Towards Real-Time Transaortic Pressure Gradient Computation

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1. Introduction

Recent developments in cardiac imaging and automatic segmentation allow for patient-specific three-dimensional computational fluid dynamics (CFD) models of the aortic valve [1,2]. However, 3D CFD models are compute intensive, often requiring minutes or hours to complete. The objective of this study is to reduce the parameterized 3D CFD simulations to a surrogate meta model.

2. Materials and Methods

Parameterized structured surface meshes of the aortic valve and left ventricle $\boldsymbol{m}(\boldsymbol{w})$ are constructed by:

$$\boldsymbol{m}(\boldsymbol{w}) = \boldsymbol{m}_0 + \sum_{i=1}^{11} w_i \boldsymbol{m}_i \quad \boldsymbol{w} \in R^{11} \quad (1)$$

With $\boldsymbol{w}$ the weight vector, $\boldsymbol{m}_i$ physically meaningful modes, and $\boldsymbol{m}_0$ a mean mesh. Surface meshes $\boldsymbol{m}(\boldsymbol{w})$ are truncated at the left ventricular outflow tract and converted to polyhedral meshes. Blood is modelled as an incompressible fluid with density 1060 kg·m-3, dynamic viscosity of 0.004 Pa·s and the SST k-ω turbulence model for turbulence. A zero-pressure outlet is considered. Simulations are performed on the ACC Cyfronet AGH Prometheus supercomputer with ANSYS Fluent (Release 18.2).

A simulation workflow is integrated with ANSYS DesignXplorer. A Central Composite Design (CCD) is used with parameters w_4, w_6 and steady-state flow rate (Q). The net pressure gradient across the valve (Δp) and the meta model, $\Delta p_M(w_4,w_6,Q)$, are computed. The meta-model is build with 2nd order polynomials.

3. Results

From figure 1 it is observed that w_4 and w_6 transition from a linear (5 L/min) to an exponential relationship (25 L/min). Figure 2 illustrates good agreement between $\Delta p_M(w_4,w_6,Q)$ and CFD results.

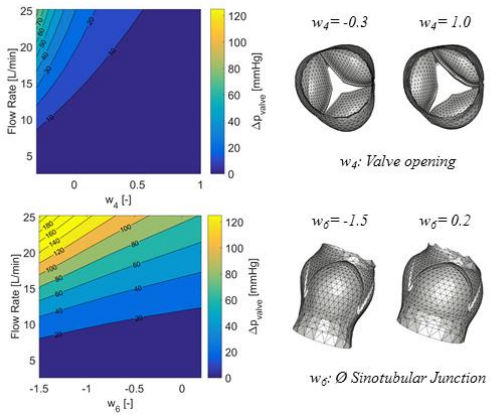

Figure 1: Response of Δp to w_4 and w_6.

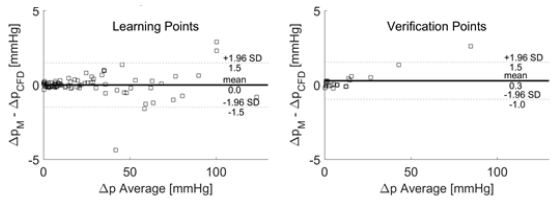

Figure 2: Difference between Δp_M and CFD. Left: for learning points. Right: for verification points.

4. Discussion and Conclusions

This study demonstrates that a meta model can replace full 3D CFD simulations of the aortic valve. Such meta models can be used to investigate parameter sensitivity.

5. References

1. Weese, J., et al., (2017). Med. Phys. 44(6)
2. Ecabert, O., et al., (2011). Med. Im. Anal. 15.

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