TUNING PATIENT-SPECIFIC CORONARY LUMPED PARAMETER MODELS IN PRESENCE OF SEVERE AORTIC STENOSIS

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Introduction

Fractional Flow Reserve derived from coronary computed tomography (FFR_{CT}) combines imaging acquisition techniques with computational fluid dynamics to serve as a non-invasive diagnostic tool in the assessment of coronary artery disease (CAD) [1].
Its use is currently limited to healthy-aortic valve patients as conventional coronary lumped parameter models may not predict the hemodynamic changes present in patients with severe aortic valve stenosis (AS) [2]. However, it is quite common to encounter patients with both diseases. This proof-of-concept study provides some guidelines for tuning patient-specific coronary lumped parameter models to predict FFR_{CT} in patients with CAD and AS.

Methods

Full-cycle hyperemic indices, such as FFR, may vary in patients with AS due to physiological changes, especially in the systolic phase of the cardiac cycle [2]. However, FFR_{CT} is blind to these perturbations unless the inlet and outlet boundary conditions are updated accordingly. Thus, there is a fundamental question, how to perform this update?
To fill this gap, several anonymous patients with moderate coronary lesions were selected. CCTA images were collected and segmented to reconstruct the coronary tree and the myocardium. Two types of simulations were performed using ANSYS© software: (1) simulation of hyperemic flow in the presence of AS and (2) simulation of hyperemic flow without AS disease, both based on previous clinical works [2,3].
Patient-specific inlet aortic pressure and outlet open-loop 0D coronary lumped parameter networks were tuned and coupled to the 3D simulation via user-defined functions (UDF), making variations in the perfusion pressure (+10% in (2)), systolic phase of intramyocardial pressure (-14% in (2)), left ventricular mass regression (-23% in (2)), which estimates total coronary flow, and microvascular resistance (-12% in (2)). FFR_{CT} was analyzed in both scenarios.

Results

Figure 1 confirms that the perturbations imposed on the inlet and outlet boundary conditions led to the desired variation in the inlet systolic coronary flow (+20 % in (2)), concordant with those reported by clinicians. The diastolic coronary phase did not show significant differences.

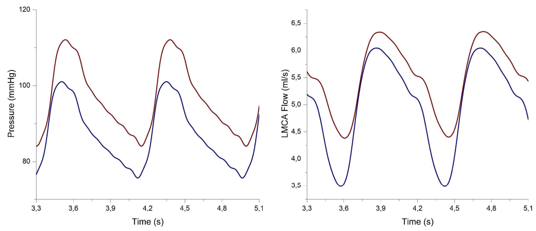

Figure 1: Aortic pressure and LMCA inlet flow rate in both simulated cases [Blue (1), brown (2)].

FFR_{CT} systematically decreased with the second simulated approach due to the increased flow during the systolic phase, as shown in Figure 2.

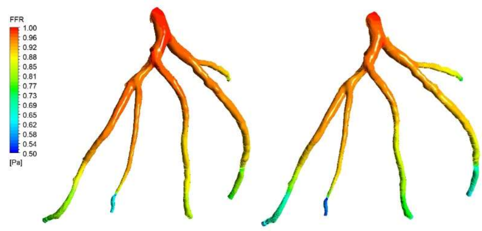

Figure 2: FFR_{CT} contours of both simulated cases [Left: (1), Right: (2)]

Discussion

Tuning coronary lumped parameter models based on standard principles [4] may lead to an overestimation of coronary artery disease in patients with severe aortic stenosis [5]. Thus, it is crucial to introduce modifications to the inlet and outlet boundary conditions based on clinical outcomes. Here, we confirm that with this approach, FFR_{CT} may be a valid non-invasive procedure for evaluating coronary artery disease in patients with aortic stenosis, and even after surgical (SAVR) or transcatheter (TAVR) aortic valve replacement.

References

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Acknowledgments

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