NO-DIALYSATE MICRO HEMODIALYSIS SYSTEM
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ABSTRACT
This paper presents a concept of no-dialysate micro hemodialysis system and discusses water permeability of the dialysis membrane. No-dialysate micro hemodialysis system allows miniaturization of the hemodialysis system, which is mandatory for our ultimate goal of implantable dialysis systems. Water permeability of the dialysis membrane is a crucial parameter to determine the system performance. We highlighted nano and micro porosity of a poly-ether-sulfone (PES) membrane and developed water-permeable dialysis membrane. Proof-of-concept experiments of no-dialysate micro hemodialysis system were successfully conducted, and we found that the thickness of nano porous structure affected water permeability.

KEYWORDS: Hemodialysis system, Water permeability, Poly-ether-sulfone, Membrane

INTRODUCTION
Hemodialysis therapy is indispensable for patients with end-stage renal disease, but the patients must undergo this treatment in hospital for four hours three times a week. Wearable or implantable dialysis systems would free the patients from frequent hospital visit and drastically improve their quality of life. These artificial kidneys have been studied to achieve high performance and long-term use with their smallness. Biocompatibility and miniaturization of hemodialysis systems are crucial in such applications that clean up the patients’ blood gradually. Our group has been developing a micro dialysis device that is composed of micro channels and nano-porous PES membranes that selectively allows low molecular weight molecules to diffuse from blood to dialysis fluid [1]. We experimentally verified that blood could be introduced into the device by blood pressure using a 14-week-age SD rat body as shown in Figure 1. The inlet and outlet of the multilayered device were connected to the renal artery and vein, respectively. However, if we use dialysis fluid to remove wastes from the blood, a pump was required to flow the dialysis fluid, which hindered miniaturization of the system. Therefore, we propose a micro hemodialysis system that does not require dialysis fluid as shown in Figure 2. In this system, the dialysis membrane allows water along with low molecular weight ions to permeate through the membrane.

Figure 1: a) Image of Implantable Hemo-dialysis System. b) Concept of Multi-layered filter with c) metal channel layer and d) PES membrane

Figure 2: Concept of “Implantable Micro Hemo-dialysis System without Dialysate.”
**THEORY**

The nano-porous PES membrane reported in [1] did not exhibit water permeability. Figure 3 shows the SEM cross-sectional image of the PES membrane, and we found that the membrane consists of a nano-porous layer and micro-porous layer. We consider that the thinner nano-porous layer will increase the water permeability.

The water permeation rate $\Delta q$ through the membrane is defined as the following;

$$\Delta q = P_w \cdot \frac{S}{t} \cdot \frac{1}{2} \rho v^2,$$  \hspace{1cm} (1)

where $P_w$ is the water permeability $[\text{m}^3/\text{s/kg}]$, $S$ the membrane area $[\text{m}^2]$, $t$ the thickness of membrane $[\text{m}]$, $\rho$ the density of liquid $[\text{kg/m}^3]$ and $v$ the velocity of liquid $[\text{m/s}]$. Thus we can obtain water permeability $P_w$ according to the equation (2).

$$P_w = \frac{2 \Delta q \cdot t}{\rho S v^2}$$  \hspace{1cm} (2)

In addition, we can calculate the solute diffusion coefficient $D_c$ following the equation (3);

$$D_c = \frac{Q \cdot t}{S} \ln \frac{C_{B,\text{out}} - C_{B,\text{in}}}{C_{B,\text{in}} - C_{B,\text{out}}},$$  \hspace{1cm} (3)

in which, $Q$ is the flow rate $[\text{m}^3/\text{s}]$, $C$ the concentration $[\text{M}]$, $A, B$ the solution type, and $\text{in, out}$ indicating inlet/outlet.

**EXPERIMENTAL**

We changed the composition of the PES casting solution as shown in Table 1, and formed the membranes. Cross-sectional image of the membranes are shown in Figure 4. And then, we measured the sodium diffusion coefficient and water permeability using the device as shown in Figure 5. In this experiment, pure water or blood was pumped and flowed at the rate of $100 \ \mu\text{L/min}$ into the one-layered device, which was composed of a fabricated membrane (penetration area was $47 \ \text{mm}^2$) and two metal layers. We continued it 100 minutes for each, and pull out the penetrated water.

![Figure 3: SEM cross-sectional image of the PES membrane.](image)

**Table 1. Mixing ratio of PES/PVP/NMP and their structures.**

<table>
<thead>
<tr>
<th></th>
<th>PES</th>
<th>PVP</th>
<th>NMP</th>
<th>solute PES</th>
<th>solvent NMP</th>
<th>additive</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>10.0</td>
<td>10.0</td>
<td>80.0</td>
<td>[Structure a]</td>
<td>[Structure d]</td>
<td>[Structure i]</td>
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<td>2</td>
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<td>15.0</td>
<td>70.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>20.0</td>
<td>20.0</td>
<td>60.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4: SEM cross-sectional image of the fabricated membranes.](image)
RESULTS AND DISCUSSION

Figure 6 shows relationship between the components’ ratio and water permeability / sodium diffusion coefficient. Water permeability depends on the ratio of PES; lower ratio realizes higher permeability. In addition, diffusion coefficients of each membrane are almost same around $3.0 \times 10^{-10}$ m$^2$/s. From these points, lower ratio membranes can be estimated to be better for our concept. However, lower-ratio membranes have less mechanical robustness or leakage of blood cells, and thus it is the best to use the membrane of 10 - 15% PES in the mixing ratio.

CONCLUSION

We experimentally verified that blood could be introduced into the device by blood pressure using a 14-week-age SD rat body. The water permeability decreased as the PES mixture ratio increased as we expected, whereas diffusion coefficient maintained almost same. Taking the mechanical robustness of the membrane into consideration, or leakage of blood cells, 10 - 15% of the PES mixture ratio was found best in the experiments.

REFERENCES