VARIABLE ROTATIONAL SPEED SUBSTANTIALLY REDUCE THE RATE OF HEMOLYSIS WITHIN IN-HOUSE ROLLER PUMP

Jiri Kohut (1), Jiri Jagos (1), Martin Formanek (1), Jiri Bursa (1)

1. Faculty of Mechanical Engineering, Brno University of Technology, Brno, Czech Republic

Introduction

In clinical practice, roller pumps (RPs) are mostly used in two medical methods – veno-arterial extracorporeal membrane oxygenation (VA-ECMO) and cardio-pulmonary bypass (CPB). Currently, centrifugal pumps (CPs) stand the competition in the VA-ECMO, mainly due to the shorter lifespan of peristaltic tubing [1]. However, the hemolysis-related complications (e.g., hemolytic anemia, hyperbilirubinemia, and acute renal failure) are usually much more prominent in CPs [2][3]. Main difference between CP and RP is that the former provides continuous flow due to the inherent design of the pump while the latter produces pulsatile flow. The pulsatile flow has been attributed to several benefits such as shorter need of intensive care, better microcirculation, lower inflammatory events, and better perfusion to organs [4]. Moreover, the correct synchronization between pulsatile flow and ECG may support the heart performance during VA-ECMO session [5].

Even though the study [5] demonstrated the pulsatile feasibility of CPs (achieved by varying the rotational speed), it carries certain limitations (e.g., the pulsatile effect diminishes with higher flow rates and may increase hemolysis). On the other hand, RPs generate intrinsically pulsatile flow, and the pressure and flow waveforms can be widely modulated through varying rotational speed profile (RSP) [6].

Since hemolysis is a crucial factor in clinical practice, the paper focuses on its evaluation within an in-house developed two-roller pump with full occlusion using computational simulations with experimentally obtained boundary conditions.

Methods

A simplified 2D finite volume (FV) model of RP was created based on its real geometry. Laminar blood flow modelled as Newtonian incompressible liquid with viscosity 2.7 cP (35% of glycerine-water solution) was assumed. Atmospheric pressure and measured pressure waveform were used as boundary conditions at the inlet and at the outlet, respectively. The computational domain was discretized in time with a step size of 0.0005 s. The results were extracted from the 8th cycle which was sufficient to reach a stabilized cyclic response. Ansys® Fluent® was used as a solver which allow us to use overset methodology for roller-tube interface. Variable RSP with different settings and so-called hemolysis index (HI) were implemented to Fluent® via user defined functions.

The Eulerian power-law model of hemolysis was used for HI evaluation and is expressed in scalar transport equation 1 as its source term ($H_L = \sqrt[\beta]{HI}$). The real shear conditions (described by a stress tensor) acting on an erythrocyte are defined by a scalar shear stress τ based on the second invariant of the tensor (von Mises criterion). Constants C, α and β are obtained from experimental measurements on human erythrocytes [7]. The successful implementation was verified with analytical solution on a simplified case (steady and laminar flow in a straight 2D tube).

$$\rho \frac{\partial H_L}{\partial t} + \rho u_i \frac{\partial H_L}{\partial x_i} = \rho C^{\frac{1}{\beta}} \tau^{\frac{\alpha}{\beta}} \qquad (1)$$

Results

Hemolysis index HI was collected at the outlet as mass weighted average and was compared for two different settings – constant (conventional) and variable RSP (rotational speed is decreased when the roller releases the tube). For both cases, the average value of RSP was maintained the same. The HI values were integrated to represent the total hemolysis value per period, where the variable RSP shows decrease by 35% compared to the constant revolution.

Discussion

The paper presents a new way of reducing the rate of hemolysis in RP by setting an appropriate RSP. It could be used together with a slight under-occlusion or lower occlusion angle to further lower the rate of hemolysis [8]. However, the benefits of these adjustments together still have to be evaluated.

Moreover, variable RSP of the RP enables to generate a required flow waveform. Such a controlled system could bring an alternative approach (similarly to CP in [5]) of compensating the malfunctioning heart in VA-ECMO with respect to a patient's ECG.

References

[1] Peek GJ, et al., Perfusion 14 (1999) 443–452.
[2] O'Halloran, et al., Pediatr. Crit. Care Med. 20 (2019) 1177.
[3] Barett, et al., ASAIO journal 59 (2013) 145-151.
[4] D.N.R. Teman, et al., ASAIO J. 60 (2014) 322–328.
[5] Ostadal, Petr, et al., PLoS One 13 (2018) 1-13.
[6] Jagoš, J., et al., CMBE22 (2022) 389-392.
[7] Yu, Hai, et al., Artif. Organs 41 (2017) 603-621.
[8] Zhou, Yang, et al., Artif. Organs 45 (2021) E1-E13.

Acknowledgements

This work was supported by Czech Science Foundation, projects No. 21-21935S.