PERFORMANCE EVALUATION OF 3D-MICROSTRUCTURED MEMBRANE MODULES FOR ARTIFICIAL LUNGS

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Introduction

Hollow fiber membranes (HFM) incorporate significant drawbacks as oxygenator membrane technology. Suboptimal blood flow conditions lead to reduced gas transfer efficiency and increased risk of thrombosis reducing device durability. Moreover, large foreign surface areas are needed for sufficient blood-gas transfer requiring mediation with anticoagulants which puts the patient at risk of internal bleeding [1]. Three dimensional membrane structures, based on triply periodic minimal surfaces (TPMS), have been proposed for usage in oxygenators as they intrinsically separate blood and gas volume and provide increased gas transfer efficiency through passive blood mixing effects [2,3]. In this study, we demonstrate a novel method for manufacturing miniaturized, dense 3D-membrane structures to be able to directly test their performance concerning blood oxygenation against HFM-modules.

Methods

A manufacturing process was established to create dense membranes with TPMS structure out of medical grade silicone. The 3D-membrane modules were created using TPMS unit cell sizes of 2 and 3 mm, which correspond to flow channel widths of 0.71 and 1.06 mm, respectively. Subsequently, the structures were analyzed under digital light microscopy. Afterwards, these modules were assembled into miniature oxygenators.

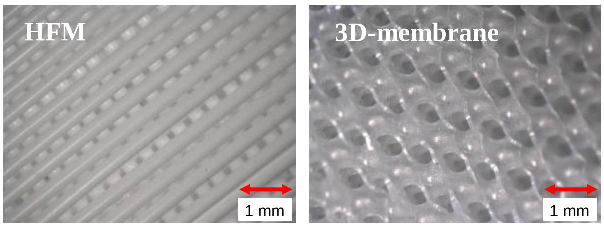

Figure 1: Digital light mircoscopy images of the HFM (left) and the 3D-membrane structure with a TPMS unit cell size of 2 mm (right).

A miniature HFM-oxygenator with similar membrane surface area, based on a modular platform developed for rodents [4], was manufactured as testing reference. Gas transfer testing according to ISO 7199 and pressure drop measurements were performed using porcine blood on both the 3D-membrane and the HFM modules. Gas transfer efficiency was evaluated by calculating the oxygen transfer coefficient, β_{O2}, for both devices.

Results

The 3D-membrane modules were manufactured successfully with a membrane thickness varying between 80 and 140 µm (cf. Figure 1). In Figure 2, the measurement results for gas transfer efficiency are shown. The 3D-membrane shows comparable oxygen transfer coefficients to the HFM with an increase of 11.16% averaged over all flow rates. Moreover, the pressure loss measured inside the 3D-membrane module was in a similar range and slightly lower than that of the HFM.

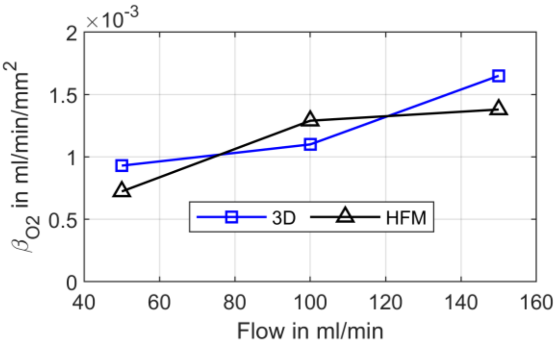

Figure 2: Measurement results of oxygen transfer efficiency for the 3D-membrane oxygenator with 3 mm TPMS unit cells ("3D") and the HFM oxygenator ("HFM").

Discussion

For the first time, we successfully manufactured micro-scale 3D-structured membrane modules and tested them directly against HFM. Comparable gas transfer coefficients as well as slighly lower pressure drops were measured when comparing the 3D-membrane with the HFM. This indicates a more efficient overall device performance being in accordance with findings of earlier studies [2,3]. However, the HFM-module is still superior in terms of low priming volumes. Additional experiments will be performed to obtain statistical certainty. Still, these early results clearly show the capability of the 3D-membrane technology. By further miniaturizing the 3D-membrane to achieve higher efficiencies, a novel membrane concept might be at hand that is superior to the HFM.

References

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