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中空糸内径および細孔径の変更が膜の透水性および濾過特性に及ぼす影響

EFFECTS OF CHANGES OF INNER DIAMETER OF THE HOLLOW FIBER AND PORE SIZE OF THE MEMBRANE ON THE FILTRATION CHARACTERISTICS

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For the purpose of reduced pressure loss and transmembrane pressure suppression, a new model with enlarged hollow fiber (HF) inner diameter (ID) and enlarged pore size membrane was evaluated in terms of its filtration characteristics together with the prototype model in which only the hollow fiber ID was enlarged. It appeared that enlarging the ID of HF membrane was effective under relatively lower flow rates; however, it was not an essential solution to suppress blood side pressure drop under the conditions of higher flow rates. When the ID of HF membranes is enlarged, the pore size must be also enlarged to keep the filtration characteristics unchanged for α1-microglobulin removal as well as albumin leakage.

***Key Words** : Hemodiafilter, Hollow fiber, Inner diameter, Pore size, Hemofiltration, Ultrafiltration*

１． Introduction

Renal replacement therapy is a blood purification therapy using an artificial kidney. In order to reduce the burden on patients and to enhance the stability of hemodiafilter, a new commercial product was released to focus on the reduced pressure loss and transmembrane pressure suppression with enlarged inner diameter (ID) of the hollow fiber (HF) from 200 μm to 215 μm.

The purpose of this study is to compare the conventional model (MFX-21S eco), the new model (MFX-21SW eco) with enlarged ID of HF and enlarged pore size, and the prototype model (MFX-21SW-PROTO) with enlarged ID of HF only, evaluating the effect of enlarged ID of HF and pore size on filtration characteristics.

２． Materials and Method

A test blood circuit for ultrafiltration experiments was prepared, mimicking the clinical treatment. All the investigated models are shown in Table 1.

（１）Bovine blood system experiments

A 27.2 g of KH_2PO_4 and 18.0 g of NaCl were added to 1500 mL of ion-exchanged water at 37℃ and pH was adjusted to 7.41 with 2M NaOH solution and was diluted in a measuring flask to 2000 mL. This was used as a buffer thereafter. Experiments

Table 1　Investigated hemodiafilters

Brand name	ID of HF [μm]	Membrane area [m^2]	Pore size
MFX-21S eco	200	2.1	Normal
MFX-21SW eco	215	2.1	Enlarged
MFX-21SW-PROTO	215	2.1	Normal

ID---inner diameter, HF---hollow fiber

were performed under the following four experimental conditions, EC#1, EC#2, EC#3, and EC#4. Hematocrit of the blood was adjusted to 34.5 ± 0.2% (EC#1, #2), 21.6 ± 0.2% (EC#3), 17.3 ± 0.2% (EC#4) and the total protein concentration was adjusted to 3.74 ± 0.13 g/dL (EC#1, #2), 2.34 ± 0.13 g/dL (EC#3), 1.87 ± 0.13 g/dL (EC#4) and the small amount of above-mentioned buffer was added so that the volume was set equal to 1500 mL. Moreover, 500 μL of α_1-microglobulin (α_1-MG) was added.

（２）Ultrafiltration experiment

The air inside the hemodiafilter was carefully removed by ion-exchanged water. Test solution was pumped by a roller pump from the tank into the hemodiafilter at a rate Q_B = 250 mL/min (EC#1, #2), 400 mL/min (EC#3) and 500 mL/min (EC#4) at 37℃. Ultrafiltration across the membrane was induced by another roller pump at a rate Q_F = 63 mL/min (EC#1), 83 mL/min (EC#2), 150 mL/min (EC#3) and 250 mL/min

(EC#4). All the experiments were performed at 37℃ for 240 min and samples were taken at various time intervals during experiments.

3. Theoretical

（1）Hagen-Poiseuille law

According to the Hagen–Poiseuille law, Eq.(1), the pressure drop ΔP is inversely proportional to the fourth power of the radius R.

$$\Delta P = \frac{8\mu LQ}{\pi R^4} \qquad (1)$$

where L is the length of the pipe, μ is the viscosity of the fluid, and Q is the volumetric flow rate. Taking the ratio of the Hagen-Poiseuille law for the new model to that for the conventional model,

$$\Delta P_{SW} = \frac{\Delta P_S}{1.075^3} = 0.805\Delta P_S \qquad (2)$$

where subscripts "S" and "SW" represent for MFX-21S eco and MFX-21SW eco, respectively.

（2）Sieving coefficient ($s.c._4$)

The sieving coefficient is the ratio of concentration in the downstream to that in the upstream. In this study, $s.c._4$ is used to represent how much solute of interest penetrates the membrane by the bulk flow [1]. The following Eq.(3) is the definitive formula of $s.c._4$.

$$s.c._4 = \frac{C_F}{\sqrt{C_{Pi} \times C_{Po}}} \qquad (3)$$

where C_{Pi}, C_{Po} are the solute concentrations in the test solution at the inlet and outlet of the hemofilter, and C_F is the solute concentration in the ultrafiltrate.

（3）Pressure loss (ΔP_B)

The following Eq.(4) defines the pressure loss (drop), meaning the blood side pressure difference between the inlet and outlet of the hemodiafilter.

$$\Delta P_B = P_{Bi} - P_{Bo} \qquad (4)$$

4. Results and Discussion

Fig.1 showed the $s.c._4$ for α_1-MG under all four experimental conditions. Values of MFX-21SW-PROTO ("PROTO") was the lowest, although it had the same pore size as "S". In other words, since enlargement of ID of HF decreases the $s.c._4$ for α_1-MG, it was necessary to enlarge the pore size in the new model ("SW") to keep the same filtration performance as the conventional model ("S").

Fig.2 showed the ΔP_B under all four experimental conditions. Values of "SW" and "PROTO" were lower than those of "S" as expected from Eq.(2) because the ID of HF in "SW" and "PROTO" was larger. This is, however, not an essential solution to suppress blood side pressure drop under the conditions of much higher flow rates. Under the higher blood and filtrate flow rates, since the applicability of the Hagen-Poiseuille law is less, little effect of reduced ΔPB was achieved (data not shown). Moreover, the permeability also decreased as a result.

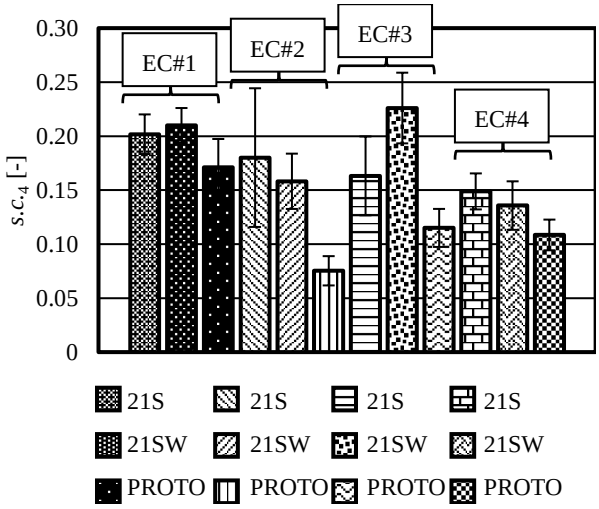

Fig.1 Comparison of the sieving coefficient for α_1-MG under various experimental conditions

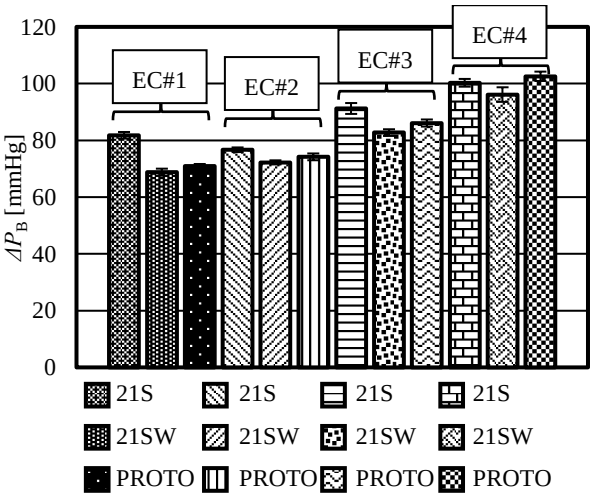

Fig.2 Comparison of average pressure loss under various experimental conditions

5. Conclusions

It appeared that enlarging the ID of HF membrane was effective under relatively lower flow rates; however, it was not an essential solution to suppress blood side pressure drop under the conditions of higher flow rates.

Reference

1. Yamashita A: New dialysis membrane for removal of middle molecule uremic toxins, *Amer. J. Kid. Dis*., **38**(4) suppl.1, S217-S219, 2001.