left) (Upper) Real vessel images used for the test and (Lower) result chart of the ML FFR test. Test is performed for both original algorithm before feedback system ad after feedback system.

3. Conclusion

Prototype of ML FFR is developed from synthetic geometry models. The result have shown high accuracy, although it is because the study only have focused on LAD of coronary artery.

For the future work, the scale of synthetic geometries should be expanded to the whole coronary artery, along with the situation of multiple stenosis. Moreover, other variables than vessel geometry should be also considered such as age or overall body parameters.

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