Effect of peritonitis on peritoneal transport characteristics: Glucose solution versus polyglucose solution

TAO WANG, HUI-HONG CHENG, OLOF HEIMBURGER, JACEK WANIEWSKI, JONAS BERGSTROM, and BENGT LINDHOLM

Divisions of Baxter Novum and Renal Medicine, Huddinge University Hospital, Karolinska Institute, Huddinge, Sweden, and Department of Nephrology, First Affiliated Hospital, Sun Yat-sen University of Medical Sciences, Guangzhou, People’s Republic of China

Effect of peritonitis on peritoneal transport characteristics: Glucose solution versus polyglucose solution.

Background. Peritonitis is a common clinical problem and contributes to the high rate of technique failure in continuous ambulatory peritoneal dialysis treatment. The present study investigated the effect of peritonitis on peritoneal fluid and solute transport characteristics using glucose and polyglucose (icodextrin) solutions.

Methods. A four-hour dwell was performed in 32 Sprague-Dawley rats (8 rats in each group), with 115I albumin as an intraperitoneal volume marker. Peritonitis was induced by an intraperitoneal injection of 2 mL lipopolysaccharide (100 µg/mL phosphate-buffered saline) four hours before the dwell. Each rat was intraperitoneally infused with 25 mL of 3.86% glucose [glucose solution control group (Gcon) and glucose solution peritonitis group (Gpts)] or 7.5% icodextrin solution [icodextrin solution control group (Pgcon) and icodextrin peritonitis group (PGpts)].

Results. Net ultrafiltration was significantly lower (by 44%) in the Gpts as compared with the Gcon group, but was significantly higher (by 138%) in the PGpts as compared with the PGcon group. The peritoneal fluid absorption rate, including the direct lymphatic absorption rate, was significantly increased (by 78%) in the Gpts as compared with the Gcon group. However, the total fluid absorption did not differ between the PGpts and the PGcon groups. The dialysate osmolality decreased much faster in the Gpts group as compared with the Gcon group, resulting in significantly lower (by 9%) transcapillary ultrafiltration in the Gpts group. In contrast, the dialysate osmolality increased faster in the PGpts group as compared with the PGcon group, resulting in higher (by 40%) transcapillary ultrafiltration in the PGpts group. The in vitro increase in dialysate osmolality was also higher in the PGpts group as compared with the PGcon group. The solute diffusive transport rates were, in general, increased in the two peritonitis groups as compared with their respective control groups.

Conclusions. Our results suggest the following: (1) Peritonitis results in decreased net ultrafiltration using glucose solution caused by (a) decreased transcapillary ultrafiltration and (b) increased peritoneal fluid absorption. (2) Ultrafiltration induced by the icodextrin solution appears to be related to the increase in dialysate osmolality (mainly because of the degradation of icodextrin). (3) Peritonitis results in increased degradation of icodextrin and a faster increase in dialysate osmolality and therefore better ultrafiltration, whereas the fluid absorption rate does not change. (4) Peritonitis results in increased peritoneal diffusive permeability.

Despite the introduction of disconnect systems that have resulted in a dramatic decrease in the peritonitis rate in continuous ambulatory peritoneal dialysis (CAPD) patients, peritonitis remains a common clinical problem and contributes to the high rate of technique failure during CAPD treatment [1, 2]. Peritonitis is associated with increased peritoneal glucose absorption and therefore decreased peritoneal fluid removal [3, 4]. Peritonitis also increases peritoneal protein loss. However, a detailed evaluation of the peritoneal fluid kinetics and peritoneal solute transport characteristics during peritonitis using a glucose solution is still needed.

Understanding the impact of peritonitis on peritoneal transport becomes even more interesting and important when a polyglucose solution is used. It has been shown in recent years that a polyglucose solution can provide sustained positive net ultrafiltration equivalent to a 3.86% glucose solution after 8 to 12 hours in CAPD [5] and for up to 16 hours in automated peritoneal dialysis [6]. More recently, the polyglucose (icodextrin) solution has been reported to extend CAPD technique survival in patients with poor ultrafiltration capacity [7], possibly through better fluid control. Interestingly, it has been observed that icodextrin solution has a better effect on ultrafiltration during peritonitis [5, 8]. Although Krediet et al proposed that an increase in peritoneal surface area during peritonitis and therefore an increase in small pores might be the reason, this hypothesis has not yet

Key words: peritoneal dialysis, fluid kinetics, osmotic agent, CAPD, dialysate.
Wang et al: Peritoneal transport during peritonitis

been proven [9, 10]. The peritoneal membrane is far more complicated than described by current transport models, including the three-pore model. Furthermore, our recent study suggests that intraperitoneal degradation of glucose polymer may be involved in the osmosis by an icodextrin solution [11]. However, it is not known how peritonitis would affect the behavior of the icodextrin solution in the peritoneal cavity.

Therefore, in the present study, we investigated the effect of peritonitis on the peritoneal fluid and solute transport characteristics using both the glucose solution and icodextrin solution.

METHODS

Thirty-two male Sprague-Dawley rats with an average body weight of 300 g were divided into four groups, with eight rats in each group. Peritonitis (only in 16 rats) was induced by an intraperitoneal injection of 2 mL lipopolysaccharide [LPS; 100 μg/mL phosphate buffered saline (PBS); Sigma, St. Louis, USA] four hours before the dwell. We have previously found that an intraperitoneal injection of pure PBS did not cause any significant changes (unpublished observation). The four-hour dwell study was modified from our previous studies [12]. Briefly, each rat was initially anesthetized with a single intramuscular injection of 60 mg/kg pentobarbital sodium. After two hours, the rat was given 25 mg/kg of pure pentobarbital sodium subcutaneously every hour to maintain the intensity of anesthesia during the experiment. The fur over the abdominal wall was closely shaved. The animal was laid in a supine position and was kept at 37°C with a heating pad (CMA/Microdialysis, Stockholm, Sweden). Isotonic saline (2 mL/h) was injected subcutaneously to prevent hypovolemia. A multiholed silastic catheter (Venoflon, 0.8 mm internal diameter, Helsingborg, Sweden) was inserted percutaneously in the left lower quadrant of the abdomen for dialysis fluid infusion and sampling. Then 25 mL of Dianeal® 3.86% glucose dialysis fluid [glucose solution control group (Gcon) and glucose solution peritonitis group (Gpts)] or 25 mL of 7.5% icodextrin solution [Extranal®; icodextrin solution control group (Pgcon) and icodextrin solution peritonitis group (PGpts)] were infused into the peritoneal cavity via a three-way valve (Viggo: Connecta, Helsingborg, Sweden) connected to the end of a 0.8 mm catheter. The dialysis solutions were prewarmed to 37°C and contained 18.5 KBq 131I-human serum albumin (RISA; Isopharma AS, Kjeller, Norway). A priming dose of 0.2 g/L of human serum albumin was added in the 3.86% glucose and icodextrin dialysis solutions to minimize the adhesion of tagged albumin to the surface of the catheter. After infusion, the dialysis solutions were allowed to remain in the peritoneal cavity for four hours. The intraperitoneal hydrostatic pressure (IPP) was measured after the infusion using a water manometer connected to the peritoneal catheter, setting the reference level at the heart of the rat. Dialysate samples (0.35 mL) were taken at 0-, 3-, 15-, 30-, 60-, 90-, 120-, 180-, and 240-minutes postinfusion. Prior to each sampling, 1 mL of the dialysate was flushed back and forth five times through the catheter. Blood samples were drawn at 0, 120, and 240 minutes from the tail artery. After 240 minutes, the peritoneal cavity was opened. The dialysate was collected using syringe and preweighted gauze tissues, and the volume was recorded. White blood cell count in the dialysate effluent was measured with a hemocytometer. The respiration rate of the rat was monitored during the experiment. The experimental study was approved by the Animal Ethical Committee of the Karolinska Institute at Huddinge Hospital.

Dialysate samples (0.1 mL) and blood samples (0.1 mL of plasma) were analyzed for RISA activity on a Gamma Counter (Packard Instrument Company, Meriden, CT, USA) for 10 minutes each. Dialysate including the residual fluid and plasma concentrations of urea (urease-glutamate dehydrogenase method), phosphate (ultraviolet-molybdate method), protein (Coomassie Brilliant Blue Dye binding method), and glucose concentration (hexokinase method), was analyzed using a Monarch™ 1000 autoanalyzer (Instrumentation Laboratory, Lexington, MA, USA). Dialysate and plasma concentrations of sodium and potassium were analyzed using a flame photometer (Instrumentation Laboratory). Dialysate (DOS) and blood osmolality were measured once (for the glucose solution) or twice (for the icodextrin solution, immediately after the samples were taken and 24 h later after storage at 4°C) by a Vapro™ vapor pressure osmometer 5520 (Wescor Inc., Logan, UT, USA).

Intraperitoneal dialysate volume was estimated from the dilution of RISA with corrections made for the elimination of RISA from the peritoneal cavity and the sample volume [13]. Note that the intraperitoneal volume at the end of the dwell was directly measured. The peritoneal fluid absorption rate was estimated as the coefficient of RISA elimination from the peritoneal cavity, KE (mL/min), and the transcapillary ultrafiltration rate was calculated as net volume change plus KE. Because only a very small amount of free iodine was found in the RISA solution [14], we did not take the free iodine into account in the KE calculation.

The direct lymphatic absorption of fluid from the peritoneal cavity was assessed as the clearance of RISA from the dialysate to the blood, KEB (mL/min). KEB was calculated from the rate of increase of RISA amount in plasma divided by the average intraperitoneal RISA concentration [15]. The plasma volume was set at 3.6 mL/100 g body wt [15, 16]. The KEB values were also corrected for the RISA “spill over” from plasma to the body interstitium during the dwell using a constant of...
0.0018 min\(^{-1}\) as described previously [16]. The remaining part of fluid absorption to the peritoneal tissue interstitium and capillaries, \(K_{\text{ET}}\) (mL/min), was calculated as \(K_{E}\) minus \(K_{\text{EB}}\).

The dialysate over plasma concentration ratios \((D/P)\) for all of the investigated solutes were calculated by dividing the dialysate concentrations of the investigated solutes at a certain time with the aqueous concentrations of the investigated solutes in plasma [17]. If no blood sample was taken at the same time as a dialysate sample, then the blood concentration of the solute was linearly interpolated from the blood sample taken before and after this moment [18]. The \(D/D_0\) for glucose was calculated as the dialysate glucose concentration \((D)\) divided by the glucose concentration in the fresh dialysis solution \((D_0)\). The diffusive mass transport coefficients \((K_{\text{BD}}, \text{mL/min})\) were estimated using the modified Babb-Randerson-Farrell (BRF) model as described previously [19, 20] using the computer program PERTRAN (Baxter Novum, Karolinska Institute, Stockholm, Sweden). The model describes the net change of the solute amount in peritoneal dialysate over a time increment equal to the rate of solute flow between blood and dialysate due to combined diffusion, convective transport, and peritoneal absorption of the solute. In addition, in this study, we set the sieving coefficients \((S)\) for glucose, urea, sodium, and potassium to be 0.55 [12, 21] and for total protein to be 0.01. The clearance of each investigated solute was calculated as the total amount of the solute in the dialysate minus the infused amount and divided by the mean blood concentration of the solute and the dwell time.

Two-way analysis of variance (ANOVA) with repeated measurements and one-way ANOVA were applied to compare intraperitoneal volume, IPP, \(K_{E}\), \(K_{EB}\), \(K_{ET}\), \((D/P)\), cell counts, and \(K_{\text{BD}}\). When ANOVA showed a significant difference among the three groups, then Fisher’s post hoc test was used to compare the difference between different groups. The results are expressed as mean \pm SD. A \(P\) value of less than 0.05 was considered significant.

**RESULTS**

**Fluid transport**

The net ultrafiltration volume \((NUF)\) was significantly lower in the Gpts group as compared with the Gcon group (analysis of variance repeated measurement, \(P < 0.01\); Fig. 1). In the Gpts group, the NUF peaked at 120 minutes of the dwell and then started to decrease, whereas NUF continued to increase after 120 minutes and started to level off after 180 minutes of the dwell in the Gcon group. In contrast, NUF decreased initially in both icodextrin solution groups, especially in the PGcon group, and started to increase after 90 minutes of the dwell. The intraperitoneal volume \((IPV)\) was significantly higher in the PGpts group as compared with the PGcon group (ANOVA repeated measurement, \(P < 0.05\); Fig. 1). There was no difference in the IPP among the four groups after infusion (Table 1). However, the peritoneal fluid absorption rate (as assessed by the RISA appearance rate in blood, \(K_{E}\)) was significantly higher in the Gpts group as compared with the other groups, whereas no significant difference was found between the other three groups (Table 1). The direct lymphatic fluid absorption rates (as assessed by the RISA appearance rate in blood, \(K_{\text{BD}}\)) were significantly higher in the peritonitis groups (Gpts and PG) as compared with the control groups (Gcon and PGcon; Table 1). There was no difference in the respiration rate among the four groups. The transcapillary ultrafiltration rate was significantly lower in the Gpts group as compared with the Gcon group (\(P < 0.01\)), but was significantly higher in the PGpts group as compared with the PGcon group (\(P < 0.05\); Table 1). The white blood cell counts in the dialysate effluents were significantly higher in the two peritonitis groups as compared with their respective control groups (both \(P < 0.01\)): 1959 \pm 572, 2108 \pm 689, 10866 \pm 2143, 11500 \pm 2350 cells/mL for the Gcon, PGcon, Gpts, and PGpts groups, respectively.

**Glucose transport and osmolality changes**

The dialysate glucose concentration (and the \(D/D_0\)) of glucose was significantly lower in the Gpts group as compared with the Gcon group, but was significantly higher in the PGpts group as compared with the PGcon group (both \(P < 0.01\), ANOVA repeated-measurements; Fig. 2). The diffusive mass transport coefficients \((K_{\text{BD}})\) for glucose were significantly higher in the peritonitis groups as compared with their respective control groups.
Table 1. Fluid and RISA transport parameters and intraperitoneal hydrostatic pressure among the four groups

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>IPP (cmH2O)</th>
<th>Qv (µL/min)</th>
<th>Net UF (mL)</th>
<th>KE (µL/min)</th>
<th>KEB (µL/min)</th>
<th>KET (µL/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gcon</td>
<td>8</td>
<td>1.80 ± 0.38</td>
<td>76.9 ± 2.6a</td>
<td>13.2 ± 0.6a</td>
<td>21.8 ± 3.8</td>
<td>3.3 ± 1.1</td>
<td>18.5 ± 3.3</td>
</tr>
<tr>
<td>Gpts</td>
<td>8</td>
<td>1.75 ± 0.29</td>
<td>69.7 ± 3.8a</td>
<td>7.4 ± 1.5a</td>
<td>38.9 ± 4.1b</td>
<td>8.1 ± 1.7b</td>
<td>30.8 ± 2.8a</td>
</tr>
<tr>
<td>PGcon</td>
<td>8</td>
<td>1.68 ± 0.41</td>
<td>25.2 ± 7.8a</td>
<td>1.3 ± 0.8b</td>
<td>19.8 ± 6.1</td>
<td>4.1 ± 1.4b</td>
<td>15.7 ± 5.1</td>
</tr>
<tr>
<td>PGpts</td>
<td>8</td>
<td>1.65 ± 0.34</td>
<td>35.2 ± 2.4b</td>
<td>3.1 ± 0.6c</td>
<td>22.5 ± 2.0</td>
<td>5.8 ± 0.6c</td>
<td>16.7 ± 2.1</td>
</tr>
</tbody>
</table>

Data are mean ± SD. Abbreviations are: RISA, 131I-human serum albumin; Gcon, glucose solution control group; Gpts, glucose solution peritonitis group; PGcon, polyglucose solution control group; PGpts, polyglucose solution peritonitis group; IPP, intraperitoneal hydrostatic pressure after infusion; Qv, mean transcapillary ultrafiltration rate between 0 and 240 min; Net UF, net ultrafiltration volume at 4 hours of the dwell; KE, total RISA elimination rate representing the fluid absorption rate from the peritoneal cavity; KEB, RISA elimination rate to the blood from the peritoneal cavity representing the peritoneal lymphatic absorption; KET, RISA elimination rate to peritoneal tissue.

aP < 0.05 compared with all the other groups
bP < 0.05 compared with the Gcon group
cP < 0.05 compared with the PGcon group

Fig. 2. Dialysate glucose concentration versus dwell time. (A) Glucose solution. (B) Polyglucose solution. Symbols are: (□) glucose control group (N = 8); (■) glucose peritonitis group (N = 8); (△) polyglucose control group (N = 8); (▲) polyglucose peritonitis group (N = 8). Data are mean ± SD.

Fig. 3. Intraperitoneal dialysate osmolality measured immediately after the samples were taken versus dwell time. Symbols are: (□) glucose control group (N = 8); (■) glucose peritonitis group (N = 8); (△) polyglucose control group (N = 8); (▲) polyglucose peritonitis group (N = 8). Data are mean ± SD.

Transport of other solutes

The D/P values for urea, phosphate, and total protein were all significantly higher in the Gpts group as compared with the Gcon group (all P < 0.01; Fig. 5). The D/P values for phosphate were also significantly higher in the PGpts group as compared with the PGcon group (both P < 0.01; Fig. 5), whereas the difference in the D/P for urea, potassium, and total protein did not reach statistical significance. The D/P of sodium was significantly higher in the icodextrin solution groups compared with the glucose solution groups and was significantly higher in the Gpts group as compared with the Gcon group as compared with the PGcon group (both P < 0.05; Fig. 3). After an in vitro incubation of dialysate sample, the in vitro increase in dialysate osmolality was significantly higher in the PGpts group as compared with the PGcon group (only up to 120 min of the dwell, P < 0.01; Fig. 4).

(discussed later in this article; Table 2). Kbd values for glucose were also significantly lower in the icodextrin solution groups as compared with the glucose solution groups (P < 0.01). The dialysate osmolality was significantly lower in the Gpts group compared with the Gcon group, but was significantly higher in the PGpts group as compared with the PGcon group.
Wang et al: Peritoneal transport during peritonitis

port characteristics. It also shows that there is a contrasting pattern of the impact of peritonitis on peritoneal fluid and solute removal between glucose solution and icodextrin solution.

Effect of peritonitis on peritoneal fluid transport

The decreased peritoneal fluid removal in the Gpts group as compared with the Gcon group is not unexpected. It has been shown that peritonitis is associated with increased peritoneal glucose absorption, and therefore decreased transcapillary ultrafiltration rate and decreased peritoneal fluid removal [4]. Our results, however, show that the decreased transcapillary ultrafiltration rate is only part of the reason for the lower peritoneal fluid removal during peritonitis when using glucose solution. Peritoneal fluid absorption, which contributes (adversely) significantly to the net peritoneal fluid removal [22], was markedly increased during peritonitis when the glucose solution was used, and this is in agreement with previous observations (abstract; Carlsson et al, J Am Soc Nephrol 8:262A,1997) [4, 23]. In contrast, the peritoneal fluid absorption rate did not increase significantly during peritonitis when the icodextrin solution was used. The process of peritoneal fluid absorption is not very well understood, but it has been suggested that peritoneal fluid absorption rate depends on IPP and peritoneal tissue hydraulic permeability [24, 25]. In a previous study using glucose solution, the increase in fluid absorption rate associated with peritonitis was not associated with any changes in IPP (similar results were found with glucose solution in the present study), and was therefore assumed to be due to an increase in tissue hydraulic permeability (abstract; Carlsson et al, ibid). However, the different results with the icodextrin solution in the present study suggests that other mechanisms may also be involved in this process.

As shown in Table 3, the peritoneal clearances for urea, sodium, and potassium are lower or tended to be lower in the Gpts group as compared with the Gcon group. In contrast, these parameters were higher or tended to be higher in the PGpts group as compared with the PGcon group. The clearances for phosphate were, however, significantly higher in both peritonitis groups as compared with their respective control group. The total protein clearance also tended to be higher in the peritonitis groups as compared with their respective control groups, although these differences did not reach statistically significant levels.

DISCUSSION

The present study shows that peritonitis resulted in significant changes in peritoneal fluid and solute trans-

Dialysate osmolality and degradation of icodextrin

Although the dialysate osmolality decreased markedly faster in the Gpts group compared with the Gcon because of the increased transport rate of glucose during peritonitis, the dialysate osmolality increased much
shown in Figures 1 and 3, the NUF decreased initially and increased only after the dialysate osmolality increased to higher than plasma level, supporting our previous finding [11] that degradation of glucose polymer may contribute to the ultrafiltration by icodextrin solution. The significantly higher NUF in the PGpts group as compared with the PGcon group is in agreement with a previous clinical observation [8]. Although the mechanism(s) for the higher net ultrafiltration in the PGpts group is not entirely clear from the present study, we believe that our data strongly support that the higher degree of icodextrin degradation (caused by higher amylase activity), which resulted in the higher increase in dialysate osmolality in this group, contributed to the higher ultrafiltration.

Note, however, that the conventional methods for determination of amylase activity measure the breakdown of a starch substrate (glucose polymer, natural or synthetic) by viscosimetric, turbidimetric, iodometric, or nephelometric procedures. With the availability of glucose polymer in the icodextrin solution, we believe that it is not possible to measure the amylase activity using these conventional methods correctly. We therefore tried to use the osmometric method [11] to determine the amylase activity in the dialysate samples. The in vitro
increase in dialysate osmolality may thus represent the amylase activity in the sample. Therefore, the higher in vitro increase in dialysate osmolality in the PGpts group compared with the PGcon group suggests that the amylase activity in the dialysate in the PGpts group may indeed be higher than in the PGcon group, possibly resulting in a higher degree of icodextrin degradation in the PGpts group within the peritoneal cavity. In fact, it has been shown that the dialysate amylase level is significantly higher during peritonitis as compared with peritonitis-free periods [28, 29], indicating that peritonitis should result in increased degradation of icodextrin in the peritoneal cavity. The lack of in vitro increase in dialysate osmolality in the sample at 180 and 240 minutes suggested that there was a lack of remaining amylase activity in those samples. However, the reason is not clear.

Note also that during peritonitis, the absorption of icodextrin (especially low molecular weight fractions in the current icodextrin solution) also may be increased, resulting in a lower dialysate icodextrin concentration even if no degradation of icodextrin occurs. The increased icodextrin absorption per se should therefore conceivably lead to decreased peritoneal fluid removal if colloid osmosis is the dominant mechanism of osmosis for icodextrin solution. The present study together with previous studies suggests that intraperitoneal degradation of icodextrin (in the dialysate and possibly in the peritoneum) may indeed contribute significantly to the peritoneal fluid removal by the icodextrin solution. It may not be surprising that even small differences in the dialysate osmolality between the two groups (PGpts vs. PGcon) could result in the difference in transcapillary ultrafiltration observed in the present study. We believe that icodextrin may not only be degraded to small molecular weight polymers, but also to larger ones, and therefore, the degradation may result in a slight increase in dialysate osmolality without significantly compromising the reflection coefficient of the icodextrin. It is still debatable whether the observed changes in rats mimic the changes in CAPD patients. We recently reviewed the literature and found that there were striking similarities between our experimental data in rats and patient data from the literature. The only difference between humans and rats was the magnitude of the changes [abstract; Wang et al, *Perit Dial Int* 19(Suppl 1):S81, 1999]. However, further studies—including clinical studies—are needed in this area.

### Solute transport

Although the D/P values for small solutes like urea and sodium were higher in the icodextrin solution group and the Gpts group as compared with the Gcon group, the solute clearances were significantly lower in these groups as compared with the Gcon group because of the significant differences in fluid removal. This shows the major importance of net ultrafiltration in small solute removal during standard CAPD treatment. The significantly higher phosphate D/P values and clearance values in the two peritonitis groups as compared with their respective control group is unexpected. As large proportions of phosphate are protein bound, the slightly higher protein transport in the peritonitis groups may contribute to the higher phosphate removal in these groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Glucose</th>
<th>Urea</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Phosphate</th>
<th>Total protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gcon</td>
<td>8</td>
<td>0.171 ± 0.013</td>
<td>0.143 ± 0.032</td>
<td>0.126 ± 0.028</td>
<td>0.178 ± 0.015</td>
<td>0.019 ± 0.007</td>
<td>0.0011 ± 0.0010</td>
</tr>
<tr>
<td>Gpts</td>
<td>8</td>
<td>0.228 ± 0.029*</td>
<td>0.235 ± 0.061*</td>
<td>0.198 ± 0.040*</td>
<td>0.214 ± 0.034</td>
<td>0.066 ± 0.006*</td>
<td>0.0020 ± 0.0008*</td>
</tr>
<tr>
<td>PGcon</td>
<td>8</td>
<td>0.083 ± 0.012*</td>
<td>0.166 ± 0.038</td>
<td>0.161 ± 0.037</td>
<td>0.252 ± 0.065</td>
<td>0.049 ± 0.006</td>
<td>0.0021 ± 0.0007</td>
</tr>
<tr>
<td>PGpts</td>
<td>8</td>
<td>0.136 ± 0.033*</td>
<td>0.227 ± 0.035*</td>
<td>0.200 ± 0.040</td>
<td>0.249 ± 0.024</td>
<td>0.127 ± 0.007*</td>
<td>0.0021 ± 0.0003</td>
</tr>
</tbody>
</table>

Data are mean ± SD.

*P < 0.05 compared with the Gcon group

*P < 0.05 compared with the PGcon group

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Urea</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Phosphate</th>
<th>Total protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gcon</td>
<td>8</td>
<td>0.132 ± 0.010</td>
<td>0.046 ± 0.003*</td>
<td>0.135 ± 0.008</td>
<td>0.065 ± 0.008</td>
<td>0.0021 ± 0.0003</td>
</tr>
<tr>
<td>Gpts</td>
<td>8</td>
<td>0.126 ± 0.011</td>
<td>0.030 ± 0.004*</td>
<td>0.119 ± 0.010*</td>
<td>0.072 ± 0.008*</td>
<td>0.0025 ± 0.0007</td>
</tr>
<tr>
<td>PGcon</td>
<td>8</td>
<td>0.095 ± 0.011</td>
<td>0.007 ± 0.003*</td>
<td>0.093 ± 0.014</td>
<td>0.052 ± 0.009</td>
<td>0.0022 ± 0.0002</td>
</tr>
<tr>
<td>PGpts</td>
<td>8</td>
<td>0.109 ± 0.010*</td>
<td>0.013 ± 0.002*</td>
<td>0.102 ± 0.007</td>
<td>0.085 ± 0.008*</td>
<td>0.0025 ± 0.0002</td>
</tr>
</tbody>
</table>

*P < 0.05 compared with all the other groups

*P < 0.05 compared with the Gcon group

*P < 0.05 compared with the PGcon group
Further studies are needed to explore other possible mechanisms. The increase in KID values for small solutes and total protein (in the Gpts group) in the peritonitis groups is in agreement with previous reports and suggests that peritonitis may result in increased peritoneal diffusive permeability.

The distinctive difference in sodium transport patterns between the peritonitis groups and control group, as well as between the glucose solution groups and the icodextrin solution groups, merits further discussion. The magnitude of the initial decrease in D/P values for sodium, using 3.86% glucose solution, has been suggested as an indicator of transcellular water transport through the ultrasmall pores (abstract; Ho-dac-Pannekeet et al, J Am Soc Nephrol 7:1481, 1996). It has also been suggested that the transport of water devoid of solute across aquaporins is apparently the main reason for the sieving of sodium during peritoneal dialysis [30–33]. However, it is important to note that the smaller than usual decrease in D/P sodium in some patients with loss of ultrafiltration capacity is also dependent to a large extent on the fact that if there is no ultrafiltration, there cannot be any sieving (as there is no convective transport). The higher D/P of sodium in the Gpts group (compared with the Gcon group) may thus, to a large extent, be due to the lower transcapillary ultrafiltration rate in this group. The markedly lower ultrafiltration in these two icodextrin solution groups certainly contributes significantly to the higher D/P sodium in these two groups. Although sodium was suggested not to be sieved using icodextrin solution [9, 10], the present study shows that the increase in dialysate sodium concentration in icodextrin solution groups is much slower than in the glucose solution groups. Furthermore, dialysate sodium concentration started to level off after 90 minutes of the dwell in the PGcon group and even decreased in the PGpts group. Although the decrease in sodium concentration in plasma in the two icodextrin solution groups may have contributed to the slower increase in dialysate sodium concentration, the changes in dialysate sodium concentration after 90 minutes (associated with an increase in ultrafiltration) suggests that sodium may also be sieved during the later part of the dwell using the icodextrin solution, especially in the PGpts group. The observation of sodium sieving using icodextrin solution supports that degradation of glucose polymer to lower molecular weight fragments (and increase in dialysate osmolality) that exhibit osmosis through transcellular water transport may be involved in the ultrafiltration process by icodextrin solution.

In summary, the present study shows that peritonitis results in increased peritoneal diffusive permeability. When the glucose solution is used, peritonitis results in: (1) increased glucose absorption and therefore decreased peritoneal transcapillary ultrafiltration rate; (2) increased peritoneal fluid absorption, including an increase in direct lymphatic absorption rate; and (3) decreased peritoneal small solute clearances caused by the decreased peritoneal fluid removal. However, when icodextrin solution is used, peritonitis results in: (1) increased degradation of glucose polymers and a faster increase in dialysate osmolality, and therefore better transcapillary ultrafiltration; (2) no changes in total peritoneal fluid absorption rate while the direct lymphatic absorption was increased; and (3) increased small solute clearance caused by the increased solute transport rate and increased peritoneal fluid removal. The present study also suggests that the peritoneal glucose transport rate is slower with the icodextrin solution than with the glucose solution, and that sodium may also be sieved during the later part of the dwell using icodextrin solution.

ACKNOWLEDGMENTS

This study was supported by a grant from Baxter Healthcare Corporation, McGaw Park, IL, USA.

REFERENCES