4.4 Dialysis as Treatment of End-Stage Renal Disease

**FIGURE 4-4**
Solute removal. The rates of change of solute concentrations are similar for 1.5% dextrose dialysis solutions (panel A) and 4.25% dextrose dialysis solutions (panel B). Hypertonic exchanges enhance solute removal owing to larger drain volumes. Net solute diffusion ceases at equilibration when the dialysate to plasma solute ratio (D/P) is near 1.0. Smaller size solutes (i.e., urea and creatinine) diffuse across the membrane faster, equilibrate sooner, and are influenced more by exchange frequency as compared with larger size solutes (i.e., uric acid, phosphates, inulin, and proteins). (From Nolph and coworkers [10]; with permission.)

**FIGURE 4-5**
Solute removal. In a highly permeable membrane, smaller molecules (i.e., urea and creatinine) are transported at a faster rate from the blood to dialysate than are larger molecules, enhancing solute removal. Similarly, glucose (a small solute used in the peritoneal dialysis solution to generate osmotic force for ultrafiltration across the peritoneal membrane) is also transported faster, but in the opposite direction. This high transporter dissipates the osmotic force more rapidly than does the low transporter. Both osmotic and glucose equilibriums are attained eventually in both groups, but sooner in the high transporter group. Intraperitoneal volume peaks and begins to diminish earlier in the high transporter group. When the membrane is less permeable, solute removal is lower, ultrafiltration volume is larger at 2 hours or more, and glucose equilibriums are attained later. Consequently, intraperitoneal volume peaks later. Ultrafiltration in a low transporter peaks late during dwell time. Therefore, a low transporter continues to generate ultrafiltration even after 8 to 10 hours of dwell. The solute creatinine dialysate to plasma ratio (D/P) increases linearly during the dwell time. Patients with average solute transfer rates have ultrafiltration and mass transfer patterns between those of high and low transporters. NIPD—nightly intermittent peritoneal dialysis; NTPD—nighttime tidal peritoneal dialysis; DAPD—daytime ambulatory peritoneal dialysis; CAPD—continuous ambulatory peritoneal dialysis; CCPD (NE)—continuous cyclic peritoneal dialysis (night exchange); CCPD (DE)—continuous cyclic peritoneal dialysis (day exchange). (From Twardowski [11]; with permission.)
Principles of Peritoneal Dialysis

Solute sieving. **A**, Dialysate sodium concentration is initially reduced and tends to return to baseline later during a long dwell exchange of 6 to 8 hours. **B**, Dialysate sodium concentration decreases, particularly when using 4.25% dextrose dialysis solution, because of the sieving phenomenon. Removal of water during ultrafiltration unaccompanied by sodium, in proportion to its extracellular concentration, is called sodium sieving [7,12]. The peritoneum offers greater resistance to the movement of solutes than does water. This probably relates to approximately half the ultrafiltrate being generated by solute-free water movement through aquaporins channels. Therefore, ultrafiltrate is hypotonic compared with plasma. Dialysate chloride is also reduced below simple Gibbs-Donnan equilibrium, particularly during hypertonic exchanges. Patients with a low peritoneal membrane transport type tend to reduce dialysate sodium concentration more than do other patients. Therefore, during a short dwell exchange of 2 to 4 hours, net electrolyte removal per liter of ultrafiltrate is well below the extracellular fluid concentration. As a result, severe hypernatremia, excessive thirst, and hypertension may develop. This hindrance can be overcome by lowering the dialysate sodium concentration to 132 mEq/L. In patients who use cyclers with short dwell exchanges and who generate large ultrafiltration volumes, lower sodium concentrations may need to be used (such as 118 mEq/L for 2.5% glucose solutions or 109 mEq/L for 4.25% solutions). In continuous ambulatory peritoneal dialysis with long dwell exchanges of 6 to 8 hours, significant sieving usually does not occur, whereas in automated peritoneal dialysis with short dwell exchanges, sieving may occur. Sieving predisposes patients to thirst and less than optimum blood pressure control, especially in those who have low-normal serum sodium levels, those with low peritoneal membrane transporter rates, or both. *(From Nolph and coworkers [10]; with permission.)*

Fluid removal by ultrafiltration. During peritoneal dialysis, hyperosmolar glucose solution generates ultrafiltration by the process of osmosis. Water movement across the peritoneal membrane is proportional to the transmembrane pressure, membrane area, and membrane hydraulic permeability. The transmembrane pressure is the sum of hydrostatic and osmotic pressure differences between the blood in the peritoneal capillary and dialysis solution in the peritoneal cavity. Net transcapillary ultrafiltration defines net fluid movement from the peritoneal microcirculation into the peritoneal cavity primarily in response to osmotic pressure. Net ultrafiltration would equal the resulting increment in intraperitoneal fluid volume if it were not for peritoneal reabsorption, mostly through the peritoneal lymphatics. Peritoneal reabsorption is continuous and reduces the intraperitoneal volume throughout the dwell. **A**, The net transcapillary ultrafiltration rate decreases exponentially during the dwell time, owing to dissipation of the glucose osmotic gradient secondary to peritoneal glucose absorption and dilution of the solution glucose by the ultrafiltration. Later in the exchange net, ultrafiltration ceases when the transcapillary ultrafiltration is reduced to a rate equal to the peritoneal reabsorption. **B**, When the transcapillary ultrafiltration rate decreases below that of the peritoneal reabsorption rate, the net ultrafiltration rate becomes negative. Consequently, the intraperitoneal volume begins to diminish. Thus, peak ultrafiltration and intraperitoneal volumes are observed before osmotic equilibrium during an exchange. *(Continued on next page)*
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**FIGURE 4-7 (Continued)**

C, Osmotic equilibrium most likely precedes glucose equilibrium because of both solute sieving and the higher peritoneal reflection coefficient of glucose compared with other dialysate solutes, allowing net transcapillary ultrafiltration to continue at a low rate even after osmotic equilibrium. D, Ultrafiltration can be maximized by measures that delay osmotic equilibrium, which can be accomplished by using hypertonic glucose solutions, larger volumes, or both, during an exchange. More frequent exchanges shorten dwell times and increase the dialysate flow rate and thus avert attaining osmotic equilibrium. Additionally, potential exists for enhancing ultrafiltration by measures that reduce the peritoneal reabsorption rate. (From Mactier and coworkers [13]; with permission.)

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**STANDARDIZED 4-HOUR PERITONEAL EQUILIBRATION TEST**

1. Perform an overnight 8- to 12-h preexchange.
2. Drain the overnight exchange (drain time not to exceed 25 min) with patient in the upright position.
3. Infuse 2 L of dialysis solution over 10 min with patient in the supine position. Roll the patient from side to side after every 400-mL infusion.
4. After the completion of infusion (0 time) and at 120 min, drain 200 mL of dialysate. Take a 10-mL sample, and reinfuse the remaining 190 mL into the peritoneal cavity.
5. Position the patient upright, and allow patient ambulation if able.
6. Obtain a serum sample at 120 min.
7. At the end of study (240 min), drain the dialysate with the patient in the upright position (drain time not to exceed 20 min).
8. Measure the drained volume, and take a 10-mL sample from the drained volume after a good mixing.
9. Analyze the blood and dialysate samples for creatinine and glucose concentrations.
10. Correct the serum and dialysate creatinine concentrations for high glucose level (correction factor 0.000531415).
11. Calculate the dialysate to plasma ratios for creatinine, and so on, and calculate the Dt/D0 glucose.

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**FIGURE 4-8**

Standardized 4-hour peritoneal equilibration test. Dt/D0 glucose—final to initial dialysate glucose ratio.

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**FIGURE 4-9**

Equation to correct the creatinine levels in dialysate and serum. The creatinine levels in dialysate and serum need to be corrected for high glucose levels, which contribute to formation of noncreatinine chromogens during the creatinine assay. The correction factor may vary from one laboratory to another. In our laboratory at the University of Missouri—Columbia, the correction factor is 0.000531415. Accordingly, the corrected creatinine is calculated as in the equation. The correction in the serum is minimal due to low blood sugar levels; however, it is significant in dialysate, especially during the early phase of dwell (0- and 2-hour dialysate samples).