CHAPTER 187

Continuous-Flow Peritoneal Dialysis as Acute Therapy

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OBJECTIVES

This chapter will:

1. Elucidate the rationale for continuous-flow peritoneal dialysis and its underlying physiology.
2. Review the historical perspective of continuous-flow peritoneal dialysis.
3. Discuss the techniques of this modality: single-pass versus recirculation, dual-lumen catheter versus two catheters, ultrafiltration control, and dose of dialysis.
4. Review the special considerations in and clinical experience of continuous-flow peritoneal dialysis in pediatric acute renal failure.
5. Describe the clinical experience with this modality in acute renal failure.
6. Discuss the advantages of and indications for continuous-flow peritoneal dialysis.
7. Consider the future directions of this modality.

RATIONALE AND PHYSIOLOGY

Peritoneal dialysis (PD) has been used in the treatment of acute renal failure (ARF) for a generation, and its details described elsewhere. Use of PD in ARF has declined largely because the slow solute clearance it achieves renders it inadequate to deal with the modern hypercatabolic patient with ARF who has multiorgan system failure (MOSF). Urea clearance in acute PD is limited, even under optimal circumstances, to 10 to 15 mL/min.[1] This limitation is not due to membrane surface area, permeability, or blood flow, which should be more than capable of delivering clearances of 40 to 80 mL/min.[2] Solute clearance is limited by the fill-dwell-drain cycle of standard PD.

Fig. 187.1 depicts an idealized PD exchange: dialysis, or solute flux across the membrane, requires dialysate contact with the membrane, which makes the fill and drain segments extremely inefficient. Flux (J) is defined mathematically as the permeability coefficient of the membrane or mass-transfer area coefficient (MTAC) multiplied by the difference between the solute concentration in the blood (C_B) and that in the dialysate (C_D), or concentration gradient, as shown in the following equation:

$$J = MTAC\,(C_B - C_D)$$

In standard PD, the concentration gradient decreases continuously as solute transport occurs during a dwell, steadily reducing the flux, or rate of transport (see Fig. 187.1).

CFPD works by constantly replenishing the dialysate, either with fresh, sterile dialysate in single-pass mode, or

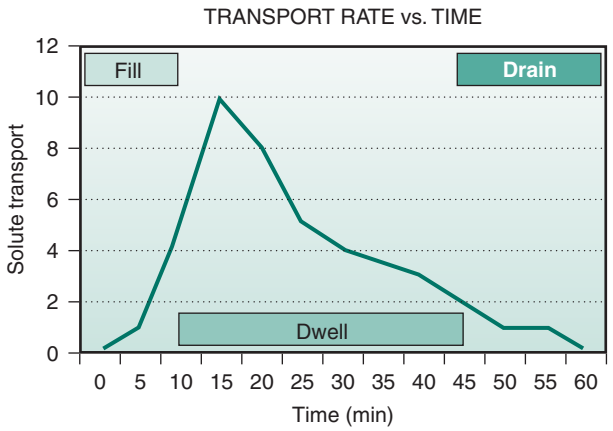

FIGURE 187.1 An idealized peritoneal dialysis exchange: Solute flux is poor during inflow/outflow and falls off rapidly during dwell as concentration gradient dissipates.

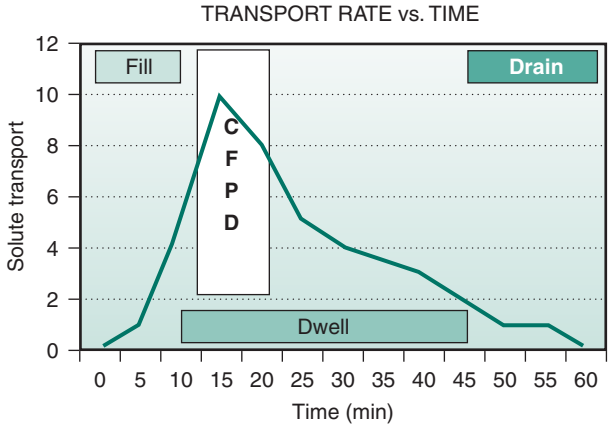

FIGURE 187.2 Continuous-flow peritoneal dialysis (CFPD) operates at maximal concentration gradient, greatly improving solute flux.

by externally purifying the dialysate with a hemodialysis (or sorbent) system in recirculation mode. In either case the net effect is to lower C_D and to keep it low throughout the treatment. This greatly enhances clearance and allows the system to perform up to the level of its inherent permeability/blood flow limitations (Fig. 187.2). CFPD has been modeled mathematically in vitro and in vivo.[3] Clearance approaches the MTAC as intraperitoneal solute concentration approaches zero. Clearance varies with intraperitoneal volume, rate of dialysate flow through the peritoneum (Q_P), and efficiency of the external regenerating circuit, which in turn depends on external dialysate flow rate or Q_D (Fig. 187.3).

HISTORICAL PERSPECTIVE

Our work in CFPD is based largely on the pioneering observations of James A. Shinaberger et al.,[4] who in 1965 reported on the first successful series of patients treated with this technique. They compared intermittent PD (IPD), then the standard of care, with CFPD in five patients. They used two catheters, one placed deep within the pelvis and the other near the diaphragm. A 2-L to 3-L intraperitoneal reservoir was drained via the pelvic catheter, recirculated through a primitive extracorporeal circuit consisting of a twin-coil dialyzer sitting in a 50-L vat of dialysate, and returned to the patient through the subdiaphragmatic catheter (Fig. 187.4).

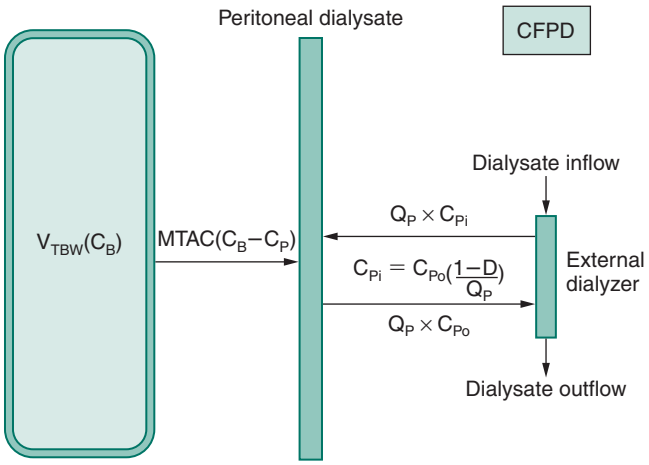

FIGURE 187.3 The continuous-flow peritoneal dialysis (CFPD) two-compartment model with solute transport across the peritoneal membrane governed by peritoneal mass-transfer area coefficient (MTAC) and the concentration gradient across the membrane. External clearance depends on rate of dialysate flow through the peritoneum (Q_P) and the dialysance (D) of the external circuit. C_B, Solute concentration in the blood; C_D, solute concentrate in the dialysate; C_{Pi}, solute concentration in peritoneal inflow; C_{Po}, solute concentration in peritoneal outflow; Q_D, external dialysate flow rate; V_{TBW}, volume of total body water. (Courtesy Frank Gotch.)

Dialysate flow was varied between 20 and 300 mL/min. At flows of 200 to 300 mL/min, urea clearances ranging from 46 to 125 mL/min were obtained.

Other researchers reported experiences over the next 15 years using different setups and home-built dual catheters.[5–10] Most of these investigators reported urea clearances of around 30 mL/min. The 1980s were dominated by continuous ambulatory PD (CAPD) and continuing cycling PD (CCPD), and little work was done on CFPD until the mid-1990s, which coincided with the end of the honeymoon with CAPD. At that time, CFPD was rediscovered.[11–15]

TECHNIQUE

CFPD can be performed in single-pass mode using sterile dialysate or in recirculating mode with external purification. A peritoneal flow rate (Q_P) of at least 100 mL/min requires 6 L of dialysate per hour, or 60 L per 10-hour treatment. This is a prohibitively large volume, both from the practical perspective of cost and because of the potential for clinically significant protein losses. An exception is in pediatric ARF, in which delivered volumes are much lower (see later). Recirculation of sterile dialysate with external regeneration is the only practical approach to CFPD in the acute (or chronic) setting. Although sorbent-based systems can and have been used,[16] we and most others have preferred hemodialysis technology to regenerate dialysate. Any hemodialysis machine can be adapted for CFPD.

As with all forms of renal replacement therapy, access is crucial. This is particularly true in CFPD, in which there is great potential for streaming of fresh dialysate directly to the draining catheter across a channel within the peritoneal fluid reservoir, generating internal recirculation and losing efficiency (Fig. 187.5).[17] A dual-lumen catheter would have to ensure minimal streaming and maximal mixing of fresh dialysate with dwelling volume. Drainage from a pelvic catheter (à la Shinaberger) with return through a diffuser positioned near the diaphragm should provide this situation

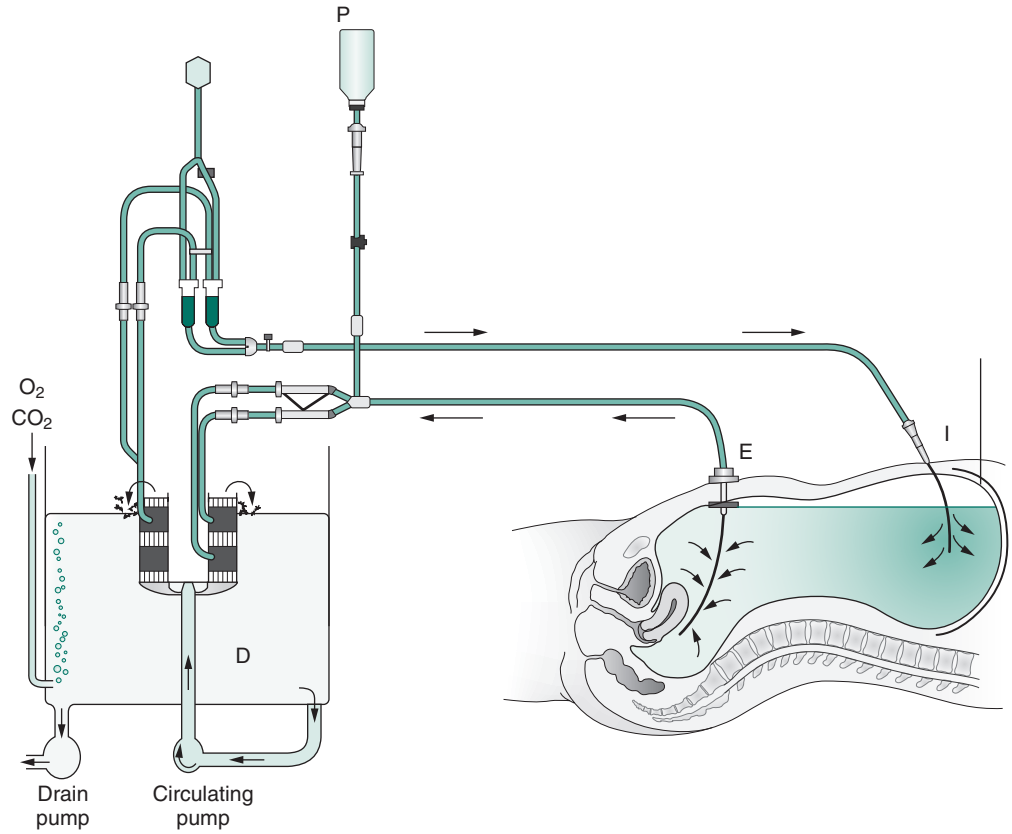

FIGURE 187.4 Original setup for continuous-flow peritoneal dialysis, with two catheters and an external circuit consisting of a twin-coil dialyzer in a vat of dialysate. *D,* External dialysate; *E,* outflow catheter; *I,* inflow catheter; *P,* peritoneal dialysate. (Modified from Shinaberger JH, Shear L, Barry KG. Peritoneal-extracorporeal recirculation dialysis: a technique for improving efficiency of peritoneal dialysis. *Invest Urol.* 1965;2:555–565.)

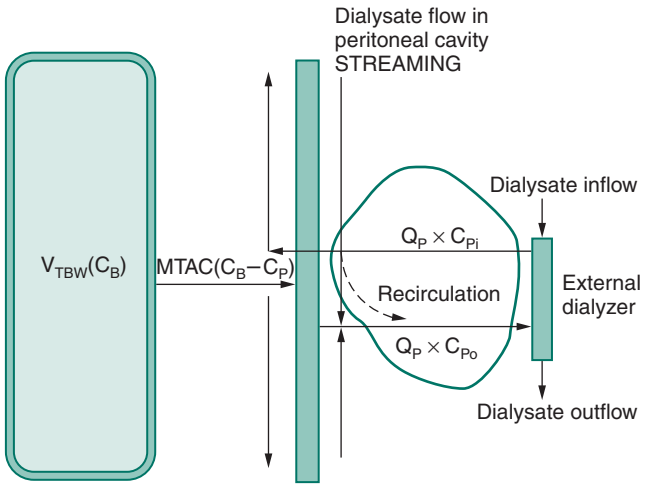

FIGURE 187.5 Intraperitoneal recirculation, or "streaming," detracts from the efficiency of continuous-flow peritoneal dialysis. C_B, Solute concentration in the blood; C_D, solute concentrate in the dialysate; C_{Pi}, solute concentration in peritoneal inflow; C_{Po}, solute concentration in peritoneal outflow; *MTAC,* mass-transfer area coefficient; Q_D, external dialysate flow rate; Q_P, rate of dialysate flow through the peritoneum; V_{TBW}, volume of total body water. (Courtesy Frank Gotch.)

(Fig. 187.6). We currently are testing a catheter designed for chronic CFPD that eventually could serve in the ICU setting (Fig. 187.7).[18] In the interim, acute CFPD can be performed successfully through the use of two catheters placed percutaneously or surgically. Care should be taken to position the intraperitoneal ports as far away from each other as possible. A short, straight Tenckhoff catheter oriented toward the diaphragm and a swan-neck coiled catheter in the pelvis can be placed through the same incision.[19]

Once access is obtained, 1.5 to 3.0 L of sterile dialysate is infused, depending on patient size, body habitus, and ventilator parameters. If tolerated, larger volumes are preferred because they are associated with less chance of streaming, and more membrane surface area is in contact with dialysate. If cells or fibrin are present (e.g., if the patient has ascites), heparin, 2000 U/L, should be added to prevent clotting in the dialyzer. The catheters are connected via standard saline-primed hemodialysis tubing to the machine, and purification of the dialysate is initiated through an artificial kidney at 200 to 300 mL/min. External clearance is optimal with a 1.5- to 2.0-m^2 kidney and Q_D of 500 mL/min.[20]

Ultrafiltration remains a challenge in recirculating CFPD. With single-pass CFPD, Cruz et al.[14] and Freida et al.[21] achieved ultrafiltration rates of 16 mL/min and 2 to 8 mL/min with 1.5% and 1.36% dextrose, respectively. In recirculating mode, the external dialysis rapidly removes dextrose and its osmotic gradient. A true CFPD machine would deliver a constant glucose concentration, controlled by the external dialysate composition. Ideally

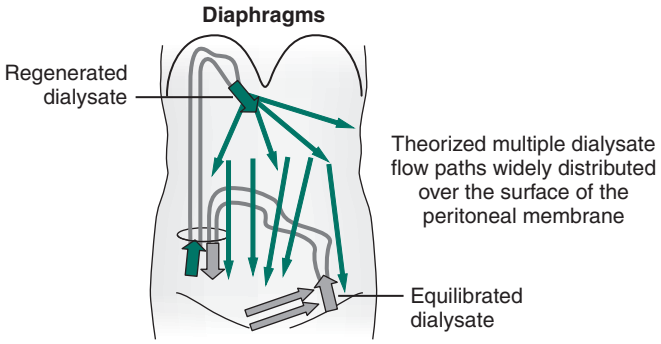

FIGURE 187.6 Ideal port position to limit intraperitoneal streaming. (Courtesy Frank Gotch.)

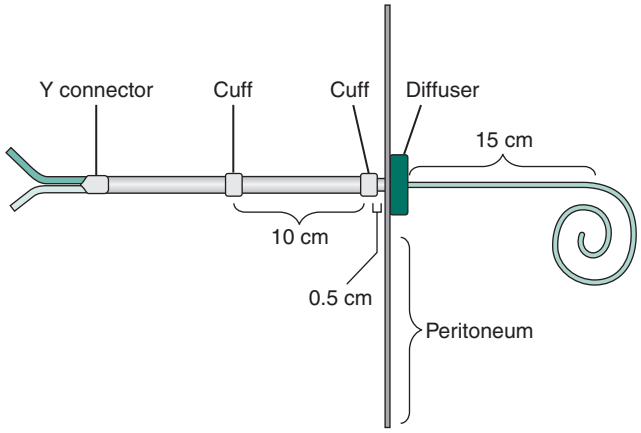

FIGURE 187.7 Dual-lumen catheter design with coiled intrapelvic drain port and subperitoneal diffuser. (Courtesy Claudio Ronco.)

this could be varied to produce different rates of internal (transperitoneal) ultrafiltration. External ultrafiltration rate can then be matched roughly by assessing intraperitoneal pressure. Because standard dialysis machines are not equipped for this requirement, alternative approaches are required. One approach is simply to interrupt CFPD with a 2- to 6-hour exchange using 4.25% dextrose solution, or icodextrin. Another would be to combine CFPD with peripheral venovenous hemofiltration. Our experience with CFPD in ARF (see later in chapter) has been limited to patients with ascites.[22] In this setting, ultrafiltration of ascites via the external circuit is straightforward. The subsequent concentration of protein within the residual ascites effectively "pulls" peripheral edema, and net fluid removal is accomplished.

Monitoring a CFPD treatment requires some attention. It is a low-resistance circuit, so "arterial" and "venous" pressures on the dialysis machine should be near zero. On a true CFPD machine, these sensors would be recalibrated to optimally detect pressures in the range of 0 to 20 cm H_2O. Ultrafiltration is assessed from changes in patient weight. Clearance can be measured directly in single-pass CFPD by collecting the dialysate, measuring the urea nitrogen and/or creatinine concentration, dividing this number by the average BUN or creatinine concentration during the treatment, and multiplying the result by the total drained dialysate volume. In recirculation mode, we measure BUN before and after dialysis and apply the Daugirdas equation to estimate Kt/V.[23] Urea clearance (K_u) can be calculated by substitution of an estimated body water volume (V) into the equation.

CONTINUOUS-FLOW PERITONEAL DIALYSIS IN PEDIATRIC ACUTE RENAL FAILURE

Renal replacement therapy in children differs from that in adults because of the variation in size and weight of the patients as well as child-specific indications such as inborn errors of metabolism. It requires special expertise because of the lower incidence of pediatric ARF and the size-specific modes of treatment.[24]

Acute PD is used frequently in pediatric ARF and is regarded by many authorities as the preferred modality.[25] It is the preferred modality in newborns and young infants because of excellent peritoneal permeability of this modality as opposed to the difficulties with vascular access and the risk of bleeding or hypotension associated with an extracorporeal circulation. Peritoneal catheters, adapted to the size of the infant, can be placed at the bedside or in an operating room, to avoid compromising a child's limited vasculature.[26] Common indications for acute PD in the pediatric ICU are refractory volume overload, severe or symptomatic uremia, and major electrolyte or acid-base disturbance. This modality is well suited to patients who are hemodynamically unstable because it achieves gentle fluid removal and its performance is largely independent of blood pressure.[27]

Two major disadvantages of PD in the child are (1) relatively poor solute clearance and (2) marked variation in intraabdominal volume and pressure with possible impairment of ventilation. The latter problem often forces a reduction in dwell volume with further loss of clearance.[28] Both problems are addressed by CFPD.

Sagy and Silver[29] treated six patients aged 18 ± 37 months who had acute respiratory distress syndrome by means of single-pass CFPD using two tunneled Tenckhoff catheters placed surgically and 2.5% dextrose solution. The patients had been ventilated for an average of 8 days before treatment was initiated and were in strongly positive fluid balance. Q_P was 10 to 30 mL/kg/hr and adjusted as needed in increments of 10 mL/kg/hr up to a maximum of 50 mL/kg/hr. Average duration of treatment was 126.7 ± 60.0 hours. These researchers achieved effective ultrafiltration in all patients (3.1–20 mL/kg/hr), resulting in an average of 30% ± 12% weight reduction and a significant improvement in respiratory parameters. There were no episodes of peritonitis. Mechanical outflow problems were managed by reversing the direction of flow. Intravenous albumin was given to blunt the effect of protein losses. Two of the six patients died; the researchers believed this ratio to be an improvement over expected outcome with standard therapy.

Vande Walle et al.[30] reported their experience treating 28 children with CFPD for ARF in the post–cardiac surgery setting. They used two catheters and a minimal dwell volume. Creatinine and urea clearance values were more than twice those achieved with standard PD. Ultrafiltration also was higher.

We are planning a study of single-pass CFPD in neonatal and infant ARF. Because the typical exchange volume in a patient of this size is 200 to 400 mL, regeneration of dialysate does not make sense. Rather, a controlled continuous infusion of 1.5% dextrose will be employed. Two pediatric peritoneal catheters will be placed surgically with one oriented cephalad and the other caudad. Intraperitoneal pressure will be monitored continuously with a transducer attached to the inflow port. Inflow will be controlled with an infusion pump, and outflow by gravity with bag height adjustment to maintain a constant intraperitoneal pressure. A Q_P of 0.5 L/hr should deliver excellent dialysis at the cost of a single 10-L bag of dialysate per day.

CLINICAL EXPERIENCE WITH CONTINUOUS-FLOW PERITONEAL DIALYSIS IN ACUTE RENAL FAILURE

We have had two experiences treating ARF with CFPD. ARF developed in both patients during hospitalization in the ICU, although one patient was stable enough to be transported to the inpatient dialysis unit for treatment. Both had considerable ascites, which facilitated catheter insertion and ultrafiltration. Both underwent percutaneous insertion of pigtail catheters in opposing lower abdominal quadrants by ICU physicians. We used the Fresenius 2008H dialysis machine (Fresenius Medical Care, Bad Homburg, Germany) in CRRT mode and an F80 artificial kidney (Fresenius Medical Care, Bad Homburg, Germany).

Patient 1 was a 66-year-old woman with ARF in the setting of a thyroid storm, multi-drug–resistant sepsis, anasarca, ascites, severe hypoalbuminemia, and marked hemodynamic instability. She was unable to tolerate an ultrafiltration of 100 mL/hr via slow hemodialysis. She underwent two CFPD treatments with the following parameters: Q_P 200 mL/min, Q_D 100 to 300 mL/min, and ultrafiltration rate 50 to 200 mL/hr. In the first treatment, 3.6 L were removed in 24 hours. The BUN value decreased from 54 to 22 mg/dL, for a urea reduction ratio of 59%. Applying the Daugirdas equation yielded a Kt/V of 1.11 and a urea clearance (V = 40 L) of 31 mL/min. The procedures were well tolerated, but peritonitis developed and the catheters were removed. The patient died about a month later, with no further attempts at renal replacement.[22]

Patient 2, a 65-year-old man with cirrhosis, had acute renal failure, likely from drug-induced allergic interstitial nephritis. He presented with oliguria, severe ascites, and peripheral edema, all of which were refractory to diuretics. He underwent 3 consecutive days of CFPD, for 5 to 8 hours a day via percutaneous pigtail catheters placed in the ICU (Figs. 187.8 and 187.9). Q_P was 250 to 300 mL/min, Q_D 500 mL/min, and ultrafiltration flow rate 400 to 500 mL/hr. More than 10 kg of fluid was removed by ultrafiltration of the ascites during the treatment. The patient was hemodynamically stable throughout. Urea clearance averaged 50 mL/min (Table 187.1), and BUN and creatinine concentrations declined with each treatment (Fig. 187.10). The catheters were removed after 3 days. The patient's renal function recovered, and he was transferred to another institution for liver transplantation.

In the dialysis of ascitic fluid, as in these two cases, clearance of the blood compartment is delayed by 30 to 60 minutes, the time it takes to remove enough solute from the ascitic fluid to create a diffusion gradient across the peritoneal membrane (Figs. 187.11 and 187.12).

FIGURE 187.8 Patient 2 with dual pigtail catheters attached to dialysis machine for continuous-flow peritoneal dialysis in the inpatient dialysis unit.

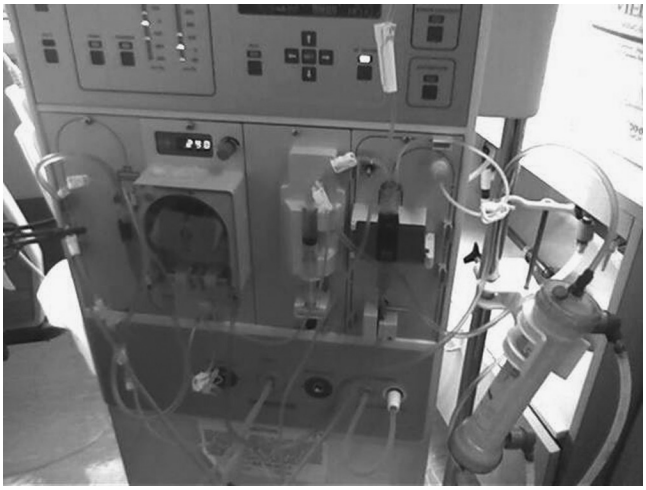

FIGURE 187.9 Continuous-flow peritoneal dialysis in progress in Patient 2 with a Fresenius 2008H dialysis machine (Fresenius Medical Care, Bad Homburg, Germany).

TABLE 187.1

Summary of Three Continuous-Flow Peritoneal Dialysis Treatments in Patient 2[a]

DATE	ULTRAFILTRATE VOLUME (L)	URR (%)	Kt/V	VOLUME (mL)[b]	TREATMENT TIME (min)	TOTAL UREA CLEARANCE (mL/min)
9 Nov	2	18	0.26	72,000	354	52.88
10 Nov	3.7	23	0.35	70,000	485	50.52
11 Nov	4.4	18	0.29	68,000	400	49.30

[a]Kt/V was calculated from predialysis and postdialysis blood urea nitrogen concentrations using the Daugirdas 23 equation. Average urea clearance was 50 mL/min. *URR,* urea reduction ratio.
[b]Volume = TBW volume estimated as weight in ks × 0.6.

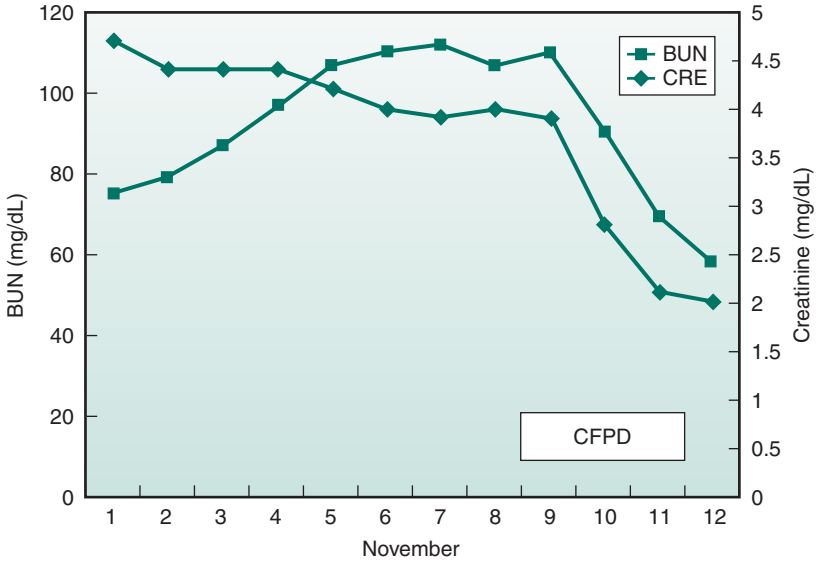

FIGURE 187.10 Evolution of blood urea nitrogen (BUN) and creatinine (CRE) concentrations in Patient 2, who has acute renal failure, with 3 consecutive days of treatment with continuous-flow peritoneal dialysis (CFPD).

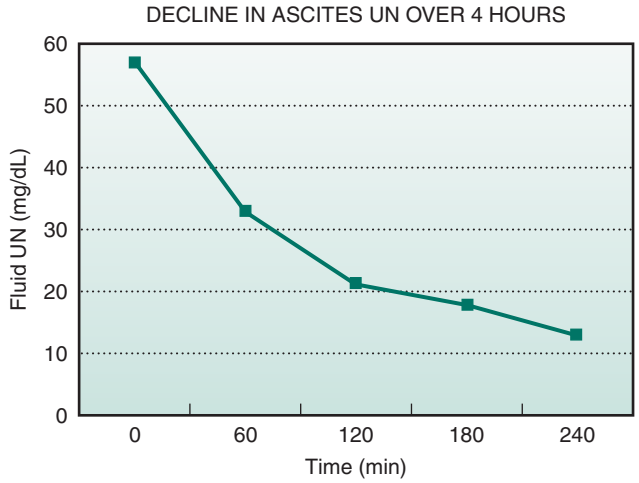

FIGURE 187.11 Decline in ascitic urea nitrogen (UN) concentration takes up to 60 minutes, delaying the onset of significant transperitoneal solute clearance.

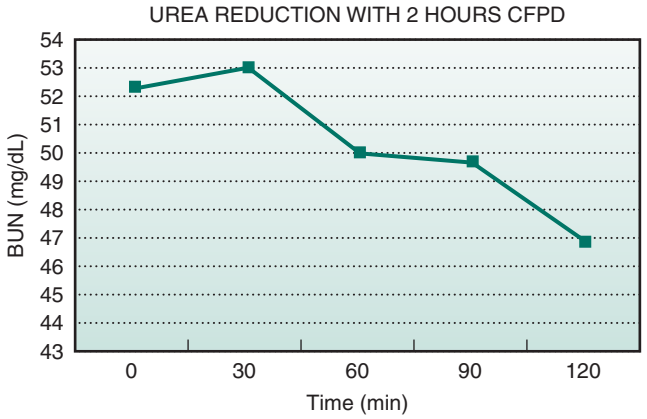

FIGURE 187.12 Decline in blood urea nitrogen (BUN) concentration with continuous-flow peritoneal dialysis (CFPD) of ascites delayed because of the need to lower ascitic UN.

ADVANTAGES AND INDICATIONS FOR CONTINUOUS-FLOW PERITONEAL DIALYSIS IN ACUTE RENAL FAILURE

CFPD combines the safety, simplicity, and hemodynamic stability of PD with the clearance of continuous venovenous hemofiltration or hemodialysis. CFPD should be the preferred renal replacement therapy in the unstable patient, particularly if blood access is problematic. Pediatric ARF is, we believe, an ideal indication. Other likely indications are ARF associated with ascites, acute pancreatitis, congestive heart failure with hemodynamic instability, and bleeding diathesis. In the patient with pancreatitis, single-pass CFPD should initiate treatment to effectively lavage the peritoneum.

Once ultrafiltration control is perfected, CFPD would be appropriate for any form of ARF in which peritoneal access is possible. Disadvantages are the requirement for two catheters or a double-lumen catheter, and the previously mentioned issues surrounding ultrafiltration. Other risks are exactly those of standard PD: peritonitis, mechanical drainage issues, transdiaphragmatic leakage, viscus perforation, and hyperglycemia.

CONCLUSION AND FUTURE DIRECTIONS

CFPD has great promise for treatment of ARF, especially in children with ARF, in whom the peritoneal route has significant advantages, and relatively low fluid requirements permit the single-pass mode to be used. The ability to offer clearances comparable to that for other forms of continuous renal replacement therapy, with the safety of peritoneal rather than blood access, makes a compelling argument to pursue this therapy. Ultrafiltration and access issues will be worked out "in the field," and it is hoped that machine manufacturers will add modifications to permit CFPD. Sorbent-based dialysis systems also could be adapted easily, as could hemodiafiltration machines that manufacture sterile dialysate.[31] Use of CFPD in the outpatient setting also is being investigated but is beyond the scope of this text.

Key Points

1. The technique of traditional peritoneal dialysis underuses the transport characteristics of the peritoneal membrane. Continuous-flow peritoneal dialysis overcomes these limitations by maximizing transperitoneal solute gradients throughout the treatment cycle.
2. Continuous-flow peritoneal dialysis has been used clinically since 1965 but was replaced by the much simpler continuous ambulatory peritoneal dialysis approach.
3. Continuous-flow peritoneal dialysis offers considerable advantages over standard peritoneal dialysis in the treatment of acute renal failure, particularly in pediatric patients.
4. This modality requires a dual-lumen catheter (or two catheters) capable of delivering the high flow rates of peritoneal dialysate. Treatment mode can be either single-pass or recirculating, with external regeneration of dialysate.
5. Continuous-flow peritoneal dialysis has been used successfully for treatment of acute renal failure in children and adults.

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A complete reference list can be found online at ExpertConsult.com.

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