A Nanoscale Membrane Oxygenator: Rationale, Design and Preliminary Findings

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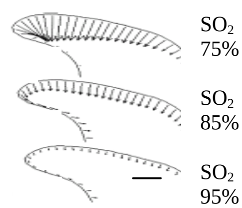
Statement of Purpose: Recent studies have demonstrated that red cells adopt a "parachute" shape upon entering the capillary, thereby markedly increasing oxygenation efficiency[1]. A nanoporous, nanoscale oxygenator has been designed to exploiting this phenomenon, thereby to enhance O_2 and CO_2 transfer rates, thus to develop next generation devices for prolonged respiratory support.

Methods: Crystalline Si membranes with precisely controlled nanopores are micromachined in nanochannels, using typical top-down micromachining and MEMS fabrication techniques. Pores 200 nm in diameter were drilled in these membranes with focused ion beam (FIB) techniques. To test the concept of pore reduction, track-etched polycarbonate membranes (Poretics, PCTE), typically 200 nm, were reduced to smaller diameter by plasma-enhanced CVD processing with C_5F_{12} monomer. Silicon membrane bending in capillary-size blood channels induced by fluid mechanical stresses was simulated by finite element analysis (FEA). Static loading of the nanoscale oxygenator was also simulated by FEA.

Results/Discussion: Fig. 1 indicates that pulmonary capillary dimensions must be reached to exploit the enhancement of oxygen transfer over the skirt of the deformed red cell. 40 µm channels with varying aspect ratios and 800nm membranes are shown in Fig. 2. Channel height can be reduced to 10 µm. 200nm pore arrays in Si with an estimated 1:5 aspect ratio are shown in Fig. 3. Calculations suggest FIB drilling of 50 nm pores is feasible. A 38% reduction of a 200 nm pore by single-sided pulsed plasma CVD is shown in Fig. 4. Similar conformal coatings of pores can be achieved with other polymers. FEA suggests Si structural elements and membranes can support the static and dynamic loading expected for capillary-sized oxygenators.

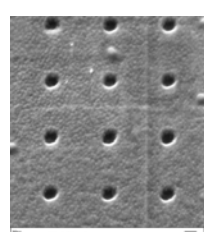
Conclusions: Results to date suggest that nanoscale, nanoporous oxygenators are feasible and can be fabricated.

References: 1. Frank A, et al. J Appl Physiol 1997; 82: 2036-44.

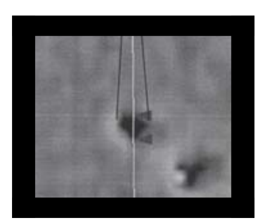


1. O_2 flux at the RBC skirt is higher than at centerline. Flow is right to left. Scale: 10 nmole/s-cm^2

2. Channel designs (topside) Varying height: width allows 1- or 2 sided gas exchange.



3. Array of 200 nm pores drilled by FIB into a Si membrane. No debris was observed.



4. 124 nm pore made by one-sided pulse plasma polymerization with a C_5F_{12} starting monomer. Coating is 36 nm thick.