On the impact of geometry on near-wall and intravascular flow features in idealized, population-based coronary bifurcations

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Introduction

Local hemodynamics is a key factor of the onset and progression of lesions at arterial bifurcations, as suggested by the so-called “hemodynamic hypothesis” [1]. Local hemodynamics is mainly determined by the anatomical features of an arterial bifurcation. While the interplay between geometry, near-wall, and intravascular flow features has been widely studied in carotid bifurcations [1], less is known about coronary bifurcations. The aim of the study is to investigate the impact of stenosis, bifurcation angle, and cardiac curvature on both near-wall and intravascular flow features by performing computational fluid dynamics (CFD) simulations on a population-based, idealized model of coronary bifurcation.

Methods

A parametric model of the left anterior descending (LAD) / first diagonal coronary bifurcation was created with realistic diameters (Fig.A) [2]. In total, 10 cases were investigated by combimbing three bifurcation angles ‘α’ within the physiological range (40°, 55°, and 70°), three cardiac curvature radii ‘R’ (∞, i.e. absence of curvature, 56.3 mm, and 16.5 mm), and the presence or absence of a 60% diameter stenosis in each branch (Medina classification 1,1,1). Transient CFD simulations were performed by imposing a typical human LAD flow waveform at the inlet. A costant flow-split of 0.65:0.35 was applied at the distal main branch (MB) and side branch (SB) outlets, respectively. Intravascular fluid structures were investigated in terms of helical flow topology and content while near-wall hemodynamics in terms of wall shear stress descriptors, such as the relative residence time (RRT).

Results

While the bifurcation angle had a minor effect on the calculated hemodynamic variables, the curvature radius influenced the generation and transport of helical flow structures. In particular, smaller curvature radius was associated with higher helicity intensity in all cases. In unstenosed cases, helical flow topology was driven mainly by the vessel curvature. In stenosed cases, the impact of curvature on helical flow structures piled up with the helicity generated because of the lumen reduction (Fig.B). Consequently, helicity intensity of stenosed models was one order of magnitude higher than unstenosed cases. Lumen areas exposed to atherosensitive (i.e. high) RRT were observed in stenosed cases at the distal MB and at the SB, close to the reattachment point of the recirculation regions (Fig.C). Smaller curvature radius led to smaller lumen area exposed to high RRT.

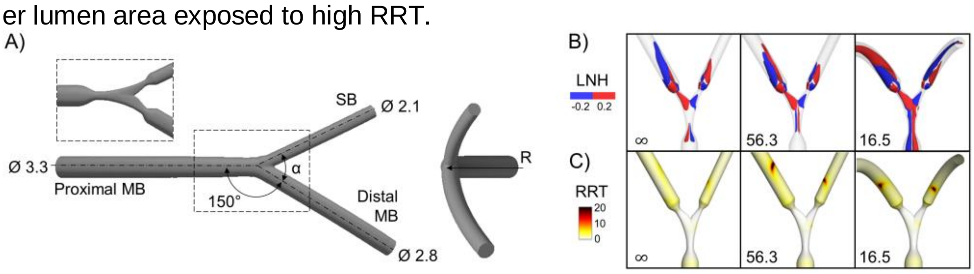

Figure 1 – A) Parametric coronary bifurcation model. Diameters are in mm. B) Isosurfaces of local normalized helicity (LNH); positive/negative values of LNH indicate counter-rotating flow structures. C) Contour maps of relative residence time (RRT).

Conclusions

A controlled benchmark to investigate the effect of geometry on local hemodynamics was provided. Results highlighted the complex interplay between anatomy and fluid structures in coronary bifurcations.

References

[1] Morbiducci U et al., *Thromb Haemost*, 115: 484-92, 2016. [2] Chiastra C et al., *Biomed Eng Online*, 15: 91, 2016.