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Computational fluid dynamics (CFD) analysis of bifurcated vessel

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Abstract

The present study focuses on the CFD analysis of bifurcated blood vessel using ABAQUS /CFD 6.14 software in order to investigate the effect of variation in fluid flow within bifurcated vessel through associated amplitudes of flow. Besides this, study also focuses majorly on the effect of different types of fluids used for flow within bifurcated vessel. The aim of the present research work is to investigate the effect of seven different Types of amplitudes of fluid flow and two different types of fluids on fluid flow field variables in a bifurcated blood vessel.

Keywords

CFD, Bifurcated vessel, ABAQUS, Analysis, Effect, Amplitude, Fluid flow, Variables.

1.Introduction

Bifurcated vessel is a fluid flow vessel divided into two branches, such as blood vessel, or a tooth that has two roots. Bifurcations are very common in blood vessels and in the bronchial 'tree' of the lungs. The present research is used to analyze the characteristics of flow field variables in a bifurcated vessel using Computational Fluid Dynamics (CFD).The research is carried out with the following objectives: (i) To conduct simulation of flow in a bifurcated vessel using the concept of Computational Fluid Dynamics commercially (CFD) through using commercial FEM software package ABAQUS 6.14. (ii) To investigate the effect of seven different types of amplitudes on fluid flow field variables in a bifurcated vessel. (iii) To investigate the effect of two different types of fluids on fluid flow field variables in a bifurcated vessel. In past years, a number of researchers contributed in the area of CFD[1]. study deals with the hematocrit level on resistance of flow, wall shear stress in a stenosed artery of permeable wall. In the study they have developed and solved some theoretical formulas based on stenosis and hematocrit effects. The results highlight that the resistance of flow increases for increasing of stenosis height where the hematocrit level (35%-45%) has significant effects [2]. study cardiovascular diseases very common in today's world. It is of great physiological significance to simulate the behaviour of diseased arteries using computational methods, as it will help the clinicians in the early diagnoses of the disease. Their study reviews the application of computational fluid dynamics (CFD), for simulating blood flow phenomenon in human arteries [3]. study to create CFD tools and models capable of simulating pulsatile blood flow in abdominal aortic aneurysm (AAA) and stent graft. A modified Womersley inlet and imbalance pressure outlet boundary conditions are originally used in this study. The Womersley inlet boundary represents better approximation for pulsatile flow compared with the parabolic inlet condition. Numerical results are presented providing comparison between different boundary conditions using different viscous models in both 2D and 3D aneurysms. Good agreement between the numerical predictions and the experimental data is achieved for 2D case. 3D stent models with different bifurcation angles are also tested. The Womersley inlet boundary condition improves the existing inlet conditions significantly and it can reduce the Aneurysm neck computation domain [4]. used hemodynamic simulation studies to gain a better understanding of functional, diagnostic and therapeutic aspects of blood flow. In this study the Newtonian effect of blood flow in the portal vein has been simulated for normal flow condition and considering portal hypertension case (with the formation of Thrombosis) and compared and validated with the results (with non-Newtonian effect) of C.C. Botar et al (2010). It has been observed that considering blood as Newtonian or non-Newtonian has no significant effect on the results for measurement of wall shear stress as the primary consideration [5]. used computational fluid flow modelling with commercially available computational fluid dynamics (CFD) software to visualize and predict physical phenomena related to human fluid flow. In this study, different human aortic models including straight, bend, T-shaped and the main arterial branching areas were analyzed for their fluid flow variables. They found that turbulent flow with complaint muscle boundaries will provide more realistic results compared to the clinical studies [6]. used Computational Fluid Dynamics (CFD) in the analysis of blood flow. They found that CFD has made impressive progress in the past decade and has evolved into a promising design tool for the development of biomedical devices. In this study utilization of computational fluid dynamics in the analysis of blood behaviour has been discussed and the potential for developing an instrumentation using flow pattern is analysed [7-8]. study to analyze drag and lift models recently developed for fluid-solid, fluid-fluid or liquid-liquid two-phase flows to understand their applicability on the computational fluid dynamics, CFD modelling of pulsatile blood flow. Virtual mass effect and the effect of red blood cells, RBCs aggregation on CFD modelling of blood flow are also shortly reviewed to recognize future tendencies in this field. They found that the recent studies on two-phase flows are very useful to develop more powerful drag-lift models that reflect the effects of blood cell's shape, deformation, concentration, and aggregation.

2.CFD analysis of bifurcated blood vessel

In the present study, blood is considered as a Newtonian fluid. For the simulation of blood flow Finite Element Method (FEM) is used. Because FEM provides rapid solutions with unmatched accuracy and thus ensure that desired results are obtained in a cost effective manner. This study describes about the mesh convergence study in which seven different mesh size of work piece are presented out of those mesh, one mesh with reasonable accuracy and less computational time is selected on the basis of convergence. Results of FEM simulation of blood (fluid) flows are also presented in seven different incremental steps. Material properties of blood (Newtonian fluid) used in this study are density and viscosity. Values of density and viscosity are shown in table below.

Material properties	Values
Density of Newtonian blood	1E-9 ton/mm^3
Viscosity of the Newtonian blood	2.5E-9 MPa.s

Variations in velocity amplitude of blood (Newtonian fluid) with time for different types of loading are shown in figure below:

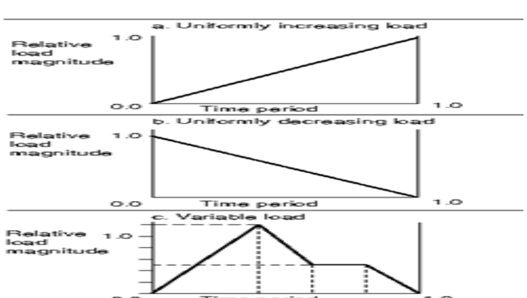

Figure 1 (a-c) (a) Ramp with uniformly increasing load

Figure 1 (b) Ramp uniformly decreasing load

Figure 1 (c) Ramp with variable load

From Figure 1(a-c), Figure 1 (a), Figure 1 (b), and Figure 1 (c) it is clear that velocity magnitude is continuously increasing with times for uniformly increasing load, velocity magnitude is continuously decreasing with times for uniformly decreasing load and velocity magnitude is combinations of continuously increasing, continuously decreasing, remains constant and continuously decreasing with times respectively for variable load.

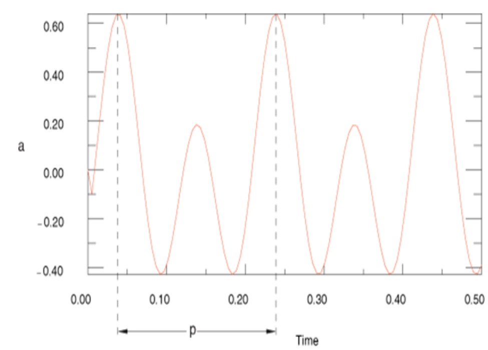

Figure 2 Graph for Periodic data

Figure 2 shows the graphical representations of variation in velocity amplitude with times for periodic data. From figure it is clear that variation in velocity amplitude is sinusoidal for periodic load.

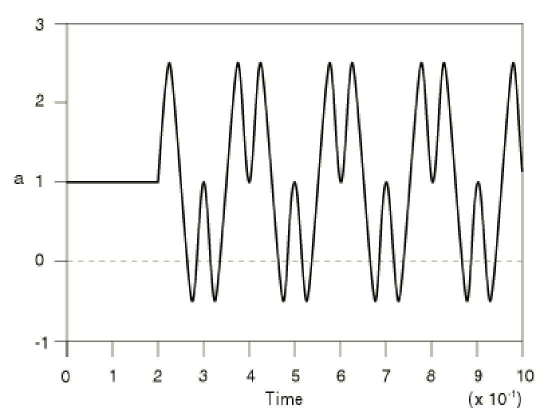

Figure 3 Graph for Modulated data

Figure 3 shows the graphical representations of variation in velocity amplitude with time for modulated data. From the graph it is clear that velocity amplitude is constant for some periods of times and after which variation in velocity amplitude becomes irregular for next periods of times.

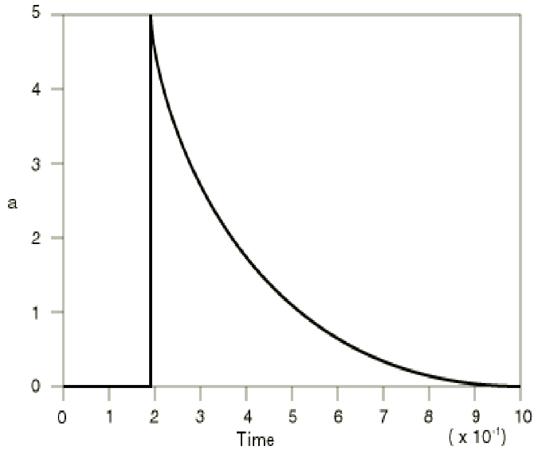

Figure 4 Graph for Exponential decay

Figure 4 shows the graphical representations of variation in velocity magnitude with times for exponential decay. From the graph it is clear that velocity amplitude is zero for some periods of times and then becomes maximum suddenly and after which it decreases exponentially.

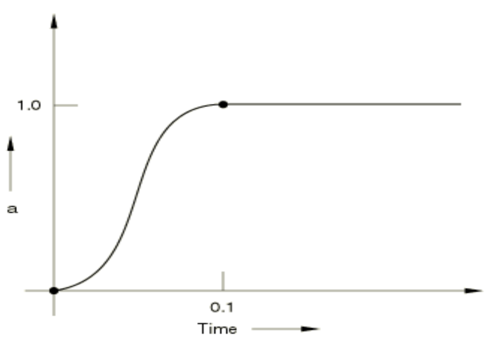

Figure 5 Graph for smooth step

Figure 5 shows the graphical representations of variation in velocity magnitude with times for smooth steps data. From the graph it is clear that variation in velocity magnitude is more as compare to time for some time periods and then it becomes constant for next periods of times.

Table 2 Nomenclature of different types of amplitudes used in CFD analysis

Sr. No.	Types of Amplitude
1	Ramp tabular (Uniformly Increasing)
2	Ramp-Tabular (Uniformly Decreasing)
3	Ramp-Tabular (Variable)
4	Periodic(Pulsating)
5	Modulated Data
6	Exponential Decay
7	Smooth Step (Two Points)

3.Results & discussion

3.1 Effect of amplitudes on resultant velocity

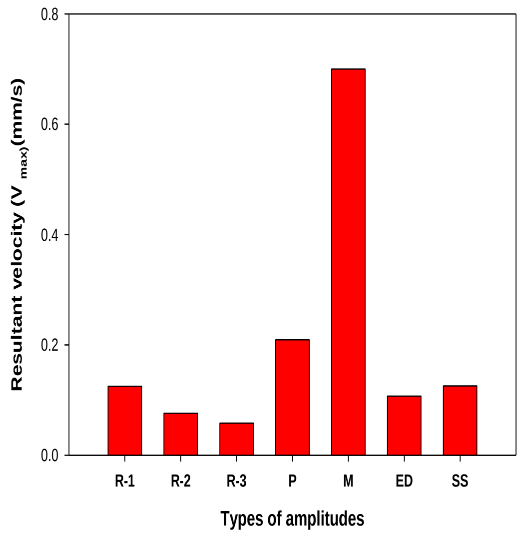

Figure 6 Types of amplitudes

Figure 6 shows the effect of types of amplitudes on maximum resultant velocity. It is observed that highest maximum resultant velocity is obtained for amplitude of modulated form. Second highest maximum resultant velocity is obtained for periodic variation of amplitude. Third highest maximum resultant velocity is obtained for ramp type amplitude for uniformly increasing and after that due to the effect of smooth step (two points) amplitude causes maximum resultant velocity. After that maximum resultant velocity is highest for exponential decay case of amplitude. Ramp amplitude with tabular variation and ramp amplitude with variable intensities causes second lowest and lowest maximum resultant velocity respectively. A negligible variation is cited in maximum resultant velocity due to the different mesh sizes. It is found that there is decrement of nearly about 750 % in maximum resultant velocity due to the effect of two amplitudes namely modulated data (highest amplitude) and ramp amplitude with variable intensities.

3.2Contour plots: Effect of amplitudes on Newtonian blood flow in Bifurcated vessel

Figure 7 to Figure 13 depict the various contour plots obtained for the seven different cases of amplitudes, when a Newtonian blood flows through a bifurcated vessel. Figure 7 shows the contour plot of cut-section model of bifurcated vessel for ramp amplitude with uniformly increasing profile. It is seen that the maximum resultant velocity of Newtonian blood is maximum at entrance of the bifurcated vessel for ramp amplitude with uniformly increasing profile. It is also gathered that minimum resultant velocity is obtained around a zone at the second outlet of bifurcated vessel.

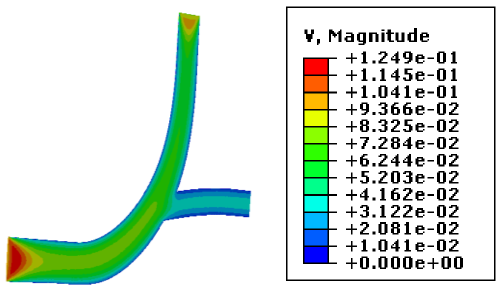

Figure 7 Contour plot of Velocity (Magnitude) for Newtonian blood with ramp amplitude (Uniformly increasing)

Figure 8 shows the contour plot of cut-section model of bifurcated vessel for ramp amplitude with uniformly decreasing profile. It is seen that the maximum resultant velocity of Newtonian blood is maximum at entrance of the second exit for ramp amplitude with uniformly increasing profile. It is also gathered that minimum resultant velocity is obtained at the corner edges of the entrance and first exit of bifurcated vessel. The maximum resultant velocity is reduced considerably for ramp amplitude with uniformly decreasing profile.

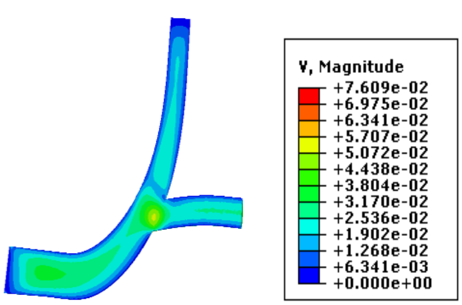

Figure 8 Contour plot of Velocity (Magnitude) for Newtonian blood with ramp amplitude (Uniformly decreasing)

Figure 9 shows the contour plot of cut-section model of bifurcated vessel for ramp amplitude with variable profile. It is seen that maximum velocity for ramp amplitude with variable profile is obtained in a zone adjoining entrance and second exit of a bifurcated vessel. Least resultant velocity is obtained at the corner edges of entrance and fort exit of the bifurcated vessel.

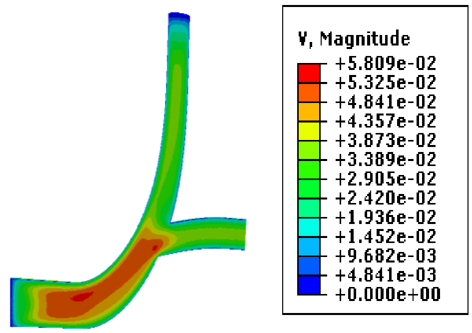

Figure 9 Contour plot of velocity (Magnitude) for Newtonian blood with ramp amplitude (Variable)

Figure 10 shows the contour plot of cut-section model of bifurcated vessel for periodic amplitude with pulsating profile. It is seen that maximum velocity for periodic amplitude with pulsating profile is obtained in a second exit of the bifurcated vessel. It can also be gathered from figure 10 that there is a reversal of fluid due to the influence of periodic amplitude, which occur right from the exit end of the second outlet section, from which the fluid flows in reverse direction upto the entrance of the bifurcated vessel. Nearly 50 % of resultant velocity is observed for the Newtonian blood at the first exit of bifurcated vessel.

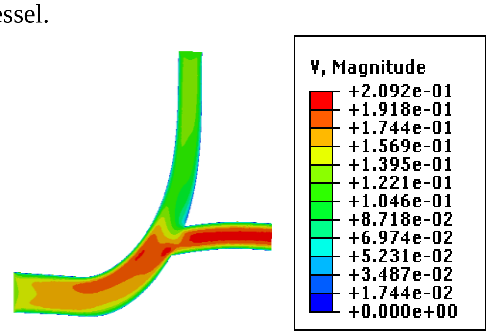

Figure 10 Contour plot of Velocity (Magnitude) for Newtonian blood with pulsating flow (Periodic)

Figure 11 and Figure 12 show the contour plots of cut-section model of bifurcated vessel for periodic amplitude named after as periodic data and exponential decay. It is seen that the maximum resultant velocity for modulated data is nearly seven times the maximum resultant velocity that of exponential decay amplitude. Besides, this it is also recognized that the maximum intensity of resultant velocity for both the cases of amplitudes is occurring at a corner junction point of second exit of bifurcated vessel. Figure 13 shows the contour plot of resultant velocity for the case of amplitude with smooth step. It can be gathered from the figure that the highest intensity of resultant velocity is occurring at the entrance of the bifurcated vessel. It is also seen that the maximum resultant velocity is varying in a somewhat parabolic manner at the entrance of the bifurcated vessel.

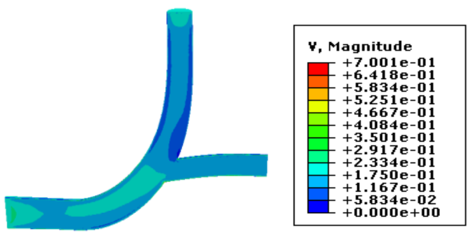

Figure 11 Contour plot of Velocity (Magnitude) for Newtonian blood with modulated data

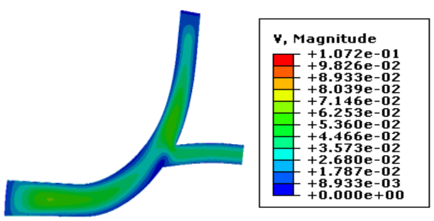

Figure 12 Contour plot of Velocity (Magnitude) for Newtonian blood with exponential decay

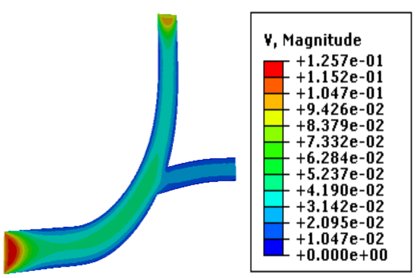

Figure 13 Contour plot of Velocity (Magnitude) for Newtonian blood with smooth step (two points)

4 Conclusion and future work

In the present research work, CFD analysis of bifurcated blood vessel has been carried out to investigate the effect of seven different types of amplitudes of velocity of flow and two different types of fluids on the fluid flow characteristics. It is found that there is decrement of nearly about 750 % in maximum resultant velocity due to the effect of two amplitudes namely modulated data (highest amplitude) and ramp amplitude with variable intensities. Amplitude with periodic profile has a considerable influence over maximum fluid pressure within bifurcated vessel as compared to other six amplitudes. It is found that the maximum resultant velocity is more for Newtonian blood as compare to non-Newtonian blood. It is also recognized that there is percentage reduction in maximum resultant velocity of nearly 4 % from Newtonian blood to non-Newtonian blood. The present work has its own limitations. The further research can be undertaken in the area of CFD analysis of bifurcated blood vessel. Effect of variation of angles between branches of a bifurcated vessel on fluid flow field variables and effect of various grades of alcoholic and non-alcoholic fluids can be considered for future work.

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