NUMERICAL MODELING TO PREDICT OXYGENATION AND FILTRATION RATES IN A COMBINED OXYGENATOR AND DIALYSIS DEVICE

Imane El Jirari (1), Lisa Prahl Wittberg (1), on behalf of the ArtPlac Research Consortium (2)

(1) FLOW, Department of Engineering Mechanics, KTH Royal Institute of Technology, Stockholm, Sweden;
(2) HORIZON-EIC-2022-PATHFINDEROPEN-01, Grant agreement ID: 101099596

Introduction

Mortality in premature infant population suffering from severe lung or kidney failure is high. Current treatments are less adapted to neonatal physiology, invasive and have side-effects. The Artificial Placenta (ArtPlac) preclinical project aims to provide a miniaturized assist device providing simultaneous pulmonary and renal support. The model configuration of the lung and kidney assists device (LKAD) will be adopted for either microfluid or hollow-fiber approach. The in-development procedure promises a low invasive support and mortality rates as well as a reduced risk occurrence of lifelong disabilities. Moreover, the innovative umbilical cannulation will provide large bore access.
One aspect of the device development lies in the oxygenation and filtration performance, achieving an efficient gas exchange while keeping resistance within the device low and minimizing device induced complications such as blood clot formation and hemolysis. To assess the computational framework to be applied on the device and associated sensitivity, a preliminary analysis was carried out on a generic geometry, evaluating the influence of methodology on species transport.

Methods

A computational fluid dynamics (CFD) analysis was carried out to mathematically assess the mass transport through membranes between gas or dialysate and blood as well as overall in-device hemodynamic performance. The models were implemented with the commercial Comsol Multiphysics software. A parametric analysis was conducted to assess the sensitivity of physical quantities of interest (related to both hemodynamics and species transport rates) to the inputs, including the influence of blood structural/rheological model, flow unsteadiness (temporal and spatial gradients), fiber arrangement, membrane porosity and species diffusivity. The oxygen transport in blood is governed by convection-diffusion equation:

$$v \cdot \nabla PO_2 = D_b \cdot \nabla^2 PO_2 \qquad (1)$$

where v is blood velocity, PO_2 oxygen patrial pressure and D_b oxygen diffusivity in blood. To consider the fraction of oxygen bound to hemoglobin, the effective diffusivity approach first introduced in reference [1] was employed:

$$D_{eff} = \frac{D_b}{1+1.34\frac{c[Hb]}{\alpha}\frac{dSO_2}{dPO_2}} \qquad (2)$$

where c[Hb] is hemoglobin concentration, α oxygen solubility in blood and the derivative dSO_2/dPO_2 is the slope of the oxygen-hemoglobin dissociation curve.

Results and discussion

Figure 1 shows oxygen concentration distribution in membrane and in homogeneous blood. The influence of oxygen diffusivity was found to be significant. Indeed, oxygen concentration varied by a factor of two depending on the assigned oxygen diffusivity (i.e. molecular diffusivity *versus* effective diffusivity). The influence of particulate nature of blood was observed to be negligible at the flow scale considered in this geometry.

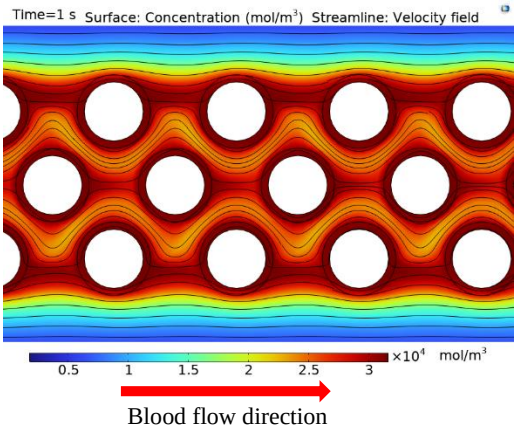

Figure 1: Oxygen concentration distribution in hollow fibre membranes and blood. Oxygen-rich gas enters through the hollow fibres, diffuses through the gas-permeable membrane and into surrounding blood.

Further investigations are needed, and will include hematocrit variation, investigation of simultaneous oxygenation and filtration plus varying fiber cross-section shape, found to be a promising approach to optimize mass transfer [2].

References

1. Vaslef et al, ASAIO Journal, 40:990-996, 1994.
2. Ecker et al, Membranes, 11(5):374-389, 2021.

Acknowledgements

ArtPlac is coordinated by Klinikum Nurnberg, Germany and funded by Horizon Europe programme under the European Innovation Council (EIC). Grant agreement ID: 101099596.