Peritoneal Dialysis using a Recycling System in Dogs

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ABSTRACT. In this study, Recirculation Peritoneal Dialysis (RPD) apparatus using a pump to circulate the dialysate was devised and its dialysis efficiency was investigated. In the experiment, 15 mongrel dogs with body weights of 6.6 ± 0.7 kg were used. The surgery to induce azotemia was performed on the dogs, a disk catheter for drainage was placed between the liver and diaphragm, and a straight catheter for infusion was placed on the abdominal side of the bladder. RPD was conducted using 2 l of dialysate containing 1.3% glucose, and the dialysate was circulated by a pump through the peritoneal cavity and the dialysate chamber at the circulation rates of 30, 60, 90 and 120 ml/min. RPD was conducted for 3 hr and the clearances of urea nitrogen, creatinine, inorganic phosphorus and potassium were recorded every hour. The clearances in RPD became higher with an increase in the circulation rate. Although RPD requires two catheters in the peritoneal cavity, it has no appreciable technical difficulty in handling and is considered to be easier than hemodialysis. RPD enabled higher dialysis efficiency to be achieved in a short time compared with conventional peritoneal dialysis. It seems reasonable to conclude that RPD is a useful new dialysis technique for animals.—**KEY WORDS:** canine, recirculation peritoneal dialysis.

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The advantage of hemodialysis over peritoneal dialysis lies in its high dialysis efficiency [1, 2]. However, hemodialysis is considered to be difficult to use in animals because it requires an expensive equipment, highly trained technicians, an artery-vein shunt and surgical vascular intervention [3, 13]. Thus, peritoneal dialysis is easier to perform compared with hemodialysis in animals, and a number of studies about peritoneal dialysis have been performed [3, 4, 19, 22, 23]. Although peritoneal dialysis is inferior to hemodialysis in removing substances of low molecular weight, it has the advantage of eliminating medium to high molecular weight substances, which are considered to be the causative substances of uremia [2, 17, 22].

Continuous Ambulatory Peritoneal Dialysis (CAPD) needs the exchange of dialysate 4–5 times a day [3]. Peritoneal dialysis for acute uremia requires increasing the times of dialysate exchange over CAPD [22]. As a consequence, peritoneal dialysis has a higher potential risk of causing infection in the peritoneal cavity at the time of dialysate exchange. Peritoneal dialysis therefore requires an enhancement in dialysis efficiency and a decrease in the number of dialysate exchanges.

To increase the efficiency of peritoneal dialysis, several methods such as an increase in the amount of dialysate [16], administration of a vasodilator [15] and circulation of dialysate with a pump have been investigated [7, 10, 14, 15, 18]. It was clarified that the increase in the amount of dialysate caused an unfavorable influence on the circulatory and respiratory systems [6, 21], and that the use of a vasodilator caused adverse effects such as a decrease in blood pressure. Against these studies, a method of high flow peritoneal dialysis was found to result in higher dialysis efficiency than conventional peritoneal dialysis, suggesting its usefulness [14, 15]. Several investigators have tried the high flow peritoneal dialysis using an

adsorbent or artificial membrane in human and laboratory dogs [7, 14, 15, 18].

The purpose of the present study was to examine the efficiency of Recirculation Peritoneal Dialysis (RPD) in unanesthetized dogs.

MATERIALS AND METHODS

RPD was performed on 15 mongrel dogs weighing 5.5–7.5 kg (the mean $\pm$ SD, 6.6 ± 0.7 kg). Anesthesia was induced with thiopental sodium (25 mg/kg) and was maintained with halothane and oxygen. To induce acute azotemia, a midline abdominal incision was made and bilateral renal artery and vein were ligated. All surgical procedures were performed according to sterile techniques.

A disk catheter was prepared from two silicone disks of 2.5 mm in diameter and 1 mm thickness; twelve silicon rings of 3 mm (I.D.), 5 mm (O.D.) and 1 mm thickness and a silicon tube of 3 mm (I.D.), 5 mm (O.D.) and 22 cm in length. A straight catheter was prepared by opening a few side holes at the top of a silicone tube of 3 mm (I.D.), 5 mm (O.D.) and 22 cm in length. At the time of celiotomy, a disk catheter was placed into the space between the sternum and liver for drainage and a straight catheter was placed on the abdominal side of the bladder for infusion of dialysate. After the surgery, the dogs were recovered from anesthesia. RPD was carried out when the levels of creatinine and urea nitrogen reached above 5.0 mg/dl and 80 mg/dl, respectively. Two liters of commercial dialysate (1.3% glucose, Perisorita 140TM, Shimizu Co., Ltd., Japan) was kept at 39°C in a thermostatic chamber. Figure 1 shows the circuit system for RPD; drainage disk catheter, dialysate chamber, circulation pump (Ube Kosan Co., Ltd., Japan) and infusion straight catheter were connected each other. About 40 ml/kg of

Fig. 1. A method of Recirculation Peritoneal Dialysis (RPD): Disk catheter for drainage was placed between the sternum and liver, straight catheter for infusion was placed dorsal side of bladder. Two litters of commercial dialysate was used, and kept at 39°C. The circulation rates in RPD were at 30, 60, 90 and 120 ml/min.

dialysate was accumulated in the peritoneal cavity. RPD was performed for 3 hr at the circulation rates of 30, 60, 90 and 120 ml/min. Intermittent Peritoneal Dialysis (IPD) was performed through a disk catheter with commercial dialysate (1.3% glucose, Perisorita 140™) of 40 and 60 ml/kg. Two ml samples of blood and dialysate were obtained from the jugular vein and dialysate chamber. These samples were used to determine the clearances of creatinine, urea nitrogen, phosphorus and glucose (Chugai Pharmaceuticals Co., Ltd., Japan). The clearances were calculated from the formula:

$$C(\text{ml/min}) = D / S \times V / T$$

{C=clearance (ml/min), D=dialysate concentration (mg/dl, mEq/l), S=serum concentration (mg/dl, mEq/l), V=dialysate volume (ml), T=time of dialysis (minute)}.

In order to investigate the ultrafiltration effect, the amounts of dialysate and body weight were measured before and after RPD. In addition, the osmotic pressure was calculated from the concentrations of sodium, potassium, glucose and urea nitrogen using the following formula [5].

$$\text{mOsm/l} = 1.86 \times (\text{Na} + \text{K}) + \text{Glu} / 18 + \text{UN} / 2.8 + 9$$

{Na=sodium concentration (mEq/l), K=potassium concentration (mEq/l), Glu=glucose concentration (mg/dl), UN=urea nitrogen concentration (mg/dl)}. The pulse, temperature and respiration of the dogs were monitored every hour from the initiation of RPD.

All values were expressed as the mean $\pm$ SD. Statistical differences were calculated by the Wilcoxon's test of each circulation rate.

RESULTS

RPD was conducted by inserting the drainage disk catheter and the straight infusion catheter into the peritoneal cavity. The recycling conditions of the dialysate were monitored with the fluid level in the dialysate chamber. Recycling of the dialysate with the pump appeared to work favorably since no change in the fluid level in the dialysate chamber was observed during dialysis. No changes in pulse rate, body temperature and respiration rate in the dogs was observed during dialysis.

Table 1 shows the clearances of urea nitrogen, creatinine, phosphorus and potassium. One hour after starting RPD, the clearances of these solutes were higher at the circulation rates of 60, 90 and 120 ml/min than of 30 ml/min ($P < 0.05$), and those of in 30 ml/min were two to four times lower than those of 60, 90 and 120 ml/min. The potassium clearances at 90 and 120 ml/min were found to be significantly higher than those at 30 and 60 ml/min ($P < 0.05$), respectively. Two hours after starting RPD, the clearances of creatinine, phosphorus and potassium were found to be significantly higher at 60, 90 and 120 ml/min than at 30 ml/min. Urea nitrogen clearances were higher at 90 and 120 ml/min than at 30 and 60 ml/min ($P < 0.05$), respectively. Three hours after starting RPD, creatinine clearances were lower at 30 ml/min than at 60, 90 and 120 ml/min, respectively. Urea nitrogen clearances were found to be significantly higher at 90 and 120 ml/min than at 30 and 60 ml/min, respectively. Phosphorus clearances showed no significant difference at any circulation rates. Potassium clearance was higher at 120 ml/min than at 30 and 60 ml/min ($P < 0.05$). The clearances of these solutes were found to decrease gradually at 60, 90 and 120 ml/min, and to slightly increase at 30 ml/min.

Table 2 shows the clearances in IPD. In 4 hr, the clearances obtained at a dialysate volume of 60 ml/kg were

found to be significantly higher than those of 40 ml/kg. The clearances in IPD were two to six times lower than those in RPD.

Table 3 shows the osmolality of the serum and the dialysate at the respective times after starting RPD. No

significant difference in the osmolality was observed between the serum and the dialysate among the circulation rate groups.

The drainage volumes of dialysate at the end of RPD were 2003 ± 28 ml in the 30 ml/min group, 2022 ± 43 ml in the 60 ml/min group, 1979 ± 34 ml in the 90 ml/min group and 2017 ± 37 ml in the 120 ml/min group. No difference was observed among the circulation rate groups. There was no difference in the body weight of animals before and after RPD.

DISCUSSION

It is essential for peritoneal dialysis to carry out completely drainage of dialysate in the peritoneal cavity. Although various types of catheters for peritoneal dialysis were used for azotemic patients [4, 19, 20, 23], Tenckhoff *et al.* [20] reported that long term peritoneal dialysis could be performed by using a straight catheter. However, when used for dogs and cats, the catheter is often obstructed by mesentery or omentum [3, 4]. In contrast, Simmons *et al.* [19] and Thornhill *et al.* [22] carried out peritoneal dialysis in dogs using a disk catheter and showed that it is tolerable for the exchange of dialysate over a long period of time. Since the catheter was placed into the abdominal side of bladder in these studies, if RPD is performed at the high circulation rate, catheter obstruction may occur by omentum and mesentery. In addition, when the catheter is occluded with omental wrapping, fibrin plugs would be needed omentectomy [3] or heparinization [8]. In RPD, the drainage catheter was placed in the space between the sternum and liver, so that no drainage obstruction was observed. This method enabled high speed circulation of dialysate by means of a pump in conscious animals. These results suggest that not only RPD but also conventional peritoneal dialysis may be possibly applied under the good drainage conditions where the catheter is placed in the space between the sternum and liver.

With respect to peritoneal dialysis, the previous studies described that an increase in the amount of dialysate in the

Table 1. Effect of the circulation rate of dialysate on the clearances in Recirculation Peritoneal Dialysis

	Flow rate	n	1 hr	2 hr	3 hr
Urea nitrogen	30 ml/min	5	5.1 ± 0.5^a	7.1 ± 1.3	7.7 ± 0.9
	60 ml/min	10	$10.9 \pm 3.1^*$	7.8 ± 2.3	6.9 ± 2.1
	90 ml/min	10	$13.5 \pm 2.7^*$	$11.1 \pm 3.1^{**}$	$8.9 \pm 2.6^{**}$
	120 ml/min	10	$14.1 \pm 2.7^*$	$10.1 \pm 2.0^{**}$	$9.4 \pm 1.2^{**}$
Creatinine	30 ml/min	5	3.1 ± 1.1	5.0 ± 1.5	5.9 ± 1.1
	60 ml/min	10	$10.2 \pm 3.7^*$	$8.4 \pm 1.7^*$	$7.4 \pm 2.3^*$
	90 ml/min	10	$9.7 \pm 2.8^*$	$8.2 \pm 1.7^*$	$7.1 \pm 1.8^*$
	120 ml/min	10	$9.8 \pm 4.6^*$	$7.4 \pm 3.2^*$	$6.8 \pm 1.9^*$
Phosphorus	30 ml/min	5	3.4 ± 0.6	4.9 ± 1.0	5.5 ± 0.9
	60 ml/min	10	$9.4 \pm 2.2^*$	$7.1 \pm 1.9^*$	6.3 ± 2.0
	90 ml/min	10	$10.3 \pm 4.0^*$	$7.6 \pm 2.1^*$	5.8 ± 2.4
	120 ml/min	10	$8.7 \pm 2.1^*$	$7.4 \pm 2.7^*$	6.8 ± 1.7
Potassium	30 ml/min	5	3.1 ± 0.5	5.1 ± 1.2	6.2 ± 0.8
	60 ml/min	10	$9.8 \pm 1.5^*$	$8.5 \pm 1.5^*$	6.4 ± 0.8
	90 ml/min	10	$12.6 \pm 3.5^{**}$	$9.2 \pm 1.7^*$	6.9 ± 0.8
	120 ml/min	10	$13.1 \pm 2.8^{**}$	$10.2 \pm 1.8^*$	$7.6 \pm 1.2^{**}$

a) mean $\pm$ SD * compared with 30 ml/min. $P < 0.05$
 ** compared with 60 ml/min. $P < 0.05$

Table 2. The clearances in Intermittent Peritoneal Dialysis in dogs

Dialysate volume	40 ml/kg		60 ml/kg	
Time	2 hr (n=5)	4 hr (n=4)	2 hr (n=5)	4 hr (n=4)
Urea nitrogen	3.3 ± 1.4^a	1.3 ± 0.8	3.1 ± 1.8	2.3 ± 0.4
Creatinine	2.1 ± 1.3	1.2 ± 0.7	2.5 ± 1.6	2.1 ± 0.2
Phosphorus	2.6 ± 1.3	1.2 ± 0.7	2.6 ± 1.5	1.9 ± 0.4
Potassium	2.7 ± 1.3	1.2 ± 0.7	2.6 ± 1.5	1.7 ± 0.2

a) mean $\pm$ SD, ml/min

Table 3. Comparison of serum and dialysate osmolality in Recirculation Peritoneal Dialysis

Flow rate	n	Pre-RPD	1 hr	2 hr	3 hr
30 ml/min					
	serum	5 335.3 ± 16.0^a	334.8 ± 13.4	339.7 ± 16.2	293.1 ± 4.5
	dialysate	5 361.2^b	326.5 ± 2.6	329.2 ± 9.7	334.3 ± 3.5
60 ml/min					
	serum	10 326.4 ± 10.1	325.9 ± 5.7	327.7 ± 17.8	326.8 ± 8.0
	dialysate	10 361.2	326.5 ± 13.6	324.7 ± 18.1	325.7 ± 14.8
90 ml/min					
	serum	10 337.9 ± 27.6	333.9 ± 21.6	334.1 ± 22.7	327.8 ± 20.6
	dialysate	10 361.2	299.3 ± 26.5	304.8 ± 22.5	307.8 ± 16.4
120 ml/min					
	serum	10 333.8 ± 16.0	329.1 ± 15.2	328.3 ± 13.6	328.9 ± 17.7
	dialysate	10 361.2	332.2 ± 25.7	338.7 ± 24.8	342.2 ± 20.6

a) Values are the mean $\pm$ S.D. (Osmol/l).

b) PerisoritaTM (Shimizu Co., Ltd., Japan).

peritoneal cavity causes diaphragm compression, which affects respiratory function [21] and has effects on circulatory function caused by a reduction of venous return [6]. In this study, the fluid level in the dialysate chamber was monitored to ascertain the amount of dialysate in the peritoneal cavity and it was considered to be maintained well. Circulatory and respiratory functions were also considered to be less affected during RPD, because no change in pulse and respiration was observed in this study.

In hemodialysis, it has been shown that an increase in dialysate circulation rate causes a reduction in the membrane resistance and increases the dialysis efficiency [11]. In RPD, high dialysis efficiency was obtained by an increase in dialysate circulation rate. Besides a reduction of the membrane resistance, two more causative factors are considered. First, by using recirculation system, dialysis could be carried out with a large volume of dialysate, but increasing the dialysate volume in the peritoneal cavity was not required. Second, the dialysate was considered to be well mixed in the peritoneal cavity because a drainage catheter was placed into the liver side and an infusion catheter was placed into the bladder side. Gordon *et al.* [7] indicated that the circulation rate of 100–120 ml/min is a limit to the increase of the dialysis efficiency. In this study, no difference in the clearances of solutes was observed between 90 and 120 ml/min and the diffusion velocity of solutes reached a maximum at the circulation rate of approximately 90 ml/min. These results indicate that an improvement of clearance can not be expected at the circulation rate higher than 90 ml/min. The clearances of each solute were observed significantly lower at 30 ml/min than at 60, 90 and 120 ml/min. Similar results were reported in other studies [7], suggesting that an adequate circulation effect was not attained at the rate of 30 ml/min. From these results, high dialysis efficiency is considered to be obtained by circulating the dialysate at the rate of 60–90 ml/min.

Azotemic patients treated with rapid hemodialysis may develop clinical symptoms characterized by mild neurological manifestations. This is called the Dialysis Disequilibrium Syndrome (DDS), and is considered to be occurred by development of a brain-to-plasma osmotic gradient [1]. In RPD, the clearances decreased gradually with time, so that there is less possibility of causing DDS compared with hemodialysis.

The decrease in clearance with time during dialysis is suggested to be caused by the time-dependent decrease in the solute concentration difference between blood and dialysate, which results from an increase in solute concentrations in the dialysate after high speed recycling dialysis. However, the clearances of each solute were slightly increased at 30 ml/min. This is considered to keep differences in solute concentration between blood and dialysate.

The volume of body fluid is controlled by varying the osmolality of dialysate in peritoneal dialysis [3, 9]. The most hypertonic dialysate (485 mOsm/L) is used for

overhydrated patients to remove excess fluid from the body, and the mildly hypertonic dialysate (346 mOsm/L) is for normovolemic patients [3]. This study used mildly hypertonic dialysate and the drainage volume was not increased from the initial dialysate volume. In addition, according to the formula of Dorwart and Charmels [5], no difference in the osmolality was observed between blood and dialysate. From these results, the use of hypertonic dialysate in RPD or joint use with conventional peritoneal dialysis is considered to be necessary to control the overhydration.

Although RPD needs two catheters in the peritoneal cavity, there is no technical difficulty in handling. RPD is therefore considered to be easier than hemodialysis. It should be concluded that higher dialysis efficiency was obtained in a short time by using RPD compared with the conventional IPD, which suggests that RPD may be an effective dialysis method for animals.

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