CHAPTER 184

Clinical Results and Complications of Peritoneal Dialysis in Acute Kidney Injury

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OBJECTIVES

This chapter will:

1. Explore the role that peritoneal dialysis may play in the management of acute kidney injury in the current era.
2. Discuss some of the clinical trials of peritoneal dialysis in acute injury vis à vis the other modalities of treatment, namely, intermittent hemodialysis and continuous renal replacement therapy.
3. Describe the complications of acute peritoneal dialysis.

Acute kidney injury (AKI) is a common condition often underdiagnosed and with an increasing incidence worldwide. It is associated with increased early and long-term morbidity and mortality.[1] Over the last two decades, the once-common treatment, peritoneal dialysis (PD), for AKI has become sidelined by newer, more technologically advanced treatments such as continuous renal replacement therapy and hemodialysis.[2]

In recent reviews of the literature on the dose of dialysis for AKI and in the KDIGO guidelines for AKI, PD was not mentioned as a potential modality[2–4] because its use in the developed world is minimal. Even in the pediatric community, where PD originally was the preferred treatment of choice,[5] the preferential use of continuous therapies appears to be increasing with a diminishing role for PD.

Some of the major concerns about PD include unpredictable solute and fluid removal, risk of peritonitis, diaphragmatic splinting with possible compromise of ventilation, and fluctuations in glycemic control.[6] These concerns were highlighted by a randomized trial conducted in Vietnam and published in the *New England Journal of Medicine* in 2002 that suggested a higher mortality rate in AKI patients treated with PD than in patients treated with continuous venovenous hemofiltration (CVVH).[7] With this apparent underutilization of peritoneal dialysis in AKI, at least in developed countries, there has been a scarcity of data in the literature, and most studies of this modality date back to the 1980s and 1990s.[9] However, this impression may be misleading because of underreporting of current practices in other parts of the world. In developing countries, the epidemiology of AKI, although beginning to follow the spectrum of the more developed nations, still demonstrates a significant number of cases of AKI secondary to medical causes such as dehydration; infections such as leptospirosis, malaria, and dengue fever; and to drugs such as herbal medication.[9,10]

PD, which uses a simple technology that is easily accessible and relatively less costly, is being used for the management of AKI in many developing countries that lack resources for more technologically advanced equipment and highly trained personnel. Thus PD still constitutes the mainstay of therapy in many of the developing countries.[10–14]

Chow et al. compared cases of AKI in a single center in Malaysia during two time periods (1994 and 2004); they found that the cause of AKI and the dialysis modality remained unchanged over that 10 years.[14] Prerenal acute renal failure (ARF) accounted for 43.6% of cases in 1994 and 53.5% of cases in 2004, and PD was the main dialysis modality in both time periods (used in 69.2% and 74.3% of cases, respectively).[14]

In 2007 Gabriel et al. from Sao Paolo, Brazil, reignited interest in PD for AKI with a series of innovative publications in which they used randomized trial designs to demonstrate the efficacy of peritoneal dialysis and to show that treatment with PD was as good as extracorporeal blood purification techniques.[15,16] Publications from other developing countries such as India, Nepal, and sub-Saharan Africa also were reporting successful experiences with the use of PD in AKI.[17–19]

HISTORICAL PERSPECTIVE

The initial description of PD for the management of ARF is credited to Professor G. Ganter, a German clinical investigator who in 1923 used this technique to treat a woman with uremia and obstructive uropathy. His recommendations then formed the basis for what later became known as intermittent peritoneal dialysis (IPD).[20]

In March 1946, Fine et al.[21] reported the successful application of peritoneal dialysis in a case of antibiotic-induced ARF. This report also established the closed dialysis system as well as the constituents of the dialysis solution, use of which became the standard for peritoneal dialysis. A number of reports followed that reviewed the literature during that period and confirmed the usefulness of peritoneal dialysis in uremia.[22,23]

By the 1970s, IPD was established as an effective form of renal replacement therapy. Subsequently, as interest in PD grew, the treatment underwent further improvement, with the development of better peritoneal access and the use of automated peritoneal dialysis machines.[24]

EFFECT ON MORTALITY

There is a paucity of data concerning the effects on mortality in patients on PD for AKI.[15,25] Chionh et al.[26] recently published a detailed systematic review to describe outcomes in AKI treated with PD and also compared PD with extracorporeal blood purification techniques such as intermittent hemodialysis or with continuous renal replacement therapy.

Thirteen studies described patients treated with PD only. Eleven studies compared PD with continuous or intermittent RRT, of which seven were cohort studies and four were randomized controlled trials. Overall there was

TABLE 184.1

Randomized Controlled Studies Comparing Peritoneal Dialysis and Extracorporeal Blood Purification

Techniques for Renal Replacement Therapy			
Variable	Phu et al., 2002 (2)	Gabriel et al., 2009 (4)	George et al., 2011 (12)
Country	Vietnam	Brazil	India
Setting	ICU	Mostly ICU (77%)	ICU
Patients			
Study group *(n)*	70	120	50
Mean age (years)	35.5	63.4	46.9
Sepsis (%)	31.4	44.5	38
PD Technique			
Exchanges	Manual	Cycler	Manual
Catheter	Rigid	Tenckhoff	Rigid
Drainage	Open	Closed	Closed
Buffer	Acetate	Lactate	Acetate
PD "dose"	70 L/day	stdKt/V_{urea} 3.6/week	K_{urea} 9.4 mL/min
EBP Technique			
Type	CVVH	Daily intermittent HD	CVVHDF
Filter	Polysulfone	Polysulfone	Polysulfone
Buffer	Lactate	Bicarbonate	Acetate
EBP "dose"	Effluent volume 25 L/day	Kt/V 1.2/session	K_{urea} 21.7 mL/min
Mortality on PD [*n*/*N* (%)]	17/36 (47)	35/60 (58)	18/25 (72)
Mortality on EBP [*n*/*N* (%)]	5/34 (15)	32/60 (53)	21/25 (84)

CVVH, Continuous venovenous hemofiltration; *CVVHDF,* continuous venovenous hemodiafiltration; *EBP,* extracorporeal blood purification; *HD,* hemodialysis; *ICU,* intensive care unit; *PD,* peritoneal dialysis.
Modified from Yeates K, Cruz DN, Finklestein FO. Re-examination of the role of peritoneal dialysis to treat patients with acute kidney injury. *Perit Dial Int.* 2012; 32(3):238–241.

no difference in mortality between PD and extracorporeal blood purification therapies in the observational studies (OR 0.96, 95% CI, 0.53–1.71) and the four randomized controlled trials (OR, 1.5: 95% CI, 0.46–4.86).[26]

Among the four randomized controlled trials, two compared PD with continuous therapies, whereas the third compared PD with daily intermittent HD. The fourth RCT randomized to either PD or intermittent HD had only eight patients with AKI.[25]

Phu et al.[7] conducted an open randomized trial comparing continuous venovenous hemofiltration (CVVHDF) with peritoneal dialysis in patients with infection-associated AKI; 48 of the patients had falciparum malaria, and 22 were septic. The mortality was significantly higher in patients treated with peritoneal dialysis (47%) than in those patients treated with CVVH (15%; $p < .005$). The CVVH group had a significantly lower mortality (15%) in spite of a lower dose of replacement fluid (24 L/day) in relation to current practice. Some adverse factors in the peritoneal dialysis group such as the use of acetate as buffer, the use of rigid catheters, presence of a cloudy dialysate suggesting infection in 42% of patients, and other technical and specific factors could have attributed to the poorer outcome in the PD group.[15,27] These factors must be considered before one can conclude that peritoneal dialysis is inappropriate for infection-associated AKI.[27,28] In contrast to this study, Mishra et al., in retrospective study of patients with cerebral malaria and AKI, showed no difference in survival between patients treated with PD versus daily HD despite patients in the PD cohort having a higher number of patients with cerebral malaria.[17]

George et al. performed a randomized study comparing CVVHDF and PD in critically ill patients looking at solute control and fluid overload.[29] Although urea, creatinine clearance, and the control of fluid overload was better with CVVHDF, acidosis was better controlled with PD. The mortality rates between the two groups were similar.[29]

Gabriel et al. performed a randomized controlled trial comparing HVPD (high-volume peritoneal dialysis) with daily intermittent HD. Both modalities achieved metabolic and acid-base control, and mortality did not differ significantly between the two groups (Table 184.1 and Fig. 184.1).[30]

Ponce et al. then compared the effects of HVPD with prolonged or extended HD (PHD) in a prospective study in patients with AKI.[31] Although the delivered Kt/V and ultrafiltration was higher in the PHD group, there was no difference in mortality or in renal recovery.

Ponce et al. recently reported a prospective cohort study in which all AKI patients on PD were studied between January 2004 and January 2014.[32] For comparison, patients were divided into two groups according to the year of treatment: 2004 to 2008 and 2009 to 2014. A total of 301 patients were included in the study. There was an improvement in patient survival and technique failure (TF) with a relative risk reduction (RR) of 0.86 (95% CI, 0.77–0.96) in patients treated during 2009 to 2014 compared with patients treated between 2004 and 2008. This improvement was thought to be related to better fluid control and improved management of PD-related infections.[32]

DIALYSIS ADEQUACY

Traditionally, IPD has been held to be potentially inadequate to control azotemia, especially in hypercatabolic patients.[32] This perception was reflected in a survey among nephrologists to determine modalities in the treatment of AKI; 90% of those surveyed believed that solute clearance with peritoneal dialysis was inadequate.[34]

In contrast to these expectations, however, a number of early studies evaluating peritoneal dialysis in patients with AKI who were deemed hypercatabolic reported satisfactory control of fluid and metabolic derangements.[35–39] These studies had major limitations. The majority of the study populations were small in numbers, were not randomized, and did not use appropriate measurements of dialysis adequacy and catabolic rate.[28]

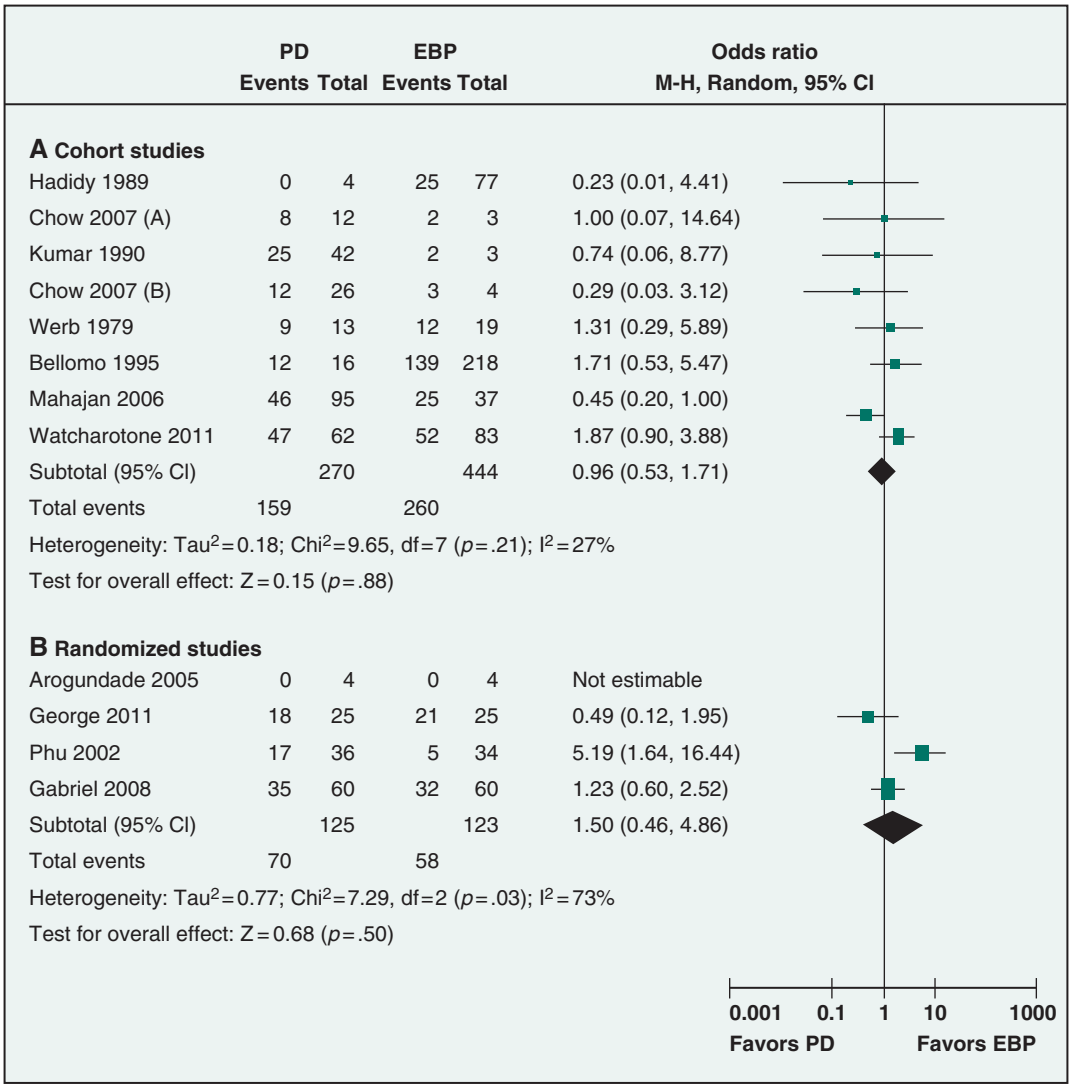

FIGURE 184.1 Effect of renal replacement therapy modality on mortality inpatients with AKI by study design. The pooled odds ratio with 95% confidence interval (95% CI) was calculated using Mantel-Haenzel (M-H) random effects. A, Cohort studies. B, Randomized studies. *EBP,* Extracorporeal blood purification; *PD,* peritoneal dialysis. (Modified from Chionh CY, Ronco C, Finklestein FO, et al. Use of peritoneal dialysis in AKI: A systematic review. *Clin J Am Soc Nephrol.* 2013;8(10):1649-1660.)

Chitalia et al.[10] conducted a randomized, prospective, crossover trial comparing adequacies of tidal peritoneal dialysis (TPD) with continuous equilibration peritoneal dialysis (CEPD) in 87 patients with mild to moderate hypercatabolic AKI (Table 184.2). Compared with CEPD, TPD produced higher solute clearance in a smaller dialysis volume. Comparing adequacy indices (Kt/V, normalized creatinine clearances, solute reduction indices), these investigators concluded that TPD and CEPD are reasonable options for mild to moderate catabolic AKI, even though CPD fell short of the adequacy standard. Because TPD offers better clearances at lower cost and time, developing countries that have access to PD cyclers should consider TPD for the treatment of hypercatabolic AKI. However, one of the limitations of the study was that the patient base was different from most of the studies dealing with hypercatabolic AKI; therefore the results may not be applicable to critically ill patients, especially in developed countries. The major limitation of the use of TDP is the high protein loss.

The study by Phu et al. mentioned earlier demonstrated that the rate of resolution of acidosis as well as the decline

TABLE 184.2

Adequacies of Both Tidal Peritoneal Dialysis and Continuous Equilibration Peritoneal Dialysis in 87 Patients With Mild to Moderate Hypercatabolic Acute Renal Failure

PARAMETER	TPD (MEAN)	CEPD (MEAN)
Urea clearance (mL/min)	19.85 + 1.95	10.63 + 2.62
Creatinine clearance (mL/min)	9.94 + 2.93	6.74 + 1.63[a]
Kt/V	2.43 + 0.87	1.8 + 0.32

[a] $p < .001$

CEPD, Continuous equilibration peritoneal dialysis; *TPD,* tidal peritoneal dialysis.

From Chitalia AC, Almedia AF, Rai H, et al. Is peritoneal dialysis adequate for hypercatabolic acute renal failure in developing countries? *Kidney Int.* 2002;61:747–757.

TABLE 184.3

Reported Indicators of Dose of Peritoneal Dialysis

REFERENCE	STD-KT/V_{UREA} (PER WK)	K_{UREA} (mL/MIN)	K_{CR} (MI.MIN)	PD VOLUME (L/D)
Ponce (40)	3.5 ± 0.68	NA	NA	32.0–44.0
Kilonzo (18)	NA	NA	NA	7.5
Ponce D (43)	3.6	NA	NA	NA
George (29)	NA	9.4 ± 4.9	10.5 ± 6.1	NA
Gabriel (30)	3.6 ± 0.6	16.1 ± 4.0[a]	NA	42.8 ± 5.72[a]
Gabriel (16)	3.9 ± 0.6	17.3 ± 5.0	15.8 ± 4.2	43.2 ± 5.1[a]
Arogundade (78)	NA	NA	8.1 ± 2.8	8.0 ± 0.6
Phu (7)	NA	NA	NA	70
Chitalia (10)	1.8–2.4	10.6–19.8	5.8–6.8	13.0–26.3

Dose is represented by the standardized weekly Kt/V_{urea} (std-Kt/V_{urea}), urea clearance (K_{urea}), creatinine clearance (K_{Cr}), and volume of PD effluent per day (PD volume). From Chionh CY, Ronco C, Finklestein FO, et al. Use of peritoneal dialysis in AKI: A systematic review. *Clin J Am Soc Nephrol.* 2013;8(10):1649-1660.

[a]Information obtained from correspondence with author.

in serum creatinine was more than twice as high in the hemofiltration group as in the peritoneal dialysis group ($p < .005$).[7] However, solute clearance and dialysis adequacy were not reported in the two study groups.

To overcome some of the limitations of PD use in AKI such as low solute clearance, especially in hypercatabolic patients and the unpredictable fluid removal, Gabriel et al.[16] proposed the use of cyclers, flexible catheters, and high volumes of dialysis fluids. In 2007 these investigators assessed the efficacy of high-volume PD (HVPD) in a prospective study of 30 patients, of whom 66% were in the intensive care with AKI. PD was performed using a flexible Tenchkoff catheter with an automated PD cycler with a prescribed Kt/V of 0.65 per session (24 hours). HVPD was found to be effective in correcting uremia, metabolic acidosis, and fluid overload. The weekly delivered Kt/V was 3.8 ± 0.6, and the mortality rate was 57%. The investigators concluded that HVPD was a viable alternative to other forms of RRT for AKI.[16]

In 2012 the same investigators performed another prospective study on 204 patients with AKI treated with HVPD (prescribed Kt/V 0.6/session). Sepsis was the main cause of AKI (54.7%), and 70% of the patients were in the intensive care unit. Urea and creatinine levels stabilized after four sessions, and the delivered weekly Kt/V was 3.5±0.68. With respect to AKI outcomes, the mortality rate was 57.3%, and 23% had renal recovery. They concluded that in selected patients, HVPD was effective in relation to metabolic and fluid control.[40]

DIALYSIS DOSE

There are also limited data on the appropriate of dose of PD for AKI.[41] Gaiao et al.'s survey regarding the use of PD in AKI among delegates at three dialysis congresses found that 70% of the respondents were not certain of the appropriate dose for AKI in ICU and 66% in the wards.[42]

In the study by Chitalia et al. mentioned earlier, TPD was more efficient than CEPD, achieving a significant higher weekly Kt/V of 2.43-± 0.87 versus 1.80 ± 0.32, respectively, with excellent outcome.[10]

Gabriel et al. conducted a prospective randomized controlled trial to compare the effect of high-volume peritoneal dialysis (HVPD) with daily dialysis (DHD) on patients with AKI. A total of 120 patients were assigned to either HVPD or DHD. The weekly delivered Kt/V was 3.6 ± 0.6 in HVPD arm and 4.7 ± 0.6 in DHD arm ($p < 0.01$), and they reported comparable outcomes.[30]

Ponce et al. then followed up with a prospective randomized trial of 61 critically ill patients with sepsis and AKI comparing two levels of intensity of HVPD. They were randomized to receive a higher dose (n = 31) versus lower dose (n = 30) of PD therapy (prescribed Kt/V 0.8/session versus 0.5/session).

The lower-dose group achieved a Kt/V of 3.43, whereas the higher-dose group achieved a Kt/V of 4.13. However, the mortality rate of both groups was similar after 30 days (55% vs. 53%, $p = 0.83$), thus showing no added benefit using higher dose of therapy.[43]

Chionh et al. in a recent review of PD dose in AKI recommended that continuous forms of PD should be prescribed with a minimum standardized Kt/V urea of at least 2.1 per week. However, the optimal dose for PD in AKI is still unclear (Table 184.3).[25,26]

RENAL RECOVERY

Recovery of renal function after an episode of AKI is an important determinant of morbidity. In many of the older studies comparing peritoneal dialysis with hemodialysis for AKI, the reason for improved survival in the peritoneal dialysis group was related to a higher rate of renal recovery.[44] Several published reports suggest that patients with AKI secondary to atheroembolic disease may have a better chance of renal recovery with peritoneal dialysis than with hemodialysis.[45] The reasons for the apparent benefit were attributed to less hemodynamic fluctuation and the absence of anticoagulation during peritoneal dialysis. It also has been suggested that there is a more rapid recovery of renal function in AKI patients treated with PD. However, some of the published reports show conflicting results. One Brazilian study showed shorter time to renal recovery with PD compared to daily HD[30]; however, studies from India and Vietnam noted patients on PD required more or longer dialysis sessions.[7,29]

Katz et al.,[46] who conducted a retrospective study in patients with AKI secondary to malignant hypertension, reported that 55% of patients undergoing peritoneal dialysis recovered renal function, compared with none undergoing hemodialysis. This finding suggests that peritoneal dialysis may be beneficial in patients whose AKI is due to malignant hypertension. Unfortunately, the rate of renal recovery is not reported in many of the other studies.

LACTATE VERSUS BICARBONATE-BUFFERED SOLUTIONS

There is one randomized controlled trial from the Cochrane database that compared the effectiveness of bicarbonate versus lactate-buffered PD solutions in 20 AKI patients and found no difference between bicarbonate and lactate with respect to mortality and other adverse events. However, for patients in shock, a more rapid increase in serum bicarbonate was seen using bicarbonate-buffered solutions (21.2. ± 1.8 mmol/L vs. 13.4 ± 1.3 mmol/L) compared with lactate-based solutions. These results suggest that patients with AKI associated with shock should be managed using bicarbonate-buffered solutions rather than lactate.[47]

FUTURE TRENDS

There is now renewed interest in continuous-flow peritoneal dialysis, which can provide higher solute clearances.[48] Several small clinical studies using this modality reported better peritoneal clearances for urea and creatinine than with conventional peritoneal dialysis.[49,50] With continuous-flow peritoneal dialysis, dialysate flow rates up to 300 mL/min can be maintained through the peritoneum, and this modality may become an attractive alternative in the intensive care unit for the treatment of AKI.[51] Ponce et al. used CFPD in two adult AKI patients and achieved a clearance similar to that reported with extracorporeal blood purification methods and an ultrafiltration rate of 200 to 500 mL/hr.[52]

COMPLICATIONS OF ACUTE PERITONEAL DIALYSIS

Although acute peritoneal dialysis has been described as a safe and effective form of renal replacement therapy,[53] only a few reports have been published that discuss complications of this procedure. PD is associated with a set of unique complications not dissimilar to those with CAPD, which can be classified broadly into infectious and noninfectious categories.

Infectious Complications

Peritonitis is a serious complication, with a reported incidence in up to 12% of procedures performed.[54] The risk of peritonitis frequently occurs within the first 48 hours of treatment,[53] and the leading cause of peritonitis continues to be contamination at the time of peritoneal dialysis exchange.[55]

The diagnosis of peritonitis is made on the presence of abdominal pain, cloudy dialysate, and a PD fluid leukocyte count exceeding 100 cells uL; this count is performed daily for surveillance in patients on acute PD. In resource-limited settings an alternative method is daily use of a urine leukocyte esterase dipstick test: if is more than 2+, the clinician should consider starting treatment while awaiting cultures. Small studies have shown these tests to have good sensitivity and specificity.[56,57]

In a prospective study, Valeri et al.[58] examined the epidemiology of peritonitis in acute IPD. They reported a higher incidence of peritonitis in the study subset compared with patients from the National CAPD registry.[59] There was also a higher rate of early peritonitis (<48 hours after dialysis). The use of a closed system reduced the incidence of early and system-related peritonitis. Gram-positive infections accounted for a substantial percentage of the cases of peritonitis, but in addition, there was a shift toward more gram-negative and fungal organisms, probably owing to the wide use of broad-spectrum antibiotics.[58]

In acute PD, because more rapid exchanges are performed, it has been suggested that antibiotics should be given intraperitoneally and with every exchange for more effective peritoneal penetration.[60] Occasionally, if symptoms persist, ultrasonography or computed tomography may be of value in localizing and draining infected collections in patients with peritonitis. The increasing use of automated dialysis via flexible catheter has led to a reduction in the frequency of peritonitis.[32]

Peritoneal Catheter–Related Infections

Catheter infections include exit site and tunnel infections. The use of silicon-cuffed catheters is reported to be associated with fewer complications. Exit site infections can manifest as erythema and tenderness with or without purulent discharge. On the basis of studies of CAPD, *Staphylococcus aureus* accounts for more than 50% of exit site infections, followed by *Staphylococcus epidermidis* (20%), *Pseudomonas aeruginosa* (8%), and *Escherichia coli* (4%).[61] These infections often can lead to peritonitis.

Catheter tunnel and cuff infections are generally an extension of exit site infections, and the distribution of pathogens is usually similar. Tunnel infections are associated with edema, erythema, or tenderness over the subcutaneous track with or without discharge around the exit site. Occult tunnel infections can be detected by ultrasonography of the subcutaneous pathway.

Revised guidelines for the treatment of CAPD peritonitis have been published; these guidelines also can be applied to peritonitis because of acute peritoneal dialysis and catheter-related infections.[62]

Noninfectious Complications

The noninfectious complications of peritoneal dialysis can be classified as follows: surgical, mechanical, related to increased intraabdominal pressure (IAP), metabolic complications, and noninfectious cause of cloudy peritoneal dialysate.

Surgical Complications

Postoperative bleeding around the catheter placement site is usually mild. However, more severe bleeding into the peritoneum has been reported. This complication was particularly common if the insertion was performed via a blind technique using rigid catheters. Mital et al.[63] reported a rate of 2% for major bleeding complications associated with peritoneal dialysis catheter insertion.[63] Visceral perforations of the bladder and bowel also have been reported.[64]

Mechanical Complications

Inflow pain has been attributed to the position of the catheter, solution's low pH or low temperature, the "jet flow" from a straight catheter tip, or the distention of tissue around the catheter.[65] Mactier et al.[66] conducted a randomized, double-blind, crossover study to compare the effects of novel bicarbonate and a bicarbonate/lactate solution in patients

who experienced infusional pain with the current lactate solution. Both new solutions caused less infusion pain than the control (original solution), but the bicarbonate/lactate solution appeared to be more effective.[66]

Inflow and Outflow Difficulty

Malposition of the catheter is suspected if there is inflow but no outflow. Other causes are omental wrap and constipation. Total obstruction to inflow and outflow suggests obstruction within the catheter lumen by fibrin, cellular debris, or blood clots.

In a prospective study by Ponce et al. on 204 patients with AKI treated with high-volume PD using a flexible catheter and cycler, 7.3% presented with mechanical complications with leakage and catheter tip migration comprising the majority of the complications. Therapy was interrupted in 36% of the affected patients.[25,40]

Complications Related to Increased Intraabdominal Pressure

Dialysate leaks can occur around the exit site and from the peritoneal cavity.[67] They can manifest as edema of the abdominal or genital wall, with a higher incidence in men owing to a patent processus vaginalis.[68] Diagnosis can be made with computed tomography of the peritoneum using iodinated contrast agent mixed with the dialysate and instilled into the abdominal cavity.[68] Using lower volumes of exchange may help reduce this complication.

HYDROTHORAX. This usually is associated with a defect in the tendinous part of the diaphragm with pleuroperitoneal communication or occurring via the lymphatics. Hydrothorax tends to occur more in women and on the right side of the chest. Large effusions may compromise respiration. Chest radiography is usually diagnostic. In uncertain cases, thoracocentesis and fluid analysis help in demonstrating a transudate with a very high glucose concentration.[67]

ALTERED MECHANICS OF BREATHING. Respiratory function may be compromised in PD, especially with high-volume exchanges. Studies in stable patients undergoing CAPD have demonstrated reduction in lung volumes, including functional residual capacity and reduced forced vital capacity (FVC), of up to 42% when patients were supine.[68] Bazari et al. reported that PD impairs diaphragm mobilization secondary to increased abdominal pressure. This results in impairment of pulmonary compliance and ventilation.[69]

In contrast, Epstein et al. found that although dialysate reduced pulmonary volume, vital capacity and expiratory volume in their subjects remained unaltered.[70]

Almeida Puato et al. in a recent prospective cohort study evaluated the respiratory mechanics; oxygenation and IAP in ventilated patients undergoing high-volume PD.[71] The results suggested that PD did not appear to worsen respiratory mechanics despite modest increase in IAP. However, this study has some limitations in that number of patients was small, a single-center study, and only one evaluation was done with a filled abdomen. This may affect the interpretation of the respiratory mechanics in relation to IAP.

Metabolic Complications

The metabolic complications of PD include hyperglycemia, hypernatremia, protein losses into the dialysate, and hypercatabolism. Hyperglycemia is due to the high glucose content in the dialysate. Dextrose content in dialysis solutions provides the osmotic gradient for fluid removal. A significant proportion of the dextrose is absorbed into the circulation, and frequent exchanges with high-dextrose fluids can give rise to significant overfeeding. This in turn contributes to fatty liver and an increase in carbon dioxide consumption and minute ventilation. This can lead to respiratory decompensation, especially in patients with limited ventilatory reserve.[72] Hyperglycemia also can predispose to further complications.

Hypernatremia is due to the short dwell and rapid volume exchanges leading to significant ultrafiltration, especially in high-volume PD. Significant hypokalemia also can develop because there is no potassium in the peritoneal fluid.

Protein losses into the dialysate can be as high as 10 to 20 g daily and even higher during peritonitis. Blumenkrantz et al. reported that up to 48 g of total protein and 26 g of albumin can be lost in 24-hour IPD during peritonitis.[73]

Goes et al. in a prospective cohort study evaluated the potential metabolic complications of glucose absorption, sodium removal, protein loss into the dialysate, and catabolism in 31 patients with AKI treated with high-volume PD.[74] Their results showed that glucose absorption remained at about 35% ±10.5% per session. Protein loss measured about 4.2±6.1 g daily, with higher values initially but subsequently reduced after two sessions of PD. The nitrogen balance was initially negative but stabilized by the third session. The results suggest that protein loss and glucose uptake remained constant throughout treatment with no increase in hypercatabolism. However, peritonitis increased glucose absorption and protein loss.[74] This tendency toward hyperglycemia decreases the osmotic gradient between PD fluid and the serum, and this may prevent adequate ultrafiltration (Tables 184.4 and 184.5).

ACID-BASE BALANCE. Standard peritoneal dialysis solutions contain lactate as the buffer, posing problems for patients with hepatic failure and those with severe lactic acidosis, in whom peritoneal dialysis may worsen the acidosis. Thongboonkerd et al.[75] reported a randomized controlled study comparing bicarbonate and lactate solution in terms of correction of metabolic acidosis, hemodynamics, and systemic host defense in patients with or without septic shock who were undergoing acute peritoneal dialysis. In the septic group, significant improvement was seen in blood pH, serum bicarbonate level, and mean arterial pressure ($p < .05$) in the bicarbonate arm compared with the lactate arm of the study. However, the serum bicarbonate and blood pH levels in the nonseptic groups were comparable. Also, lactic acidosis was corrected more rapidly with bicarbonate solution in both groups ($p < .05$).[75]

More recently, Bai Z et al.[75a] in a randomized controlled trial compared the effectiveness of bicarbonate versus lactate-buffered PD solutions and found no difference between bicarbonate and lactate in mortality. However, with patients in shock, serum bicarbonate was corrected more rapidly using bicarbonate-buffered solutions (21.2.±1.8 mmol/L vs. 13.4±1.3 mmol/L).

CULTURE-NEGATIVE CLOUDY PERITONEAL DIALYSATE. Up to 22% of PD patients may have culture-negative cloudy dialysate.[76] Szeto et al. found 45% of cases were associated with technical difficulties in sampling.[77] In patients with persistent culture negative peritonitis, other causes should be considered, such as unusual or fastidious microorganisms (e.g., fungi or microbacteria) and other noninfective causes (e.g., catheter-related trauma, contamination PD fluid, visceral inflammation, drug reactions, icodextrin, and any cause of hemoperitoneum and malignancy [rare]) (Table 184.6).[76]

TABLE 184.4

Metabolic Implications of High-Volume Peritoneal Dialysis in Patients With Acute Kidney Injury

	VALUE AFTER SESSION							
VARIABLE	1	2	3	4	5	6	7	*p* VALUE
Patients *(n)*	29	31	24	23	21	14	14	
Glu absorption (%)	37.5 ± 11.2[a]	38.2 ± 10.9[a]	35.6 ± 8.0[a]	35.6 ± 9.9[a]	36.4 ± 10.8[a]	29.9 ± 8.3	32.2 ± 11.3	0.01
Protein loss (g)	7.3 ± 2.1	5.0 ± 1.7[b]	4.5 ± 2.1[b]	2.8 ± 0.4[b]	2.7 ± 0.6[b]	3.2 ± 1.0[b]	3.4 ± 1.4[b]	0.001
Na removal (mEq)								0.004
Median	9.1[a]	45.3	32.2	34.3	45.5	50.4	21.6	
Range	–88.4 to 203.1	–163.1 to 155.6	–182.3 to 136.8	–68.7 to 99.1	–157.1 to 129.9	–57.3 to 74.1	–99 to 49.8	
UNA (g)	8.9 ± 2.6	8.8 ± 4.6	9.0 ± 2.9	8.5 ± 2.4	10.3 ± 4.1	10.4 ± 1.9	10.4 ± 1.8	0.34
Nitrogen balance (g)								0.26
Median	–5.2	1.5	0.3	2.1	–1.0	0.5	3.8	
Range	–9.6 to –1.9	–7.6 to 1.3	–6.5 to 6.6	–7.1 to 4.4	–5.2 to 4.5	–5.7 to 3.9	–6.5 to 4.8	

Glu, glucose; *UNA*, urea nitrogen appearance.
[a]Significantly different from the value after session 6.
[b]Significantly different from the value after session 1.
Modified from Goes et al. Metabolic implications of peritoneal dialysis in patients with acute kidney. *Injury Perit Dial Int.* 2013;33:635.

TABLE 184.5

Metabolic Implications of High-Volume Peritoneal Dialysis in Patients With Acute Kidney Injury, by Presence or Absence of Peritonitis[a]

	PERITONITIS		
VARIABLE	NO (*n* = 188)	YES (*n* = 20)	*p* VALUE
Glucose absorption (%)	34 ± 5.2	46.7 ± 3.5	< .001
Protein loss (g)	3.9 ± 1.4	7.5 ± 2.4	.002
Na removal (mEq)	1.8 (–149.8 to 89.6)	131.5 (–24.6 to 303.3)	.015
UNA (g)	9.1 ± 2.4	9.1 ± 1.8	.986
Nitrogen balance (g)	1.4 (–5.8 to 5.2)	0.5 (–7.3 to 5.2)	.479

UNA, Urea nitrogen appearance.
[a]Values shown as mean and standard deviation or median and quartiles.
Modified from Goes et al. Metabolic implications of peritoneal dialysis in patients with acute kidney. *Injury Perit Dial Int.* 2013;33:635.

TABLE 184.6

Differential Diagnosis of Sterile Peritonitis

- Cellular Causes
  - Increased neutrophils
    - Atypical infection
      - Mycobacteria
      - Fungi
    - Intraperitoneal disease
      - Cholecystitis
      - Appendicitis
      - Small bowel incarceration
      - Mesenteric ischemia
      - Sterile abscess rupture
    - Retroperitoneal disease
      - Pancreatitis
      - Splenic infarction
      - Abscess
      - Renal cell carcinoma
    - Drugs
      - Amphotericin B
      - Vancomycin
    - Contamination of PD fluid
      - Endotoxin
      - Acetaldehyde
  - Increased Eosinophils
    - Allergic reaction
      - Tubing
      - Bags
    - Intraperitoneal air
    - Drugs
      - Vancomycin
      - Gentamicin
      - Streptokinase
      - Cephalosporins
    - Following peritonitis
    - Infection
      - Fungal
      - Parasitic
    - Retrograde menstruation
  - Increased monocytes
    - Icodextrin related
    - Mycobacteria
    - In association with eosinophilia
  - Increased erythrocytes
    - Any cause of hemoperitoneum
    - Retrograde menstruation
      - Ovulation
      - Ovarian/hepatic cyst rupture
      - Peritoneal adhesions
      - Strenuous exercise
      - Catheter-associated trauma
  - Increased malignant cells
    - Lymphoma
    - Peritoneal metastases
      - Adenocarcinoma
- Noncellular Causes
  - Increased fibrin
    - Post peritonitis
    - Starting PD
  - Increased triglycerides
    - Acute pancreatitis
    - Neoplasms
    - Catheter-associated trauma
    - Superior vena cava syndrome
    - Drugs
      - Calcium channel blockers

Modified from De Frietas, Gokal. Sterile peritonitis in the peritoneal dialysis (PD) patient. *Perit Dial Int.* 2005;25:144–151.

CONCLUSION

PD, although marginalized as a form of renal replacement therapy in the developed world, still plays a major role in the management of AKI in developing countries. PD been shown to be safe, effective, and inexpensive. Technologic advances in PD have led to better outcomes in patients undergoing continuous ambulatory peritoneal dialysis. Applying these new developments to the management of acute kidney injury requires further research.

Future clinical trials should focus on ways to optimize the potential of PD through (1) appropriate patient selection, (2) using the capabilities of the latest automated cyclers, (3) use of biocompatible solutions, and (4) determination of appropriate dose and methods of measuring peritoneal dialysis adequacy. As knowledge evolves, PD may play a bigger role in the management of acute renal injury in the future.

Key Points

1. Peritoneal dialysis currently is underused in the management of acute kidney injury in the developed world but still plays a major role in treating this disorder in the developing world.
2. Peritoneal dialysis has been shown to be comparable to extracorporeal blood purification therapies in certain populations.
3. There is evidence to suggest that tidal or high-volume peritoneal dialysis is a reasonable option for patients with mildly to moderately hypercatabolic acute kidney injury.
4. Based on the current ISPD guidelines for PD in AKI, a minimum standardized Kt/V urea of at least 2.1 per week should be prescribed.
5. Future research should be directed at optimizing the potential of peritoneal dialysis in acute kidney injury.

Key References

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

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