AN INVESTIGATION ON TIP CLEARANCE EFFECT ON PVAD's PERFORMANCE

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SUMMARY
Thousands of pediatric cardiac patients suffer from end-stage congestive heart failure (CHF). An available option for these patients is Pediatric Ventricular assist devices (PVADs). The present studied PVAD is expected to deliver 0.5 to 4 l/min at rotational speeds of 7000 to 9000 rpm over physiologic pressures and has a selected design point of 3 l/min and 90 mmHg. In this case, the axial blood pump with a magnetically levitated impeller has selected to numerical simulation. This selection is based on VAHI’s axial flow pump with different blade profile for each fluid region and effect of tip clearance is studied on its performance such as Efficiency, Wall Shear Stress and considering effective operation for pediatric cardiac failure patients. In order to achieving best result with the ANSYS software, k-ε turbulent model has been applied to obtain the flow characteristics from Inducer Inlet to Straightener outlet of the pump. numerical results acceptable performance for pediatric (5 to 9 years old patients) to deliver physiologic pressures with hydraulic efficiency of 10 to 37 % as well as acceptable Maximum shear stress level along the blade tip surface of the impeller.

INTRODUCTION
The ventricle assist device (VAD) has been used for the recovery of a failing natural heart, as a bridge to transplantation or even long-term cardiac support [1]. The size of an implanted VAD at aortic valve position is an important factor, especially for women and children. The intra cardiac axial flow pump has several advantages such as fitting well anatomically in the circulatory system and the smaller blood-contacting surface of the pump [2]. However, the effect of the high-speed impeller used in an axial blood pump on blood damage (Hemolysis) should be considered [3]. The tip clearance between the rotor and the housing has vital effects on the pump performance. A small clearance will increase hydraulic efficiency simultaneously will induce high shear stress in the gap resulting in high hemolysis [4]. Hemolysis usually occurs in the areas of high shear stress, and these areas in the pump must be identified to improve the pump design. In the present investigation, the effect of clearance on the efficiency and blood damage (hemolysis) is considered. Recently Computational methods are widely used as complementary tools for the blood pump development in early stages of the design process [5] as they offer a convenient and efficient means for the analysis of flow pattern.

METHODS
The PVAD is a scaled down version of the VAHI’s axial flow [6], PVAD intended to support pediatric CHF patients (5 to 9 years old [7]). The pump incorporates a magnetic suspension and motor configuration into the overall design. The PVAD has four internal fluid regions: an inducer region with six stationary blades to reduce any flow swirl, to eliminate pre-rotation of the entering fluid, and to house active magnetic bearings for the suspension system; an impeller with four rotating blades to impart kinetic energy to the fluid; and a stationary diffuser section with curved blades designed to convert the kinetic energy to potential pressure [8] and the last region, Straightener to make straight flow regime. The axial flow PVAD is initially Design to have a length of 65 mm and outer diameter of 14 mm. (Figure 1) illustrates the conceptual design of the PVAD.

Figure 1: Conceptual Flow Path Design of the PVAD

Blood is assumed as an incompressible Newtonian fluid with a density of 1050 kg/m$^3$ and viscosity of $3.5 \times 10^{-3}$ Pa.s. In this model, the Reynolds number ($Re = r^2 \rho \omega / \nu$, where $r$ is the inner radius of the pump housing, $\omega$ is the rotating speed, and $\nu$ is the blood kinematics viscosity) of the blood pump is about 19100, which is far beyond the critical laminar Re of 2000–3000 and as a result, the flow regime should be considered turbulent. In order to simulate, flow through the pump regions, the k-ε turbulence model has been used. These have applied to model in ANSYS software.

A. Hemolysis
The dominant mechanism of hemolysis in PVADs is deformation and fragmentation of RBCs due to shearing. This phenomenon is highly dependent upon the shear stress level and the exposure time to such stress, hemolysis increasing with the time of exposure. [Fig. 3] was obtained from experimental investigation that can be used as criteria to evaluation of the PVADs’ Hemolysis performance.

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B. Boundary conditions

The applied boundary condition is No-slip wall, constant inlet pressure at 4,000 Pa beside of 16,000 Pa as a reference pressure; outflow range was considered 0.5 to 3 lpm, rotational speed range from 7000 to 9000 rpm.

C. Grid generation

The full computational model of the axial pump consists of approximately 728,030 elements (Figure 2). Table 1 shows the final grid densities for each region of the pump:

<table>
<thead>
<tr>
<th>Table 1: Regional Grid Densities for the Full PVAD</th>
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<tbody>
<tr>
<td>Region</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>Inducer</td>
</tr>
<tr>
<td>Impeller</td>
</tr>
<tr>
<td>Diffuser</td>
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<tr>
<td>Straight</td>
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<tr>
<td>Total Size of Computational Grid</td>
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</table>

Figure 2: PVAD topology and grid generation

RESULTS AND DISCUSSION

The fluid efficiency for each CFD simulation was determined according to:

\[ \eta = m/\rho(p_2 - p_1/m\omega) \]

Where \( \eta \) is the power efficiency, \( m \) is the mass flow rate, \( \rho \) represents the fluid density, \( p_2 \) symbolizes the total pressure at the pump’s outlet, \( p_1 \) represents the total pressure at the inlet, \( m \) corresponds to the applied mechanical torque, and \( \omega \) signifies the rotational speed. CFD results [Figure 3] is estimated Best Efficiency Points (BEPs) for these operating conditions. As it can be seen from [Figure 4], all designs are in the acceptable range. But the Point (I), have exposure time less than others. Also, From [Figures 3] and [Figures 5] it can be found that as tip clearance decreased, the generated differential pressure was growth up and consequently output efficiency increased.

CONCLUSIONS

This blood pump produces 0.5 to 4 lpm for physiologic pressures of 50 to 110 mmHg over 7000 to 9000 rpm. Regarding obtained results, decreasing tip clearance will cause increasing of hydraulic efficiency as well as increasing of wall shear stress and exposure time of the blood particles through the pump that can cause hemolysis phenomenon. It can conclude that the PVAD with 0.075 mm of tip clearance is the best design regarding these two considerations.

REFERENCES