BLOOD FLOW MODELLING IN CORONARY ARTERIES: NEWTONIAN OR NON-NEWTONIAN?

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Introduction

The role of local hemodynamics in coronary atherosclerosis natural history is widely acknowledged [1]. In recent years, the combination of computational fluid dynamics (CFD) and medical imaging has allowed to profile wall shear stress (WSS) with high spatial and temporal accuracy [2]. However, the clinical use of CFD simulations is still hampered by the necessary assumptions related to the model-based strategy. This study is framed in the context of the evaluation of the budget of uncertainty associated with the adoption of blood rheology models in coronary angiography-based CFD simulations, with focus on WSS-based quantities linked to vascular diseases.

Methods

The geometry of 50 right coronary arteries (RCAs) of hemodynamically stable patients were reconstructed from angiography. Unsteady-state CFD simulations were performed with generalized Doppler-derived inflow waveform [3]. On each RCA model, two CFD simulations were performed: one adopting a Newtonian blood rheology model, the other adopting the shear thinning model proposed by Carreau (widely adopted in coronary hemodynamics simulations) [3]. The impact of blood rheology behaviour was evaluated in terms of the canonical WSS-based quantities TAWSS, OSI, and RRT. Additionally, the amount of variation in WSS contraction/expansion action on the endothelium along the cardiac cycle T was quantified by the Topological Shear Variation Index (TSVI) [4]:

$$\mathrm{TSVI} = \left\{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}}[\mathrm{DIV_{WSS}} - \overline{\mathrm{DIV_{WSS}}}]^2 dt\right\}^{1/2} \quad (1)$$

where $\mathrm{DIV_{WSS}}$ is the divergence of normalized WSS vector field. Luminal surface areas (SAs) exposed to disturbed hemodynamics (low shear area: LSA, oscillatory shear area: OSA, residence time area: RTA), and to high variation in WSS contraction/expansion action along the cardiac cycle (topological shear variation area: TSVA) were identified, based on objective thresholds on the patient-specific luminal distributions: the 20th percentile of TAWSS; the 80th percentile of OSI, RRT, and TSVI. The thresholds were obtained from Carreau model-based simulations, here considered as reference. The co-localization of Newton-*vs.* Carreau-based SAs was quantified by the similarity index (SI) (0= no overlap; 1= total overlap) [3].

Results

Overall, the luminal distribution of the WSS-based quantities was remarkably similar, independent of the adopted blood rheology model (an explanatory case is presented in Fig.1). No remarkable differences emerged in the extension of disturbed SAs (Fig. 2), as confirmed by median [interquartile range] SI values close to one (SI_{LSA}=0.92 [0.89, 0.95]; SI_{OSA}=0.95 [0.94, 0.96]; SI_{RSA}=0.92 [0.89, 0.95]; SI_{TSVA}=0.95 [0.94, 0.96]).

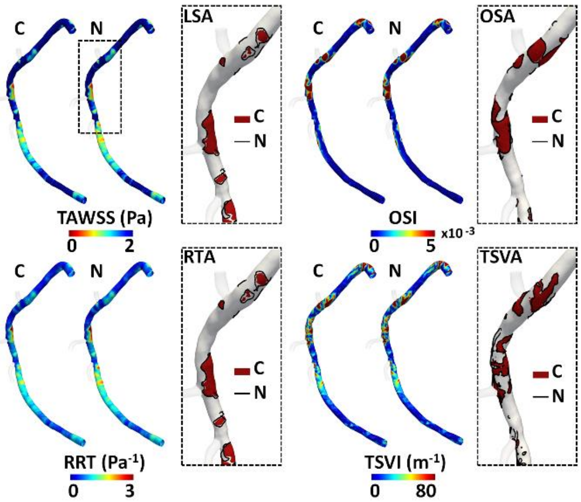

Figure 1: Luminal distribution and SAs for TAWSS, OSI, RRT, and TSVI in an explanatory case. C: Carreau; N: Newton.

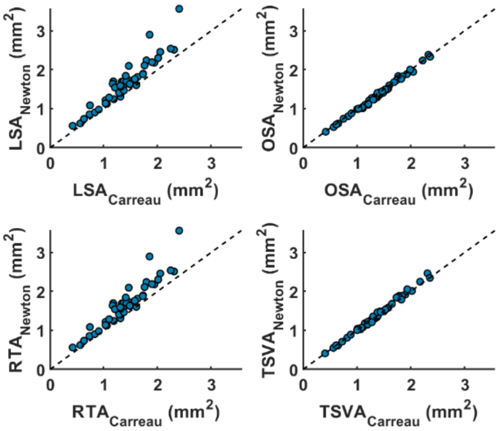

Figure 2: Scatter plots of disturbed hemodynamics SAs.

Discussion and conclusion

This study on 50 RCAs (which we are extending up to 144 models) suggests that assuming a Newtonian behaviour for blood in coronary hemodynamics simulations poorly impacts on WSS profiles.

References

1. Candreva A et al., Rev Cardiovasc Med, 23(11):377, 2022
2. Gijsen F et al., Eur Heart J, 40(41):3421–3433, 2019
3. Lodi Rizzini M et al., Comput Methods Programs Biomed, 221:106882, 2022
4. Mazzi, V et al., Ann Biomed Eng, 49:2606–21, 2021