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NUMERICAL STUDY OF ATHEROGENESIS RISK ASSOCIATED TO DIFFERENT STENOTIC ARTERIES

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ABSTRACT

The present numerical work focuses on the evaluation of the atherogenesis risk associated to stenotic arteries - left coronary artery (LCA small artery without flare) and common carotid artery (CCA large artery with a flare). In LCA, the atherosusceptible zones increase strongly with the occlusion degree of an existing stenosis. In CCA, the occlusion growth tends to accelerate the flow in the flair, inducing high wall shear stresses in the bifurcation and in the inception region of the branches. As result, from an increase of 30 to 70% occlusion percentage, the atherosusceptible area grows around 66% in LCA and only 12% in CCA.

Keywords: computational fluid dynamics, atherogenesis risk, stenosis, hemodynamic descriptors, artery anatomy.

INTRODUCTION

Cerebrovascular and cardiovascular diseases, as atherosclerosis in humans, have been one of the main causes of death in the worldwide (Mozaffarian et al. 2015). From clinical analysis, certain sites in the human circulatory system, such as bifurcations and branch origins are more prone to develop atherosclerosis lesions than others. Much of the risk of atherosclerosis is not explained by conventional vascular factors. Schulz et al. (2001) investigated *in vivo* why the extent of atherosclerosis disease diverges so considerably between individuals with similar systematic risk factors. They highlighted the potential importance of the bifurcation anatomy as a risk for atheroma and provided a basis for further flow modeling studies. Numerical hemodynamic tools increase the understanding of unexplained risks of atherosclerosis, improving their treatment and follow-up. Hemodynamic descriptors (Santis et al. 2013) in arteries are important parameters to understand blood flow patterns, predicting disturbed flow conditions and achieving a better explanation of the potential zones of atherosclerosis appearance and development.

The goal of the present study is to quantify, numerically, the risk of atherogenesis in two types of stenotic arteries, LCA (small artery without flare) and CCA (large artery with flare). *Fluent Meshing* ANSYS® software was used for the numerical simulations. Wall shear stress (WSS) based descriptors - Time Averaged Wall Shear Stress (TAWSS) and Relative Residence Time (RRT) - were implemented in the data treatment to support the numerical study. The percentages of surface area exposed to TAWSS lower than 0.4 Pa and RRT higher than 8 Pa^{-1} - atherosusceptible zones (Malek et al. 1999 and Lee et al. 2009) - will be quantified.

RESULTS AND CONCLUSIONS

Fig. 1 shows the hemodynamic descriptors, TAWSS and RRT, for stenotic LCA and CCA models. Montenegro et al. (1968), Tuzcu et al. (2001) and Katranas et al. (2015) showed, through *in vivo* studies from patients, that atherosclerosis tend to appear with more frequency in the left anterior descending artery (LAD) than in the left circumflex artery (LCx). Ku et al. (1985) also presented an *in vivo* work claiming that prone atherosclerosis regions are predominantly located in the internal carotid artery (ICA) than in the external carotid artery (ECA); and just after the bifurcation. Authors of the present study sit the stenosis, according to the literature: in LAD and ICA (see Fig. 1). The occlusion percentages considered are 30%, 50% and 70%.

The angle between LAD and LCx is 85º and between ICA and ECA 22.5º. The assumed flow rate ratio between the branches follows Murray´s law (Murray, 1929). The flow splitting in LAD:LCx is 61:39(%) with diameters 3.5:3.0 mm (diameter of the main LCA 4.12 mm). The flow rate distribution ICA:ECA is 50:50(%) being the distal diameters 5.2:5.1 mm (diameter of the main CCA 7.8 mm).

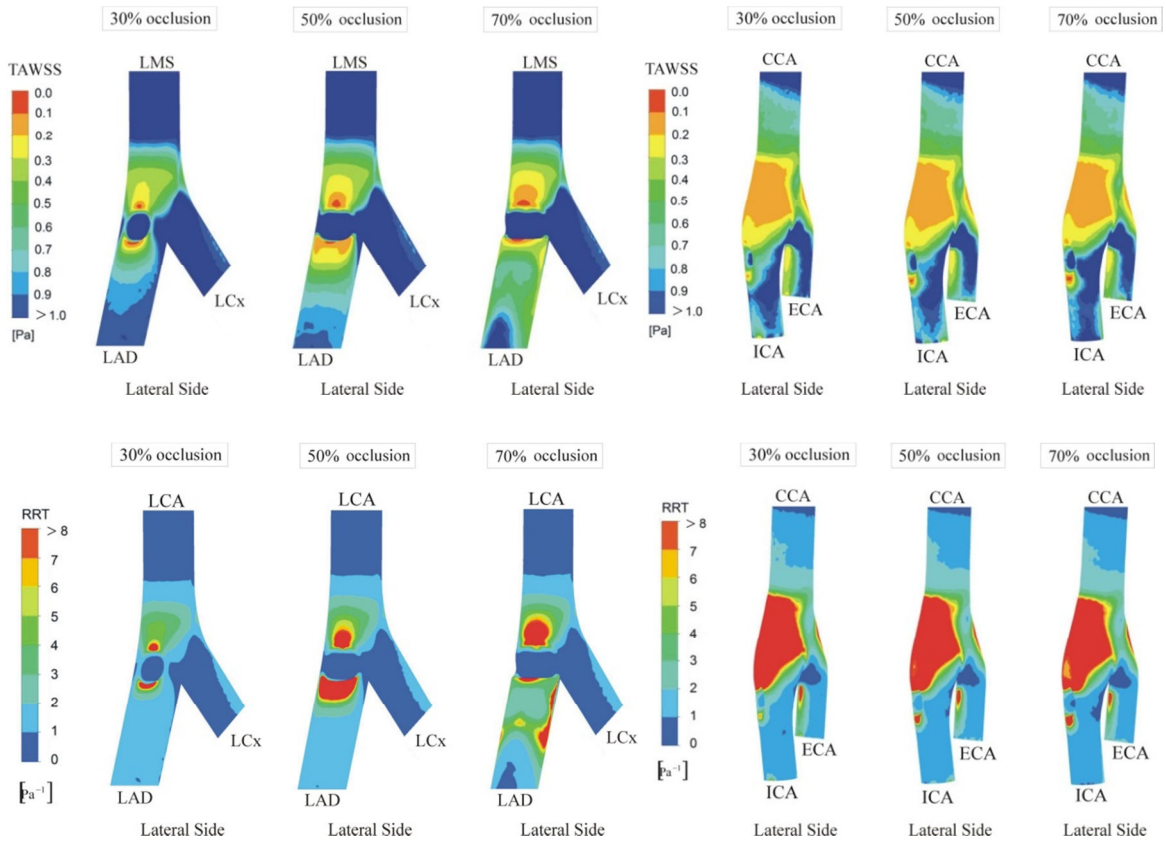

Fig. 1 - TAWSS and RRT considering different percentages of occlusion for a stenotic LCA (left) and stenotic (right)

For the LCA and CCA, very low TAWSS (near 0) and high RRT values (around 8 Pa^{-1}) are observed behind and in front of (according to the flow direction) the stenosis (see Fig. 1). When the percentage of occlusion increases, from 30 to 70%, the regions susceptible to atherosclerosis tend to grow around the stenosis. The effect is emphasized in the LCA: for 70% of occlusion percentage, regions with RRT > 8 Pa^{-1} appear in the opposite side of the stenosis. Atherosusceptible zones tend to expand around 66% in LCA and only 12% in CCA.

Table 1 - Surface area percentages of TAWSS lower than 0.4 Pa and RRT higher than 8 Pa^{-1} for different stenosis % and different arteries (LCA and CCA models)

Stenosis %	LCA TAWSS < 0.4 Pa	LCA RRT > 8 Pa^{-1}	CCA TAWSS < 0.4 Pa	CCA RRT > 8 Pa^{-1}
30%	4.2 %	1.1 %	29.5 %	14.7%
50%	7.1 %	3.7 %	28.1 %	15.1%
70%	9.2 %	4.9%	26.4 %	12.4%

Surface area percentages of TAWSS values lower than 0.4 Pa and RRT values higher than 8 Pa^{-1} are represented in Table 1. In LCA, both surface percentages increase with the occlusion degree - stenotic effect is emphasized - while in CCA the percentages tend to stabilize with the occlusion degree. A growth of the occlusion in proximal ICA tends to accelerate the flow in the stenotic flair, inducing high wall shear stresses in the bifurcation and in the inception region of the branches. This acceleration inhibits the expansion of the atherosusceptible regions.
In a near future, other geometric and hemodynamic effects such as bifurcation angle and flow rate distribution influences will be analyzed.

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