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Computational Analysis of Blood Flow in a Curved Bifurcated Coronary Artery

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ABSTRACT

Nowadays, Cardiovascular Diseases (CAD) are very prominent in many countries. Lot of research is going on in the medical field for finding the best solutions and cures to these diseases. Bifurcation of the arteries is one of the most common reasons for these Cardiovascular Diseases. The damages caused due to the bifurcation of the arteries have a great impact on the flow variables of the blood. In this study, by using the Autodesk Fusion360 the geometry has been created. There are two models based on the angle of bifurcation of the artery and the number of the bends. The flow analysis of the fluid has been done using the ANSYS FLUENT software which is one of the most popular software used by the solvers for Computational Fluid Dynamics (CFD). In the first model the bifurcation angle is 70° and there are two bends. And in the second model the bifurcation angle is 50° and it contains a single bend. This study helps us to know about the change of flow variables of the fluid like velocity, wall shear stress (WSS), pressure as the flow passes through the bifurcation region. It was found that the recirculation increased as the angle of the bifurcation increased.

Keywords: Arteries, Bifurcation, Computational Fluid Dynamics (CFD), Cardiovascular Diseases (CAD), Hemodynamics.

1. INTRODUCTION

These days CAD are one of the prominently increasing problems in the medical field. These problems are due to the disturbances instigated in the blood flow which results in the damage of the inner layer of the blood arteries i.e., endothelial cells. The endothelial cells are the inner lining of the arteries. Also, these cells are highly elastic in nature. When the blood flows at high intensities at the bifurcation regions and the bends, those regions are prone to damage. These damages can influence the blood flow variables and lead to the CAD [1, 2]. The damages caused to the arteries due to the bifurcations and the bends is a prime region of the study [3, 4].

The work of coronary artery is to supply the oxygenated blood to the heart [5, 6]. The CAD is caused due to the low wall shear stress and deposition of matter which are present in the blood in some of the regions where the flow recirculates. Computational Fluid Dynamics (CFD) and Hemodynamics are used to study the flow disturbances in the blood. Hemodynamics is the dynamic study of the blood flow. The parameters like sudden bifurcation, bends, decrease in the diameter of the artery and bends affects the hemodynamic factors [7, 8, 9]. Quemeda viscosity model is used to study the velocity, wall shear stress and pressure of the different viscous models. And laminar flow condition is used to study the bifurcated models.

Study conducted by Giannoglou et al. [10] deals about the Endothelial Shear Stress (ESS). ESS has been considered as a prime feature in their study. It affects the atherosclerosis distribution in the bifurcation. They concluded that ESS is high in the areas where the plaques are more. Buradi et al. [11] have studied the impact of coronary tortuosity on the artery. They have discussed about the influence of tortuosity morphological indices on coronary hemodynamics. Rabbi et al. [12] have considered both bifurcations and trifurcations of arteries for their study. They have compared and analyzed both ideal and patient specific models. They have also considered tortuosity of the arteries in their study. Their result depicted that bifurcation angle effects the blood flow variables.

Many authors have considered effect of bifurcation in their study, but in this case, we have considered effect of the bifurcation and the bend on the blood flow. Our main intension is to study the impact of the bifurcation and the bend on the blood flow.

2. METHODOLOGY

2.1 Geometry of the coronary bifurcated artery

Autodesk Fusion360 software is used for designing the 3D model. The coronary artery 3D model is an idealized model. It has a constant 4 mm diameter throughout the model. The first model has two U bends and the bifurcation at the end of the second bend. The second model has a single bend and a single bifurcation which is present in between the U bend. Both the models have one inlet and 2 outlets as shown in the Figure 1.

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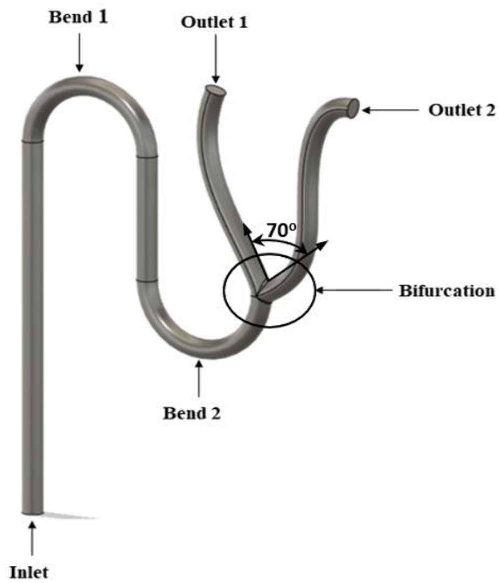
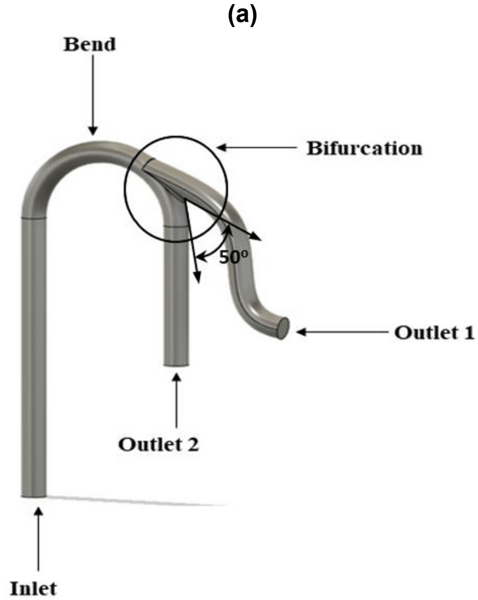


(a)



(b)

Figure 1: Geometry of the coronary bifurcated artery (a) Model 1 and (b) Model 2

In model 1, the height of the blood vessel from the topmost point to the bottom most point is 90mm. And the distance between the two U bends is 25mm. The bifurcation angle is 70°. And the radius of the bend is 12.5mm. In model 2, the height of the blood vessel from the topmost point to the bottom most point is 72.5mm. The bifurcation angle is 50°. And the radius of the bend is 12.5mm.

2.2 Blood flow governing equations:

The density of the blood is set to 1060 kgm^{-3}. Blood is considered as a non-Newtonian fluid in this study. To describe the blood viscosity, Quemada model is used. And Quemada Viscosity Model UDF was incorporated to define the velocity of the blood flow. The fluid flow should always satisfy the continuity and momentum equations. The continuity and momentum equation can be written as:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \rho\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z}\right) = 0 \quad (1)$$

Momentum Equation:

$$\rho\frac{\partial u_x}{\partial t} = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \quad (2)$$

$$\rho\frac{\partial u_y}{\partial t} = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \quad (3)$$

$$\rho\frac{\partial u_z}{\partial t} = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (4)$$

Here f_x, f_y and f_z are the pressure forces. In this study the effect of gravity has not been considered.

The viscosity of the blood is related to RBC volume fraction ($\boldsymbol{\varepsilon}$) and structure parameter (u). The relation between these two is given by an equation:

$$\mu = \mu(\alpha\boldsymbol{\varepsilon}) = \mu_{\boldsymbol{a}} \frac{\mathbf{1}}{(1-0.5u\varepsilon)^2} \quad (5)$$

where, μ= Viscosity of the plasma in the blood

μ_a=0.00132 Pa s and $u = \frac{u_0 + u_\infty\sqrt{\alpha^s/\alpha}}{1+\sqrt{\alpha^s/\alpha}}$

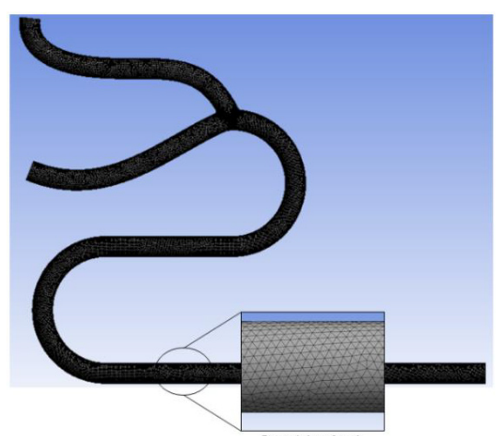
where, u_0, u_∞ and α^s are the functions of $\boldsymbol{\varepsilon}$ and their values are given in Table 1 [14,15].

Table 1: Values of u_0, u_∞ and α^s

u_0	u_∞	α^s (sec^{-1})
3.691	1.778	2.30

2.3 Computational modelling

2.3.1 Computational mesh



(a)