

Numerical study of an impeller design for a new ventricular assist device

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Abstract: This work presents a numerical study of two new designs of an axial ventricular assist device (VAD). The aim of study will be to choose the better of the two designs in terms of hemolysis and thrombosis. For this purpose, an analysis of the flow generated by the rotors is carried out in order to identify the critical zones for the two major problems cited above.

Keywords: *Ventricular assist device (VAD), Computational fluid dynamics (CFD), thrombosis, hemolysis*

1. Introduction

Congestive heart failure (CHF) is a chronic, progressive condition in which the heart ventricles don't contract adequately to pump enough blood through to meet the body's needs for blood and oxygen. One of the commonly used solution to overcome this problem is the replacement of the diseased heart with a donated one. However due to the lack of donators and the difficulty in finding the suitable donor hearts for some patients, using an artificial heart or a ventricular assist device are effective solutions for patients with end-stage heart failure. The most used solution is Ventricular Assist Device (VAD), first because it doesn't require heart removal, and in some cases it allows the heart to recover by reducing the load applied on it.

While VADs have already helped a lot of patients, they have the potential to help a lot more if blood damage problem is eliminated which include both thrombosis and hemolysis [1].

Hemolysis is damage to the erythrocyte that causes a rupture or a formation of pores in blood cell membrane which will results a release of the cytoplasm into surrounding blood plasma. Hemolysis is caused by exerting sufficient stress on the cells or when the critical stress or strain is exceeded [2]. In addition to shear stress magnitude, the interaction of erythrocytes with solid surfaces, centrifugal force, or cell-cell interaction, hemolysis can also be caused by high exposure time to an elevated shear stress.

In the other hand, Thrombosis is the formation of a blood clot (thrombus) inside a blood vessel or inside the

ventricular assist device, which can result a blocking of the flow of blood through the circulatory system. The causes of thrombosis can be categorized into three main categories: the pump (centrifuge/axial, magnetic levitation/regular bearings, pump's material compatibility...), the patient (age, gender, heart size, hyper coagulation state...) and the clinician (anticoagulation protocol, pump speed ...) [3].

The objectives of this work were to investigate the flow domains in the VADs and determine the best one the will provide: better flow, less stress shear, minimum thrombosis. Thus, the purpose of our wok is to proceed to a selection of design that showed the best results during initial tests to be worked on and developed

2. Methods:

Devices: A certain number of different axial impellers designs that were modeled using a 3D modeling software were studied and analyzed by our group. After discussion two models were retained for further investigations.

Geometry: the basic geometry was obtained from a computer aided drawing (CAD) file or by measuring the actual device components. Using ANSYS, blood flow was constructed by filling the fluid volume between the inlet and the outlet with a specific fluid.

Pump construction:

- Straightener: its role is to facilitate the entry of the fluid into the impeller zone
- Impeller: its job is to push the blood from the inlet toward the outlet
- Diffuser: its role is to absorb the rotating energy
- Inducer (only in the 2nd model): it plays the same role the straightener
- Housing: it's the parte that contain the whole assembly
- Magnetic ring: it's connected to the impeller
- Motor stator: it generates a magnetic field that results the rotation of the magnetic ring which mean rotation of the impeller

To avoid any friction between the impeller and the stator a small gap was left between them; other reason is to eliminate any radial movement of the impeller in both ends of the magnetic ring. With the blood flowing through the blades of the impeller, we can assume that the probability of thrombosis occurrence is low [4].

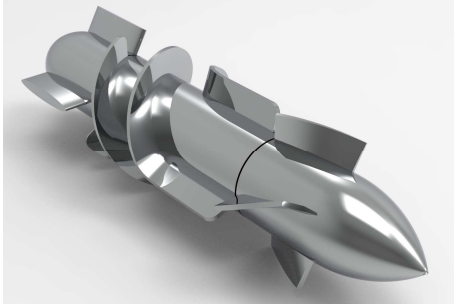


Figure 1 : first VAD model, components from left to right (straightener, impeller, diffuser,)



Figure 2 : second VAD model, components from left to right (Inducer, impeller, diffuser, straightener)

Meshing: A combination of tetrahedral, prism and hexahedral elements were used in the VADs meshing. For the fluid domain we used a fine ANSYS CFX meshing with elements sizing between 0.5mm-1.5mm. To ensure a high concentration of elements in the blades of the intern parts we used a sizing tool to minimize the size of the elements to 0.5 mm.

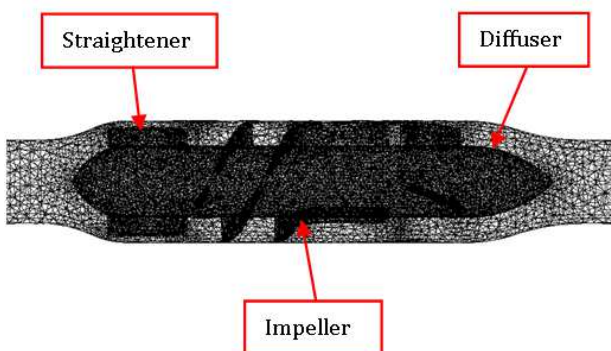


Figure 3: Mesh used for the first VAD's calculations

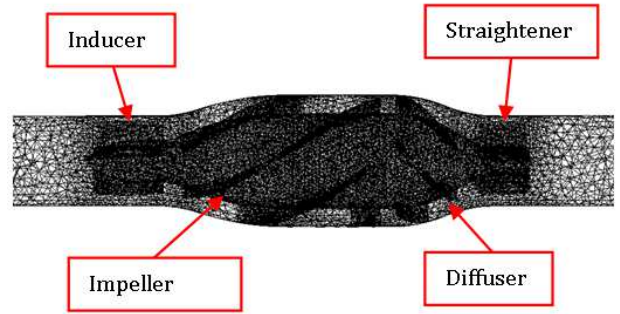


Figure 4: Mesh used for the second VAD's calculations

Computational Fluid Dynamics: the blood flow was calculated using the commercial finite volume software CFX 18.0 (Ansys Inc.). To run this calculation we choose the steady state analysis type because it's similarity to the actual flow.

The impeller was modeled as immersed solid; the flow in the areas surrounding it was calculated in a moving reference frame with different angular velocities (5000 rpm, 7000 rpm and 10000 rpm), the flow surrounding the other parts was calculated in a stationary reference frame.

As a condition to get better results, CFX require to set boundary conditions in both inlet and outlet. For that reason our boundary conditions were specified based on the normal status of a healthy cardiovascular system. The velocity at the outlet was set equal to the average velocity in the aortic valve [4], since CHF specifically refers to the stage in which fluid builds up around the heart and causes it to pump inefficiently; we choose to set the pressure at the inlet to be equal to the minimum systolic pressure.

Results:

Flow Fields: the velocity contour of the two VADs is shown in figure 5, these results were obtained by simulations

VAD_1: the flow entered the pump through a stationary 3blades straightener which minimizes the recirculation zone. At low or high speeds we can see that the straightener help preventing pre-swirls creation in the entry of the impeller.

VAD_2: the same as the first VAD, the inducer help preventing the creation of pre-swirls in the fluid while entering the impeller. At all operating conditions the flow enters the impeller smoothly following the blades shape. However in low rotating speeds there were small turbulence in some zones, but the flow take its normal shape while passing through diffuser and straightener

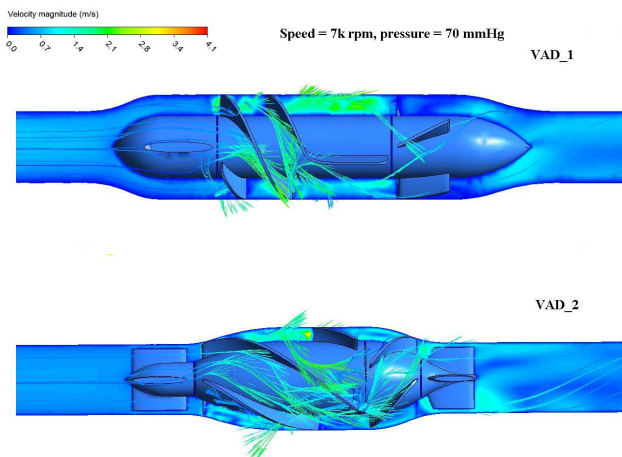


Figure 5: flow field in both VADs at specific operating conditions

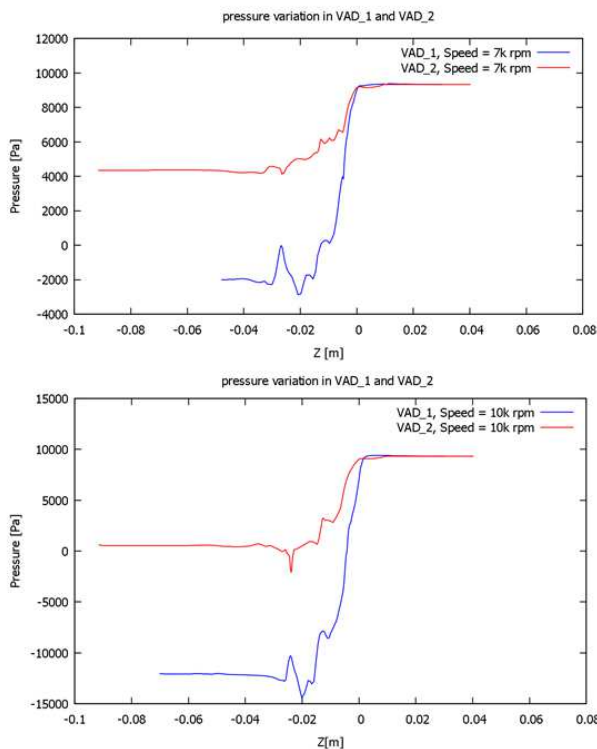


Figure 6 : comparison of the variation of the two VADs

From the results presented in this paper, we can note that both of designs showed good capacities in terms of flow rate, pressure head, and minimized turbulence. However, in terms of thrombosis we can see in the velocity contours that the first design have lot of zones in which blood velocity is almost null, which can results creation of thrombus.

3. CONCLUSION

Pressure head, velocity contours and streamlines were extracted from this study shows that the second axial pump design is the best material to work on and develop.

Further investigations will concentrate more on optimizing the operating conditions, minimizing hemolysis by decreasing the amount of shear stress applied on erythrocytes while maintaining high performance, and eliminating the thrombosis.

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