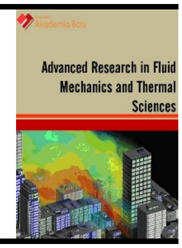
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html

ISSN: 2289-7879



Haemodynamics Study in Subject-Specific Abdominal Aorta with Renal Bifurcation using CFD - A Case Study

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ARTICLE INFO

Article history:
Received 30 July 2018
Received in revised form 2 October 2018
Accepted 7 October 2018
Available online 12 October 2018

Keywords:
Haemodynamics, abdominal aorta, renal artery, subject-specific modelling

ABSTRACT

Study of haemodynamics with advances in computational simulation is beneficial in demonstrating the flow dynamics of cardiovascular diseases such as atherosclerosis. Numerical simulation investigation on subject specific models provides detailed information on haemodynamic conditions. In the present study, two separate cases of subject specific abdominal aorta with renal bifurcation is investigated. Both the cases are diagnosed to be normal with any plaque sites. 3D subject-specific CAD models are generated based on CT scan data using MIMICS-16.0 and numerical analysis is performed using Computational Fluid Dynamics (CFD) in ANSYS-17. The blood flow is assumed to be incompressible, homogenous and Newtonian. Flow equations are simulated for three pulse cycles and haemodynamic parameters such as flow pattern, Wall Shear Stress (WSS) and pressure contours are studied at the bifurcation and critical zones. The variation in flow behaviour is investigated throughout the pulse and simulation results obtained demonstrate that there is a considerable flow recirculation in the downstream side of abdominal aorta and distal side of renal branches. The obtained results agree well with the clinical observation and demonstrate the potential of subject-specific numerical studies in prognosis of disease progression.

1. Introduction

Cardiovascular diseases is found to be major cause of death rate across the world, especially the atherosclerosis. In the atherosclerosis, the plaque formation generally occurs close to bifurcations and curvatures, and the affected arteries get hardened as a result of formation of plaques [2]. The growing interest to understand the biomechanics of generation, detection and the treatment of

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stenosis vascular diseases combined with advanced computational simulations has helped the medical doctors/biomedical engineers in developing the bio-medical instruments for treatment (surgical) modalities [3]. Existing clinical imaging modalities such as CT/MRI and Ultrasound Imaging techniques in coupling with the numerical simulation such as CFD can enhance the understanding of detailed physiology of blood flow in diseased vessels [4]. Many of the previous studies have demonstrated the feasibility of computational methods such as Computational Fluid Dynamics (CFD) technology in the haemodynamics simulation based on image data obtained from MRI/CT data [5]. Haemodynamics study using CFD shall provide the valuable information to doctors to understand the mechanisms of stenosis development and progression in patients.

Hence, in the present study an attempt is made to investigate the haemodynamics in two normal subject-specific abdominal aorta with renal bifurcation model without any stenosis. CFD simulation is carried out and focusing on haemodynamics parameters such as velocity, wall shear stress and pressure profile, in detail. Thus, simulation observations are demonstrate the flow behaviour in subject-specific cases and help in understanding of flow behaviour at the bifurcations and curves.

2. Methodology

In the present study, blood flow is assumed to be incompressible, Newtonian fluid [19]. The dynamic flow is governed by the continuity and Navier-stokes equations [1,20], respectively as

$$\nabla . u = 0 \tag{1}$$

$$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = -\nabla p + \mu \nabla^2 u \tag{2}$$

Where ρ is the density, p is the pressure, μ is the viscosity and u is the velocity.

In the present study, two healthy cases of normal abdominal aorta with renal bifurcations on both sides are considered to evaluate the importance of flow behavior. The geometric modelling is generated based on data obtained from CT angio scan. Figure 1 shows the different views of CT scan data and the encircled area highlights the location of abdominal aorta with renal bifurcation in addition to the 3D geometric model generated in MIMICS of both case-1 and case-2. The CT angio scan of case-1 and case-2 is obtained from a 40 year old male and 50 year old female subjects respectively. Although the geometry of both side renal bifurcation is slightly different, but there are no sites of plaque formation as observed in the CT angio scans. 3D CAD models are generated in CATIA based on the export data obtained from MIMICS. CFD models of both the case-1 and case-2 are generated in ANSYS WORKBENCH.

3. Results

In the present study, blood flow is assumed to be Newtonian even though it is non-Newtonian physiologically as the focus in on large arteries and hence, Newtonian assumption is acceptable as relatively high shear rate occurs. In medium and smaller arteries, non-Newtonian assumption is valid as shear rate is lower than $100s^{-1}$ and shear stresses depend non-linearly on the deformation rate. The density and dynamic viscosity of the blood is considered to be 1050 kg/m^3 and 0.004 $N\text{-}sec/m^2$ respectively. Pulsatile time varying velocity profile as shown in the Figure 1 is applied at the inlet. Also, to include the peripheral resistance, a time varying pressure wave form is applied at the outlet as shown in the Figure 2. Each pulse cycle during rest and exercise conditions is discretized into 180 time steps to simulate the flow behavior more accurately. A user-defined function is developed to provide the pulsatile inlet velocity profile for rest and exercise condition and also pulsatile outlet pressure. These simulation results provide useful data in quantifying the haemodynamic changes in understanding the haemodynamics in abdominal aorta renal bifurcation.

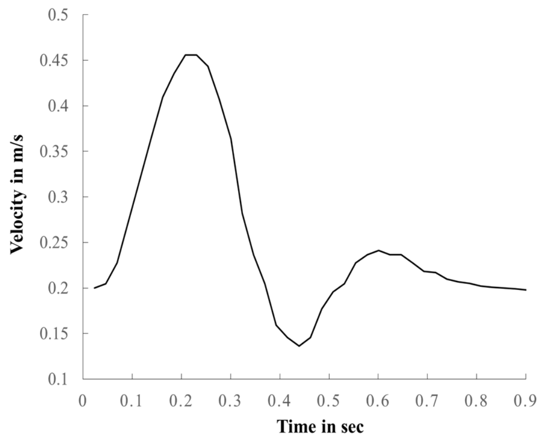

Fig. 1. Time varying inlet velocity

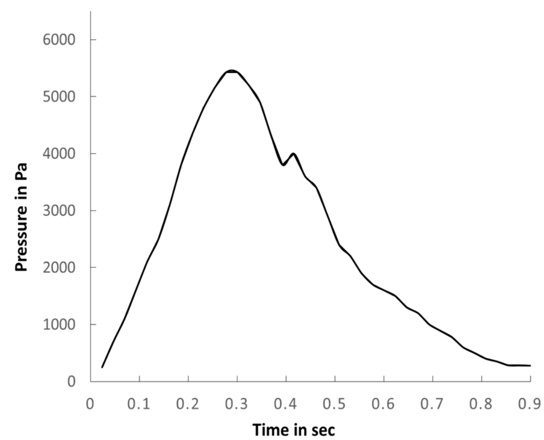

Fig. 2. Time varying outlet pressure

Numerical simulation of different models with rest and exercise conditions is carried out for three pulse cycle and results obtained in the last cycle is considered for the investigation. The haemodynamics parameters like velocity, wall shear stress and pressure are studied at specific instants of pulse cycle like early systole, peak systole, early diastole and late diastole. These parameters varies with time due to the pulsatility of the flow waveform and the maximum value generally occurs at the peak systole when the inflow is maximum.

4. Conclusions

Numerically simulation of case studies of subject-specific abdominal aorta branching into renal artery are investigated in this present study. The inflow is higher during peak systole in cardiac cycle and flow decelerates during diastole. The present study demonstrates the fundamental aspects of haemodynamics in subject-specific cases.

Acknowledgement
Authors acknowledge the support by Fundamental Research Grant Scheme (FRGS/1/2015/TK03/ MIU/02/1).

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