Development of an Apparatus to Measure Plasma Colloid Osmotic Pressure Mounted on the Extracorporeal Hemodialysis Circuit

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ABE, R., OOISHI, S., SATO, K., SUMA, H., WAKABAYASHI, T., SAWATANI, S. and TAKEUCHI, H. Development of an Apparatus to Measure Plasma Colloid Osmotic Pressure Mounted on the Extracorporeal Hemodialysis Circuit. Tohoku J. Exp. Med., 1995, 176 (3), 149-154 — We newly developed an apparatus to measure colloid osmotic pressure (COP) of blood plasma continuously by hemodialysis (HD) or extracorporeal ultrafiltration method (ECUM) without any invasive procedure or blood sampling. The COP value measured by this apparatus highly correlated with the COP value calculated from the concentration of total protein of blood plasma (TP) sampled simultaneously \(y = 21.182 + 0.96256x, r^2 = 0.911\). Measurement of the COP with this apparatus seems to be reliable.

Because most of the fluid removed by hemodialysis (HD) or extracorporeal ultrafiltration method (ECUM) comes from the interstitial space of the body (Kimura et al. 1984), we have to pay attention to the exchange of body fluid between the interstitial space and vessels. The exchange is affected to a considerable degree by colloid osmotic pressure (COP), produced by the plasma proteins such as albumin, globulin, fibrinogen and other macromolecules (Weil et al. 1974). COP is one of the important components of Starling's hypothesis that prescribes body fluid balance between interstitial space and vessels (Starling 1896). We know that COP increases while plasma volume decreases in the course of HD and ECUM. Therefore, if we can know COP in real time and continuously, it is possible to control the fluid exchange between interstitial space and vessels in real time. And hypotenion or shock, the most frequent and severe complication during hemodialysis or ECUM, can be prevented. In fact, conventional method of the measurement of COP needs blood sampling and is time-consuming. We have tried to develop an apparatus that is mounted on the line of extracorporeal circuit of HD and ECUM, and can provide COP data continuously without blood sampling and waste of time.

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**APPARATUS AND METHODS**

The apparatus is shown schematically in Fig. 1. It is built in the blood line of the dialyzer circuit as a detour circuit between the blood pump and the dialyzer. This detour circuit consists of a blood pump, a dialyzer for COP measurement and a pressure sensor. The dialyzer for COP measurement was equipped with high performance membrane (FB9U; Nipro Co. Ltd., Osaka). The pressure sensor (P-3000S-501D-10; Copal electronics Co. Ltd., Tokyo) was used as a pressure difference sensor. This can sense a pressure difference of 1,000 mmH₂O at maximum, and the sensing error was less than 0.3%. One of arms of the pressure sensor was connected to the blood line before the dialyzer for COP measurement and the other to one of the two dialysate ports of the dialyzer, while the other port was plugged up. To adjust head level of the sensor, two level chambers were set within the arms before and after the sensor.

Twelve patients (10 men and 2 women) at the initial stage of the hemodialysis were studied, and their ages were distributed between 37 to 78 years (58.1 ± 12.8), under the ultra-filtration at a rate of 1,000 ml per hr. Measurement was undergone at predetermined times of the hemodialysis after closing the detour circuit for 19 sec. Simultaneously blood was sampled to measure the concentration of total protein in the blood plasma.

Values of TP were converted into COP after Landis and Pappenheimer’s formula \(\text{COP} = 2.1C + 0.16C^2 + 0.009C^3\) \(C = \text{TP}\) (Landis and Pappenheimer 1963), to compare with the COP value measured by the apparatus.

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**Fig. 1.** The apparatus to measure plasma colloid osmotic pressure.
RESULTS

The average values of COP measured by the apparatus were 282±43 (s.d.) mmH₂O (range: 202–377 mmH₂O) at the start of the ultrafiltration and 376±81 (s.d.) mmH₂O (range: 210–497 mmH₂O) at its finish. Changes in the COP values in the course of the ultrafiltration in a case was shown in Fig. 2.

The TP values were 6.5±0.7 (s.d.) g/100 ml (range: 5.0–8.0 g/100 ml), and correlated highly with the COP values measured by the apparatus (y = -133.84 + 70.259x, r²=0.914, Fig. 3). TP values could be calculated from the measured COP.

Fig. 2. Time course of alteration of colloid osmotic pressure measured with the present apparatus in undergoing dialysis.

Fig. 3. Correlation between measured TP and measured COP.
COP after Landis and Pappenheimer's formula in an opposite way. Correlation between calculated TP and measured TP was also high \(y = 0.37112 + 0.96226x, r^2 = 0.914\), Fig. 4.

Correlation between the COP measured by the apparatus and the COP calculated from the measured TP was also high \(y = 21.182 + 0.96256x, r^2 = 0.911\), Fig. 5.

**DISCUSSION**

Plasma colloid osmotic pressure is hydrostatic pressure produced by plasma
protein. It can be measured by using a semipermeable membrane that is impermeable to the plasma protein but permeable to the other components of blood plasma (Morissette 1977).

There are two types of apparatus for measurement of plasma colloid osmotic pressure; one is membrane type developed by Hansen (1961) and the other is needle type developed by Kakiuchi et al. (1979).

These conventional apparatus require a blood sample set in them. Some clinical studies done using these apparatus were reported. Sugita (1983) reported that COP decreased immediately after cardiopulmonary bypass in the cases of open heart surgery. Nambu et al. (1985) applied COP measurement to determine an optimum ultrafiltration rate on hemodialysis. In spite of their trials, COP measurement by their methods hardly contributed to clinical application, because their apparatus could not continuously provide COP data.

On the other hand, some methods to measure COP continuously were tried on animal models. Prather et al. (1968) made an apparatus of membrane type set on extracorporeal circuit of a dog. Kakiuchi et al. (1979) and Tanaka et al. (1981) respectively made one of needle type. Their apparatus could not be applied to clinical use, because they had some problems. As the circuit of their apparatus was in common open to the air for measurement of COP by direct method, bacterial contamination and blood clotting were not avoidable. Furthermore, much skill was necessary for their operation and economical expense for their disposal parts.

We used a pressure difference sensor instead of a conventional pressure sensor. Therefore, blood circuit could be closed to the atmosphere, and the operation was done under sterile and unclotting conditions. Almost all parts that needed sterility were available from disposral products for usual hemodialysis. COP, produced by plasma protein, depends on the composition of the protein. But TP and COP highly correlate in usual condition. Their correlation coefficient measured by many workers, such as Sugita (1983) and Nambu et al. (1985), were distributed between 0.90 to 0.93. The value, we obtained, 0.914 was similar to theirs. The relation between the two variables is shown by Landis and Pappenheimer's formula. We used this equation to standardize the results obtained by our apparatus. As it gave us high correlation, we could know TP values from the COP values.

Our apparatus is designed to measure the pressure difference between patient's blood and its dialysate. As the dialysate does not contain high molecules, it can be regarded theoretically as absolute COP.

References

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