EFFECTS OF BIFURCATION ANGLE ON THE WALL SHEAR STRESS IN STENOSED CORONARY ARTERY BIFURCATION

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INTRODUCTION

From clinical practice, it is known that coronary artery bifurcations are regions where the flow is strongly perturbed, and is prone to the development of atherosclerotic lesions. Coronary bifurcation lesions have always represented a major challenge for percutaneous treatment. Part of this challenge is related to the variety of coronary lesions located at bifurcation which present wide range of anatomical morphologies. Investigation of blood flow hemodynamics and shear forces are of great importance in understanding the regions of lesion formation and development. Wall Shear Stress (WSS) is the most important flow related factor in the development of atherosclerosis in arterial branches. Evidences show that changes in bifurcation angles alters the flow conditions and changes the magnitude of WSS within the vessel [1]. It is believed that critical bifurcation angles might create low shear regions that could influence the development of coronary atherosclerosis [2]. In this study, a two dimensional numerical analysis of blood flow in the threshold stenoses of 50% in coronary artery bifurcation is performed for seven different lesion types classified by Medina et al. [3]. The effects of bifurcation angle on the WSS distributions on the inner and outer walls of side branch are investigated.

METHODS

A comprehensive hemodynamic analysis was carried out to obtain the WSS distribution on the walls of stenosed coronary artery bifurcation. The geometrical model corresponds to the bifurcation between left anterior descending artery and a side branch. Figure 1 shows the geometrical model of the bifurcation (main branch proximal (I), main branch distal (II) and side branch (III)) as well as the lesion locations according to Medina lesion classification.

Numerical simulation of blood flow was performed for two bifurcation angles (45° and 75° which correspond to the anatomical range) to investigate the effect of side branch angle on WSS distribution in stenosed arteries. For the study of blood flow, we assumed that blood can be represented by an incompressible fluid which is governed by the momentum and continuity equation:

\[ \rho \left( \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla p + \nabla \eta \left( \nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) \]  

(1)

and the continuity equation:

\[ \nabla \cdot \mathbf{u} = 0 \]  

(2)

where, \( \rho \) denotes the density of the fluid (Kg/m³), \( \mathbf{u} \) the velocity vector (m/s), \( p \) the pressure (Pa) and \( \eta \) the viscosity of fluid (Pa.s). The shear rate (\( \gamma \)) , for two dimensions is defined by equation:

\[ \gamma = \sqrt{\frac{1}{2} \left[ (2 \frac{\partial u}{\partial x})^2 + 2 (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2 + (2 \frac{\partial v}{\partial y})^2 \right]} \]  

(3)

where \( u, v \) are the velocity vectors.

To solve the governing equations, a set of boundary conditions is required. The maximum velocity varies between 24 cm/s and 46 cm/s [4]. Velocity
variations were obtained from blood flow rate during the cardiac cycle [4]. At the walls, the velocity obeyed the no-slip condition and at the outlet of main branch distal and side branch, a stress-free condition was considered. The Newtonian blood properties in this model are blood viscosity \( \mu = 0.035 \text{ mPa.s} \), and blood density \( \rho = 1060 \text{ Kg/m}^3 \) respectively [5].

RESULTS AND DISCUSSION

We investigated the WSS distribution in all seven types of the Medina classification for 45º and 75º branch angles. Figure 2 shows the WSS distributions on the outer wall of side branch for (1, 1, 1) type of Medina classification in a cardiac cycle.

![Figure 2: WSS on the outer wall of side branch for 45º (a) and 75º (b) branch angles.](image)

WSS on the outer walls of side branch of all types of Medina classification for 45º and 75º branch angles are shown in Figure 3.

![Figure 3: WSS on the outer wall of side branch.](image)

Magnitudes of WSS on the inner wall of side branch in the stenosed artery with bifurcation branch angles of 45º and 75º of all types of Medina classification are presented in Figure 4.

![Figure 4: WSS on the inner wall of side branch.](image)

Comparison of the values of WSS in three regions of cardiac cycle showed that the significant changes in WSS magnitude for 45º and 75º bifurcation angles appears at the mean diastolic period of a cardiac cycle.

CONCLUSIONS

We studied the effect of side branch angle on the WSS values in side branch when the entire vessel was subjected to atherosclerosis. Magnitudes of WSS values were obtained for various lesion locations according to Medina classification. By investigating the distribution WSS on the inner and outer walls of side branch for 45º and 75º bifurcation angles, it was found that higher branch angle creates lower magnitudes of WSS on the vessel walls which could be more problematic. The lower magnitudes of WSS on the side branch walls appeared at mean diastolic period of a cardiac cycle with 75º branch angle. It is interesting to note that, the conventional Medina lesion classification doesn’t take in to account the bifurcation angel.

REFERENCES