



Micro-Arterial Flow Simulation for Fluid Dynamics: A Review

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Abstract: The planet is evolving technologically in all respects, but mortality due to various diseases continues to be a concern. In particular, the cardiovascular disease mortality rate is high and affects people of all ages. Innovation and technology are progressing quickly in every industry. The use of technology in the medical field is currently limited. Many developments are being made in this area, so that the treatment can be done in an easy and efficient manner. One such cost-effective technology that maximizes performance efficiency is computational fluid dynamics. Computational Fluid Dynamics (CFD) is a commonly used mechanical engineering approach to solve complex issues by using simulation to analyze fluid flow, heat transfer, and related phenomena. Due to its high-performance hardware and software, CFD has been increasingly utilized in the biomedical research of coronary artery disease. This paper focuses on "Micro-Arterial Flow Simulation for Fluid Dynamics," specifically designed to predict the velocity flow and the stress in the coronary arteries via Anastomosis, which helps to reduce the complexity of the issue

Keywords: *Computational fluid dynamics, Anastomosis.*

I. INTRODUCTION

Over the years, technology has changed our lifestyle dramatically. Technology has provided incredible tools and resources that bring us valuable information. Technology has made our lives comfortable with all of these revolutions. Technology is taking positive and negative steps forward. There is a great impact on people's lifestyles. Tuberculosis is the only illness that in many countries around the world is the greatest murderer. But now the predominant non-communicable diseases are. Non-communicable diseases (NCDs) kill 41 million people a year, which is 71% of the world's deaths. Most of these NCDs are killed in cardiovascular diseases or 17.9 million people each year, followed, by cancers (9.0 million), respiratory diseases (3.9 million), and diabetes (1.6 million) [1]. Research conducted in partnership with the World Health Experts by Washington-based Global Burden of Disease (GBD), Registrar General of India (RGI), showed that most people have cardiovascular issues.

II. BACKGROUND OF SMALL VESSEL DISEASE

Coronary micro vascular or small artery disease is a heart-related disease that affects many people worldwide. Small vessel disease is the disorder in which the small branches of the main coronary arteries are weakened and are not adequately distended. The blood flow to the heart reduces when it is impaired. Small arteries must thus expand to supply blood to the heart with oxygen-rich blood. If angioplasty and stents are taken to cure coronary artery disease, signs and symptoms are not lost, people can even have small vessel disease. Symptoms of small vessel disease include chest pain, angina that can intensify during every day work and stress, shortness of breath, fatigue, and energy shortage. The coronary artery structure is shown in Fig 1.

One of the most recent strategies for restoring damaged vessels and blood supplies in extreme limbs is micro-Anastomosis [3]. This operation establishes contact between two neighboring remote portions of the artery/vein. There are great demands on the latest surgical techniques to produce vascular Anastomosis in some specialties, such as orthopedic, plastic, reconstructive, head and neck, cardiac, and organ transplantation [4, 5] that are simple, savings, and less damageable but reliable [4, 5]. In general, three forms of anastomosis can be divided based on the two sutured conduits, (I) end-to-end, (ii) end-to-side, and (iii) side-to-side as referred to by Li et al [4]. The two ducts are sutured to a transverse diameter in the end-to-end form [6]. The vessel is laterally sutured to the parent vessel in end-to-side form, while in side-to-side the two vessels are attached along the longitudinal direction. Anastomosis alters the arteries and restores blood supply [7]. Since simulation is an alternative method to understand and analyze the biological and geometry parameters that can support further arterial hemodynamic study [8].

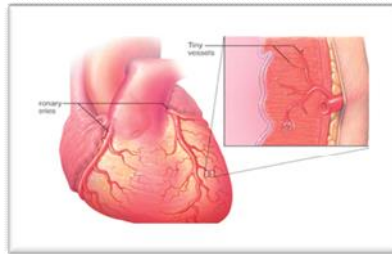


Figure 1 General Layout of Coronary artery

2.1 Evolution of Hemodynamic

Blood is Non-Newtonian, better studied with rheology than with hydrodynamics. Hydrodynamics and fluid mechanisms dependent on the use of classic viscometers are not able to describe hemodynamic [9] and are thyrrotrophic; as a result, blood vessels are not solid tubes. Literature has shown that the concept of Newtonian properties is adequate in relatively smooth, uniform vessels with more and nearly 0.5 mm diameter, but non-Newtonian effects are also important in larger vessels in irregular geometries (stenosis, aneurysm, Anastomosis, etc.). CFD experiments in anatomically realistic arterial geometries, based on the first images, were based on clinical x-ray angiograms [10, 11]. For imagery vessels, MRI is used in particular, as the blood itself can be used as a contrasting agent. Unlike MRI or x-ray images, ultrasound imagining is used manually without a connection to a set coordinating scheme, so it's difficult to rebuild a sequence of them in 3D. Doppler ultrasound is usually used to deliver real-time velocities measurements on the nominal line of the container, which can calculate the average velocity and flow rate gave the vessel's radius, provided a fully defined velocity profile has been developed [12]. These processes help to construct the 3D CFD model.

Microsurgical tissue auto-transplantation is the latest technology focused on modern techniques for reconstruction of defects after trauma, and surgical cancer; where there is a diameter mismatch for suturing side-to-side in Anastomosis. There are various ways to have blood vessels anatomized. One of the methods was taken into account. Previous studies by Rickard et al. [13, 14] developed the rodent model for Anastomosis analyses (Fig. 2.1); resin cast of the Anastomosis artery was used from these studies to generate the digital CFD input scan micro-CT geometry.

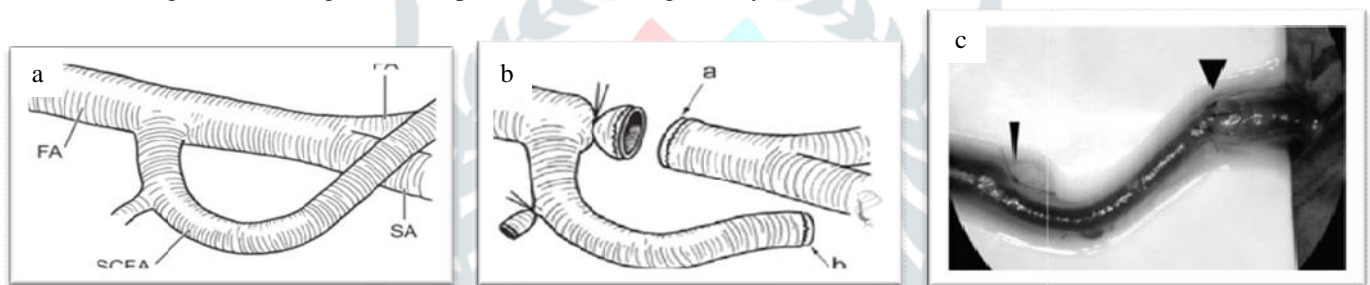


Figure 2 Rodent Anastomosis model (from Rickard et al. [13]) (a) Anatomy of the distal femoral artery (b) View before anatomizing (1) to (2). (c) A completed Anastomosis (small arrow: tie around FA; large arrow: sutured Anastomosis SCEA to FA) Key; FA: femoral artery; SCEA: superficial caudal epigastria artery; PA: popliteal artery; SA: saphenous artery.

2.2 Problem Statement and Objectives

To study velocity and pressure fluctuations in various coronary artery outlet diameters. Earlier treatments, such as angioplasty, are used for heart vascular disease resolution, but the signs are not gone. A new technique was developed, called Anastomosis. Micro Anastomosis is the new surgical treatment to save time from end-to-end vessels. Simultaneously, CFD analysis is an alternative to costly, time-consuming, complex, risky, or impossible experiments as well as to theoretical approaches for handling simpler situations. Our research mainly focuses on determining the speed flow at the adjacent artery walls and analyzing it using ANSYS-CFD Fluent software.

III. METHODOLOGY

This project is mainly motivated by the nature of the velocity flow and pressure variance in different diameters. The following methods are used for obtaining the difference in speed and pressure variation:

- 3D model re-construction
- Initial and boundary conditions
- Analyzing the model in CFD

These methods are described below.

3.1 3D Model Reconstruction

The 3D model underwent revisions using SOLIDWORKS software, guided by a standard coronary artery template. It accommodates two outlet valves of equal diameter, alongside another valve with a larger diameter, and a counterpart with a smaller diameter, each interchanging positions. Thus, it is assumed that all artery configurations under consideration are circular. The angle between the two outlet valves measures approximately 83 degrees. Figure 3 illustrates the overall arrangement of inlet and outlet valves within a coronary artery.

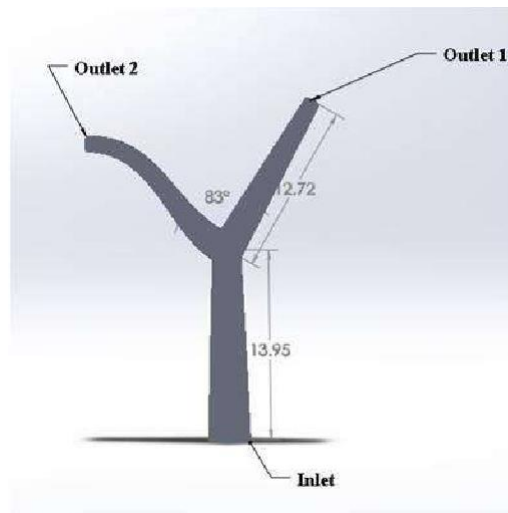


Figure.3 General Representation of Coronary artery

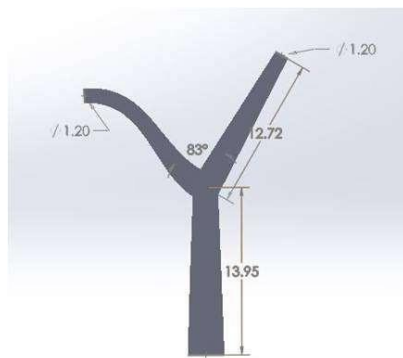


Figure 4 The reconstructed 3D models are represented in figs. 4, 5 & 6:
Condition-1: Diameters of the outlets are constant which is 1.2mm
Coronary artery with same outlet diameters

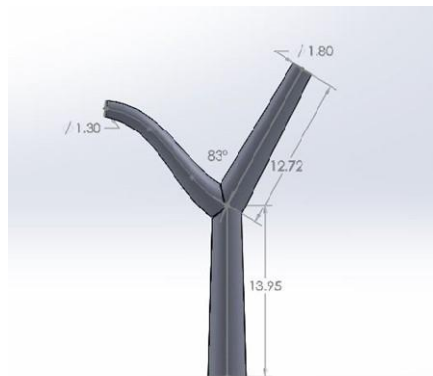


Figure 5 Condition-2: The diameter of outlet 1(1.8mm) is greater than the diameter of outlet 2(1.3mm),
Coronary artery with larger outlet 1 diameter

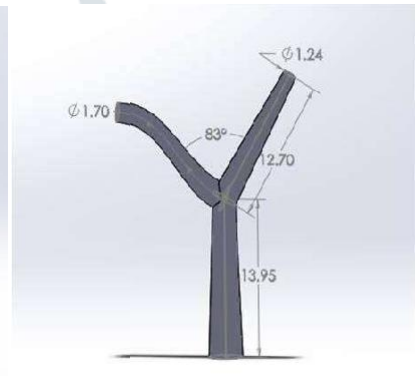


Figure 6 Condition- 3: The diameter of outlet 2(1.70) is greater than the diameter of outlet 1(1.24).
Coronary artery with larger outlet 2 diameter

3.2 Initial and Boundary Conditions

The blood rheology was assumed to be Laminar and non-Newtonian fluid. The blood density is 1060 kg/m³ and the blood viscosity is known to be 0.003 Pa.s. The blood enters the inlet valve at a speed of 0.3 m/s. The limits such as specific heat were 3513 j/kg.k and thermal conductivity was 0.44 W/m.k.

3.3 Analyzing the Model in CFD

Based on the 3D model, simulation on CFD-FLUENT software was performed. It is meshed tetrahedral before analysis, meshing increases simulation precision and speed. The meshed model is initialized and the results of approximately 150 iterations were determined. The differences in speed are simulated by streamlines. In streamlines, the velocity flow variation with different colors is indicated. The results obtained are discussed below.

IV. RESULTS AND DISCUSSIONS

In this study, we have compared three different categories of coronary arteries, based on the diameter of the outlets. In the first type, both the outlets are having the same diameter which is a very rare possibility, and the results of the analysis are given below. The following diagrams represent the results from the analysis-

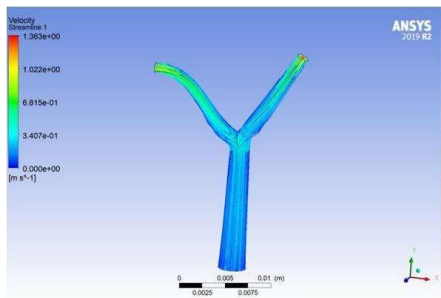


Figure 7 Diameters of the outlets are constant which is 1.2mm

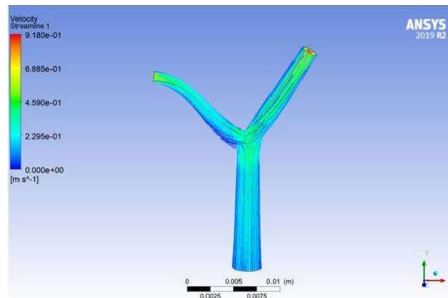


Figure 8 The diameter of outlet1(1.8mm) is greater than the diameter of outlet 2 (1.3mm)

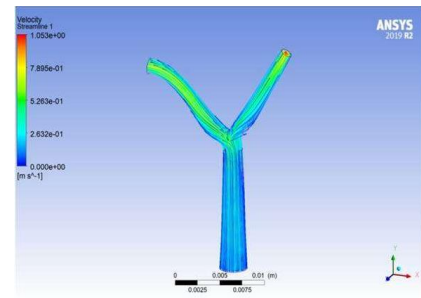


Figure 9 The diameter of outlet2(1.70) is greater than the diameter of outlet1(1.24)

These are the speed streamlines derived from the three different mesh models. They reflect the flow of velocity in different colors at every point. The plots of pressure and speed are given below:

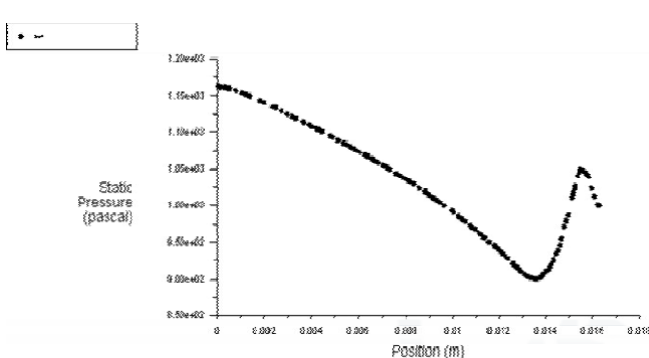


Figure 10 Static pressure Vs. Position plot of the first condition

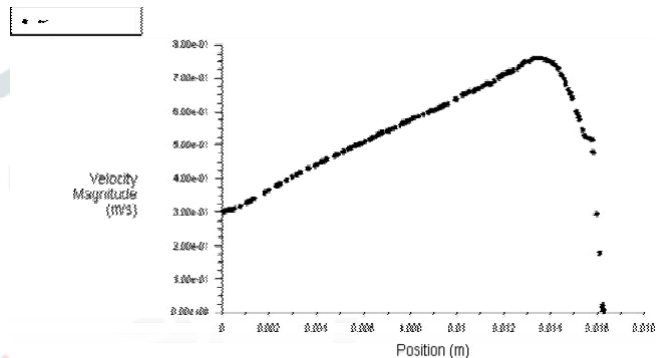


Figure 11 Velocity Vs Position plot of the first condition

The Figure 10, this XY plot is between the static pressure within the coronary artery and the position from the inlet. This condition has the highest pressure at the vessel inlet, but the pressure drops dramatically as the distance increases. The pressure is less at the connection and steadily increases after a certain distance. Figure 11 this is a plot for velocity Vs the position from the inlet. The velocity of the blood inside the artery is increasingly rising. The initial blood velocity was 0.3 m/s, and the maximum speed was 0.78 m/s. As the blood flows into various outputs, the velocity decreases continuously. At the end of the outputs, it becomes zero.

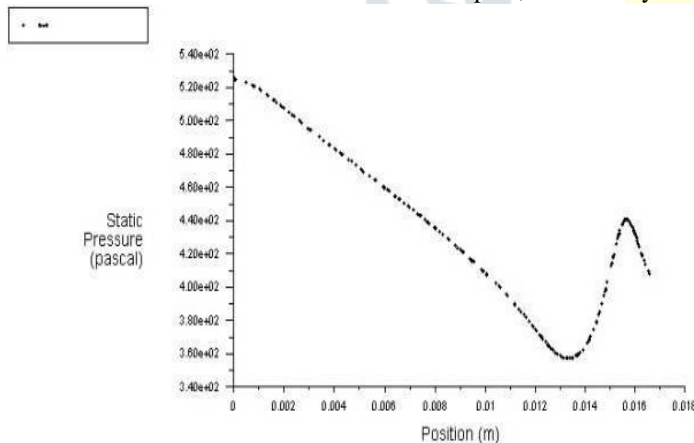


Figure 12 Static pressure Vs. Position plot of 2ndCondition

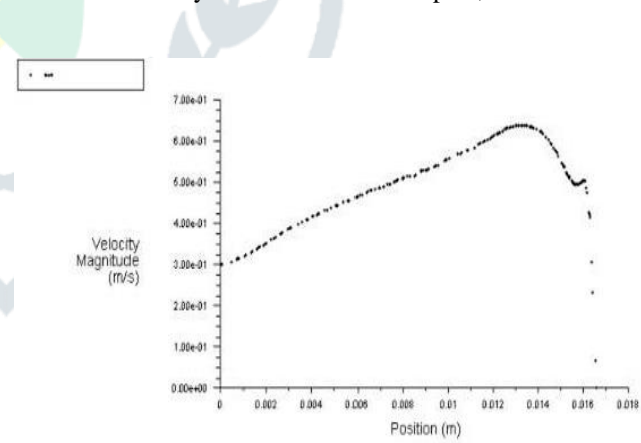


Figure 13 Velocity Vs Position plot of 2nd condition

In the second type (Figure 12), the output diameter is larger than the output diameter 2, and all other parameters are constant. In this case, the blood flow pressure is lower than in the previous case. Like the previous situation, the pressure quickly decreased with the location increasing. At the connection of the coronary artery, the pressure is at its lowest value and also increased as it moves to the outlets. Similarly, the velocity of the blood sent through the inlet continuously increases and reaches a limit of approximately 0.78 m/s. As the previous condition speed declined near the diversion and was nil at the end of the outlets. In Figure 13, if the outlet 2 diameter is higher than outlet 1, the findings are very similar to the cases above. The pressure vs. position plot pressure decreases by a very high rate compared with the previous case. In this situation, the blood pressure is very high even after the branching the blood pressure suddenly increases as the blood flows to the outlets.

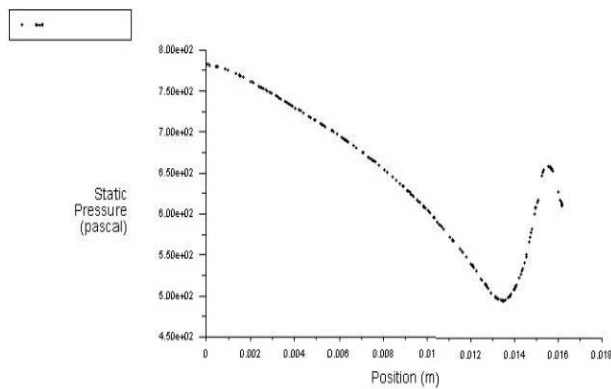


Figure 14 Static pressure Vs Position plot of the third condition

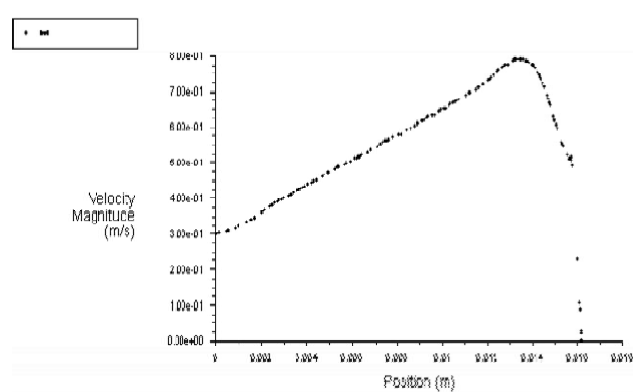


Figure 15 Velocity Vs Position plot of the third condition

In the next plot figure 14 & figure 15, there is a linear increase in the velocity until a distance of 0.013m. Here the velocity of blood started decreasing at the branching due to obstructions. The velocity is greater than the previous case; also it dropped to zero at the end of the outlets.

V. CONCLUSION

The analysis involved modeling and reconstructing three coronary arteries with varying outlet diameters. Each model underwent a steady Computational Fluid Dynamics (CFD) flow study to examine flow patterns under different conditions. Velocity streamlines obtained from the study demonstrated variations in blood velocity corresponding to outlet diameters.

- In the initial condition, uniform speed prevailed within the vessel, but velocity diminished at the edges due to disruptions. Furthermore, the pressure curve indicated higher blood pressure at the vessel inlet compared to the other scenarios.
- In the second condition, owing to a larger diameter and lower pressure, outlet 1 exhibited higher flow velocity relative to outlet 2. The pressure and velocity curves indicated optimal values, with the maximum velocity occurring at the intersection.
- In the third condition, outlet 2 experienced greater velocity compared to outlet 1. Across all conditions, the speed at the branch was highest while pressure values remained low. Consequently, variations in outlet diameter resulted in disparities in both speed and pressure.

The introduction of Anastomosis represents a significant advancement in the treatment of coronary artery disease, promising time and cost savings. Numerous techniques based on CFD are emerging to enhance the reliability and simplicity of this method. This research aids in understanding artery conditions, particularly in relation to outlet diameter variations.

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