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Computational Fluid Dynamic Analysis of Blood Flow Pattern - A Review

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Abstract: ***Computational Fluid Dynamics (CFD) has made impressive progress in the past decade and has evolved into a promising design tool for the development of biomedical devices. Rheology deals with the flow and deformations of fluids in a set of given conditions Blood being a biological fluid has its own behaviour and rheology, flow pattern of blood varies during the flow of blood in the blood vessels in the body. The 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.***

Keywords: Blood, Blood Flow, Haemorheology, Haemodynamic, Blood vessels

1. Introduction

Computational Fluid Dynamics (CFD) has made impressive progress in the past decade and has evolved into a promising design tool for the development of biomedical devices. CFD presents itself as a useful tool for investigating domain space for physical system design and performance variables [1] and for diagnosing system behaviour. Computational fluid dynamics (CFD) is a software- based application of numerical methods that allows the prediction of fluid flow fields through the computational solution of the fundamental governing fluid dynamic equations relating to continuity, momentum and energy [2]. Computational Fluid Dynamics (CFD) can be applied to gain insights into most fluid processes and associated phenomena. Computational Fluid Dynamics (CFD) is a group of techniques aimed at solving the Navier-Stokes equations [24] or strictly Reynolds-Averaged Navier-Stokes equations in most cases, thereby satisfying the conservation of mass, momentum and energy to predict the behaviour of fluidic systems

The application of CFD may replace existing analytical techniques when a higher number of design variations are to be analysed [33] and where physical testing may be prohibited due to restricting factors, such as scale, cost, accessibility, or the presence of physical or environmental hazards. Fluid (gas and liquid) flows are governed by partial differential equations which represent conservation laws for the mass, momentum, and energy. Computational Fluid Dynamics (CFD) is by means of replacing such PDE systems by a set of algebraic equations which can be solved using computers.

Rheology deals with the flow and deformations of fluids in a set of given conditions this rheology [14] various from each fluid based on their physical properties such as Viscosity, density, specific gravity and pressure which determines the deformation occurring in the fluid. The fluid on its flow path alters its pattern of flow based on the flow path dimensions this provides the degree of deformation of fluid from its original flow. Blood is biological fluid and has its own behaviour and rheology, flow pattern of blood varies during the flow of blood in the blood vessels in the body [13].The blood which has a non-Newtonian behaviour has a standard viscosity and this varies based on pathological condition of the individual which is determined by the hematocrit value, plasma viscosity and the properties of red blood cells.

Hemorheology deals with the deformation occurring in blood during its flow in a blood vessel this requires various levels of analysis and geometries of blood and blood vessels which would define the exact rheological changes occurring in blood flow [10]. The non-Newtonian effects are also influenced by the type of deformation, being shear or elongation. The non- Newtonian nature of blood acts as a regulating factor to reduce resistance and stress and hence contribute to the body protection [14].

Considering the circulatory system the non-Newtonian effects is highly dependent on the shape and size of the flow vessels which alters different non-Newtonian rheological behaviour [16] in the vessels and hence different flow modelling approaches should be applied to the different parts of the circulatory system. Non-Newtonian effects in general are dependent on the magnitude of deformation rates and hence they can exist or be enhanced at certain low regimes such as low shear rates [38].

The major aim of the study is to analyse the various studies which were carried out using CFD for analysing the behaviour of blood in various parts of the body's blood vessels for gaining knowledge on the application of CFD and for determining the potential of CFD in the field of medical instrumentation for the analysis and development of new techniques and diagnostic methods for disease diagnosis using CFD studies.

2. Blood Flow Analysis in Portal Vein

The blood flow parameter for the hepatic portal vein was considered during the simulation with an average pressure of 40cm water column. The study has shown the potential of computation fluid dynamics study over the analysis of blood flow parameters during clots in hepatic portal vein with which the impact of the clots altered the velocity magnitude, pressure, strain rate and sheer stress which shows the variation in the blood flow pattern can be deduced during a particular condition such as a clot in the flow path of blood. The variation in the velocity magnitude was observed due to the clot restraining the flow path. The variation of pressure

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can be seen due to the variation in the velocity magnitude. The sheer stress exerted on the surface of the walls and the strain developed over the blood vessels [34]. The study proves the application of CFD in the field of medicine and has provided an insight on the behavioural changes of blood during the flow in hepatic portal vein systems.

3. Coronary Artery Analysis Using CFD

The principal findings of this study by [26] are that both of the aneurysms which was taken for consideration was present parallel to the main flow and behave like a cavity. The flow pattern in the artery was analysed and found that recirculation fluid region was formed inside the aneurysms at the diameter of eight millimetres. The strong secondary flow was detected inside both aneurysms with the changing diameters of four to eight millimetres. The study also dealt with the secondary flows in the coronary artery at the inlet of LCX and LAD arteries. The effect of the size of aneurysms on the exit flow ratios was also studied and the flow reduction on the branch which has the aneurysm was located. This study is driven by the need to establish a technique that can identify the optimum regions for analysis of aneurism and its effects on blood flow. The study proved that CFD can be potentially exploited for the patient specific identification and it could benefit the diagnosis for the advanced intervention techniques. The further analysis by using CFD could generate flow pattern data for the exact determination of aneurism in the coronary arteries.

4. Analysis of Blood Pumps

A review of the currently existing Ventricular assist devices (VAD) [22] showed the annotation of the current devices which are being used for the assisting of the heart. The review deals with the VAD designs, requirements and the importance of the development of such devices using CFD. The complex structure of blood, including its shear-thinning and viscoelastic behaviour, as well as tank-treading of RBCs have been analysed on an overview of by current state-of the- art methods for the analysis of blood flow. Quantitative results for unsteady blood flow have been given for the GYRO blood pump before which the CFD based predictions of hydraulic pump performance fit well the experimental data at lower rotational speeds taken for analysis. The work reviewed in this paper are that blood behaves like a Newtonian fluid and reduces the three-dimensional shear forces acting on the RBCs by a scalar shear-stress, which is then correlated to experimental results under steady flow. A tensor RBC model, derived from a model of a deforming droplet was modified to include tank-treading. Comparative studies in blood pumps between a stress-based and a strain-based method for calculating the stress and strain relationship can serve to evaluate the predictive potential [19]. The blood pumps used and the potential for the development of new blood pumps based on flow pattern is analysed.

5. Simulating Blood Flow in an Aortic Arch

Blood flow patterns in the blood vessels have been handled and identified through which typical thoracic aorta and its relevance to the aortic diseases. In the analysis of the aorta by [25]. Computational fluid dynamics approach is adopted to investigate blood flow patterns in thoracic aorta. Geometrically variant models are reconstructed from CT scans of patients of the age of 50 years. A pulsatile input velocity waveform and output pressure waveform were applied on the models for 5 cycles and the results were compared across the models. The demonstrated velocity profiles were skewed towards the inner bend throughout the ascending aorta and aortic arch, before shifting into symmetry in the descending aorta. Comparisons reveal that the angle of the outlet branches and curvature profile play a vital role in affecting the skewness of velocity profiles obtained. The wall shear stresses are also affected by geometric features of the aorta proving the detection of the variation in flow pattern due to the variation in the geometry of the flow path of blood.

6. Cardiomyopathy Analysis Using Fluid Dynamics

The study on heart and the circulation process requires proper knowledge of the circulatory system to inspect flow abnormalities within a diseased heart. It is important to have an understanding of the blood flow process and its pattern in a normal circulatory process which is understood by efficient and consistent flow patterns. Various pathological patterns and affected areas have different effects on the blood flow pattern in the blood vessels. The cardiomyopathy is characterized by enlarged left ventricle chambers and reduced wall motion, both globally and regionally. Thrombus and its formation were detected and analysed in cardiomyopathy through the use of CFD analysis. Geometrical analysis methods in CFD approach were used to study hemodynamics within the left ventricle. Therefore a precise study design has been provide with the insight to develop a heart assisting device [8].

7. Modelling of Intracranial Network

The flow pattern simulations of unsteady flow in complex arterial networks of the brain have been achieved with 1D and 3D numerical models in respect with the arterial wall elasticity. In simulations using CFD tools the pressure and flow rates were analysed under various conditions. However, the fluctuations in the pressure and flow rates predicted by the model are significantly higher [18]. Convergence of the flow rates and pressure predicted by the 1D model to the 3D model was observed based on stiffening of the arterial walls. There were influences due to the local area fluctuations which contributed significant to the long range effects on the flow and pressure waveforms in distant regions of the relatively large arterial network. The Windkessel effect was observed due to the elasticity of the blood vessels in the arterial system where blood pumped by the heart during systolic phase is partially stored in the vessels. This study proves the variation in the flow as the modelling carried out at 1D and 3D shows the variation and the pattern changes occurring in arterial networks.

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8. Geometric Model Generation of Blood

The work explains the utilization of CFD analysis for the improved analysis and construction of geometric models for blood flow. The image processing of the blood vessels has been carried out utilizing local constrained watershed algorithm. An adaptive algorithm is utilized for the anatomic model analysis and simulation. The geometric model of the patient's specific carotid arteries the hemodynamic parameters will provide a practical tool for diagnosis planning, and postoperative monitoring of arterial diseases. By comparing the blood flow pattern before and after the therapy, the model can be used to assist the optimal therapeutic dosage. The variations and development of a new algorithm for the flow pattern detection in arterial diseases has exploited the implications of CFD in the field of medical diagnosis [29].

9. Conclusion and Future Perception

The paper gives a potential insight into the utilization of CFD in the field of medicine and diagnosis of human systems. The work on the [34] portal vein system with and without clots gives an potential to utilize CFD analysis for the understanding and analysis of blood vessels and blood flow. The study provided the variations of results which has been determined during clots and free flow of blood in the portal vein.

The analysis on the coronary artery provided [26] the precision of CFD analysis in complex branched network like the coronary artery which is a crown around the heart has explained the determination precession of fluid dynamic analysis in complex systems. The potential in the analysis of variation in biological systems can be analysed using CFD for developing new and efficient systems for the easy diagnosis of medical conditions.

Devices relating with the heart is also analysed using CFD [22] for development new and efficient instrumentations for the development of a tensor RBC model derived from a model of a deforming droplet was analysed. This shows the accuracy of the simulation and values obtained through CFD for designing of instrumentations.

The analysis of the blood flow pattern in aorta based on the case history of various patients [25] was analysed for the validation of precision and prediction methods using CFD, the potential variations in blood flow across the aorta in various patients showed the maximum similarity which was analysed using simulation in comparison to the conventional detection methods.

Cardiomyopathy which is analysed in the left ventricle [8] proves the efficacy of the analysis by CFD for determining various disease conditions in the human system, the simulation and precise geometry analysis of the left ventricle in cardiomyopathy has been determined.

The modelling and study of blood flow in 1D/3D determined the pattern variation of blood during circulation. The Windkessel effect was observed due to the elasticity of the blood vessels in the arterial system where blood pumped by the heart during systolic phase is partially stored in the vessels [18]. This study proves the variation in the flow as the modelling carried out at 1D and 3D shows the variation and the pattern changes occurring in arterial networks. The tiniest variation in the flow pattern can be analysed using CFD analysis.

The study based on the application of computational fluid dynamics has provided numerous new opportunities for the development of new diagnostic methods for detection of clots and aneurysms. The study on flow pattern in hepatic portal vein [34] showed the variation of flow pattern during a clot and free flow in the vein. The programming of an algorithm for the comparison of flow pattern analysis [29] validated the possibilities of a programming device by using the flow pattern variation. The further exploitation of the CFD in the field of medical diagnosis of blood and its components can pave a way for the development of instrumentation for early clot detection using the behavioural changes occurring during the blood flow. The potential designing of a instrumentation and effective diagnosis of the early clot formation can be carried out through which the diagnosis of myocardial infarction can be made efficient.

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