MULTI-SCALE CORONARY SIMULATION PIPELINE: VALIDATION AGAINST INTRAVASCULAR VELOCITY AND PRESSURES

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Introduction

Multi-scale computational fluid dynamics (CFD) simulations are a popular tool to obtain coronary pressures and velocities to make diagnostic assessments or study plaque remodelling. However, validation of these simulation tools, especially those based on non-invasive approaches are currently lacking. The goal of this study was to utilize a fully non-invasive approach to coronary CFD, based on computed tomography angiography (CTA) and evaluate predicted velocities and pressures against invasive measurements.

Methods

Patient Data: CTA, intravascular pressure and Doppler velocity were measured in 13 patients for 120 $\pm$ 55 cardiac cycles under resting conditions (see Figure 1A).
Multi-Scale CFD pipeline: Coronary anatomy was reconstructed for 13 patients. Fluid-structure interaction simulations were coupled to lumped parameter network (LPN) to model the heart and distal physiology (see Figure 2B) [1]. ~4% of the cardiac output was fed to the coronary arteries with 70-30 split to left vs. right side.

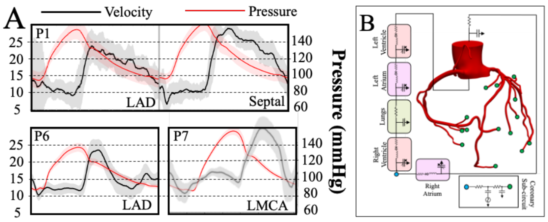

Figure 1: A) Doppler velocity (black) and pressure (red) tracings in three representative patients. B) Multi-scale CFD pipeline, combining fluid-structure interaction simulations with closed-loop LPN.

Coronary Flow Rate Estimation: Doppler flow rate was estimated assuming a parabolic velocity profile, according to the following formula:

$$Q_{Doppler} = Area \,.\, \frac{Average\ Peak\ Velocity}{2} \qquad (1)$$

CFD velocity, flow rates and pressures were extracted at locations where intravascular data were measured.
Statistical Analysis: A Shapiro-Wilks test was performed to check for normality. Since all anatomic and hemodynamic variables were found to be non-normally distributed, a two-sided paired Wilcoxon signed rank-sum test was used to compare CFD vs. intravascular data.

Results

Pressure: Figure 2 (top panel) shows a statistically significant correlation between CFD vs. intravascular pressures (*p<0.01*). Bland-Altman plot showed a positive bias of 26.5 [49 – 3.4] mmHg.
Velocity and Flow Rate: Figure 2 (bottom panel) shows no statistically significant correlation between CFD- vs. intravascular Doppler velocity. The same was true for flow rates. Bland-Altman plot showed a negative bias of -3 [-16.3 – 10.4] cm/s for velocity (Figure 2, bottom panel), and a negative bias of -16.5 [-86 – 53] mL/min for flow rate.

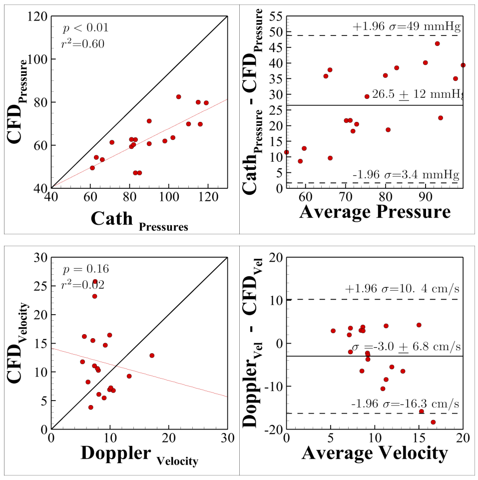

Figure 2: Correlation and Bland-Altman plots comparing CFD vs. intravascular pressure and velocity data.

Discussion:

Our findings demonstrate that multi-scale CFD simulations can predict invasive pressures but not velocities. The poor correlation for velocity data is attributed to boundary conditions that are derived from generic scaling laws and anatomical relations, an approach which is prevalent in the coronary CFD literature. Similar findings have been reported in a recent study that also highlights the deficiency of using such scaling-laws [2]. Improved approaches need to be developed if absolute velocity and flow rate are needed.

References

1. Tran, JS. et al., *Computers and Fluids*, 142:128-138, 2017.
2. Lodi Rizzini, M. et al., Computer Methods and Programs in Biomedicine, 106882, 2022.

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