Predicting Removal of β-2-Microglobulin in the Silicon Nanopore Membrane Based Artificial Kidney

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Background:

Recent research has demonstrated that low removal of middle molecular weight solutes such as β-2-microglobulin (B2M) is correlated with poorer clinical outcomes for kidney dialysis patients. Thus, in developing an implantable artificial kidney, the removal of these middle molecule solutes through hemofiltration membranes is of particular interest. However, at small pore sizes (5 to 15 nm) the influence of intermolecular forces such as van der Waals (vdW) and acid-base (AB) interactions can become important, significantly affecting the rate of transport. We present a mechanistic transport model accounting for the impact of these intermolecular forces in the unique slit pore geometry of silicon nanopore membranes (SNM), enabling the design of a robust artificial kidney with high middle molecule removal that would improve patient outcomes.

Methods:

Goniometric measurement was conducted in order to characterize the vdW and AB surface tension parameters of polyethylene-glycol (PEG) modified SNM and B2M. Coupling these empirically determined values with parameters for surface charge density and solute size, we applied the surface element integration method to numerically determine the solute partition coefficient and hindrance factors for transport of a spherical solute through a slit pore. Combined with existing membrane filtration models accounting for concentration polarization, the overall rate of transport of B2M through SNM was determined and validated experimentally by membrane sieving experiments over a range of pore sizes and operating pressures.

Results:

AB and vdW interaction energy values between B2M and PEG modified SNM were determined to be 33.7 mJ/m2 and -4.0 mJ/m2, respectively. Experimental data corresponds well with predicted model values (RMSSD = 2.75) over relevant operating pressures (1 to 4 psi) and pore size (8.5 nm). The model serves as a valuable tool in demonstrating how an artificial kidney with targeted membrane structure can optimize removal of clinically relevant middle molecular weight solutes.