Peritoneal Dialysis in Critically Ill Patients

Time for a Critical Reevaluation?

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Abstract

Peritoneal dialysis (PD) as an AKI treatment in adults was widely accepted in critical care settings well into the 1980s. The advent of extracorporeal continuous KRT led to widespread decline in the use of PD for AKI across high-income countries. The lack of familiarity and comfort with the use of PD in critical care settings has also led to lack of use even among those receiving maintenance PD. Many critical care units reflexively convert patients receiving maintenance PD to alternative dialysis therapies at admission. Renewed interest in the use of PD for AKI therapy has emerged due to its increasing use in low- and middle-income countries. In high-income countries, the coronavirus disease 2019 (COVID-19) pandemic, saw PD for AKI used early on, where many critical care units were in crisis and relied on PD use when resources for other AKI therapy modalities were limited. In this review, we highlight advantages and disadvantages of PD in critical care settings and indications and contraindications for its use. We provide an overview of literature to support both PD treatment during AKI and its continuation as a maintenance therapy during critical illness. For AKI therapy, we further discuss establishment of PD access, PD prescription management, and complication monitoring and treatment. Finally, we discuss expansion in the use of PD for AKI therapy extending beyond its role during times of resource constraints.

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Introduction

AKI is associated with substantial mortality among patients admitted to intensive care units (ICU).[1–3] Patients with kidney failure are more frequently admitted to critical care units, facing higher death risks compared to those with preserved kidney function.[4,5] Peritoneal dialysis (PD) was historically the initial KRT modality successfully used in patients with AKI and widely utilized well into the 1980s.[6] Although a mainstay of pediatric AKI treatment, and a commonly used AKI treatment modality in adults in many middle- and low-income countries, the use of PD in AKI in critically ill patients has declined across high-income countries. This is attributable to the introduction of and advances in extracorporeal continuous KRT (CKRT).[7–9] Decreasing comfort among intensivists and nephrologists in PD use among critically ill patients may also generate a self-sustaining cycle. This may be due to limited exposure to PD during training and, up until recently, years of historically declining PD use among maintenance dialysis patients across many high-income countries.[10–13]

A recent resurgence of interest in the use of PD for AKI treatment in high-income countries was largely related to the coronavirus disease 2019 (COVID-19) pandemic. The pandemic saw critical shortages of resources and staff needed to provide hemodialysis (HD) and CKRT, particularly during the early waves. Many centers relied on PD for AKI treatment.[14] This review provides evidence-based approaches, practical considerations, and treatment approaches using PD for AKI treatment and discusses the management of maintenance PD patients following cardiac surgery or admission to critical care units.

Rationale for and Advantages of PD for AKI Treatment

The International Society for Peritoneal Dialysis (ISPD) has published updated guidelines for PD treatment for AKI, affirming PD as an acceptable form of KRT in patients with AKI in all settings.[6] Two meta-analyses (including a Cochrane review) indicate that PD is non-inferior to extracorporeal modalities in the management of patients with AKI.[15,16] In recent experience from the United States during the surge of COVID-19 in 2020, nephrologists from four medical centers in New York rapidly and successfully implemented acute-PD programs over a period of 2 months for the treatment of COVID-19–related AKI-requiring dialysis.[17]

PD for AKI therapy can provide several advantages over intermittent HD and extracorporeal CKRT (Figure 1). In addition to the technical simplicity that requires less infrastructure, PD is likely less costly and better tolerated than intermittent HD in hemodynamically unstable patients, resulting in less fluctuations in BP.[18,19] This may possibly explain why previous studies have shown higher rates of kidney recovery with PD compared to intermittent HD or CKRT.[20,21] Unlike extracorporeal modalities, PD precludes the need for vascular access and its intendent risks of bacteremia and venous thrombosis. PD avoids the need for systemic anticoagulation, which is particularly important in critically ill patients with

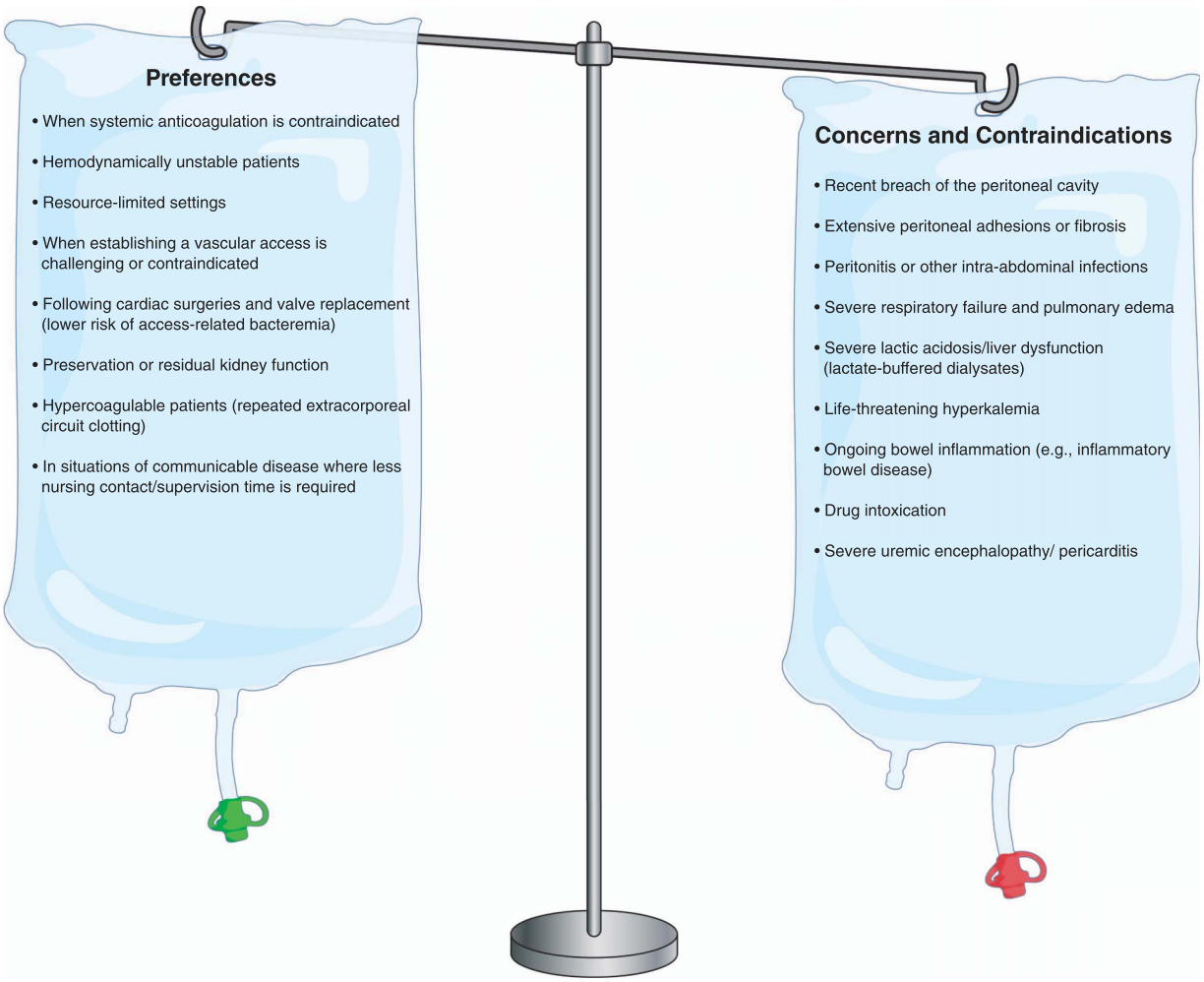

Figure 1. Potential preferences for peritoneal dialysis in AKI versus concerns and contraindications.

bleeding risks. Additionally, PD may be preferable in critically ill patients with hypercoagulable states where HD and CKRT can be interrupted due to repeated circuit clotting. Of note, PD for AKI in the context of cardiorenal syndrome and heart failure may be attractive and more hemodynamically tolerated compared to other modalities. Emerging experience in decreasing the sodium content of PD fluids has demonstrated potential benefits in acute decongestion protocols for congestive heart failure patients with acute volume overload.[22]

During natural or human-made disasters, abrupt loss of infrastructure and resources may result in more rapid mobilization of PD as an AKI treatment compared to HD if expertise in PD delivery exists. Previous experiences of dialysis patients during natural disasters such as Hurricane Katrina, the Queensland Australia floods, and earthquakes in Japan have demonstrated that PD patients were less likely to experience prolonged treatment interruptions compared to their HD counterparts.[23–25] In disaster-prone regions, establishing urgent start PD programs along with maintaining competencies in PD for AKI treatment is of critical importance to build resilience for future nature disasters and emerging threats. In isolation settings, and in situations of communicable diseases such as COVID-19, the use of extension tubing during automated PD treatment and remote patient monitoring can limit direct nursing contact with patients during adjustments and setup of the automated PD cycler compared to intermittent HD treatment, which typically requires nursing supervision over the entire treatment.

Randomized Controlled Trials Comparing PD Versus Extracorporeal Modalities for AKI Treatment

Few randomized control trials (RCTs) have examined the outcomes of AKI patients treated with PD, compared to other modalities (Table 1). In a study from Saudi Arabia evaluating the outcomes of critically ill patients with AKI-requiring dialysis, 125 patients were randomized to receive either continuous venovenous hemodiafiltration (CVVHDF) (N=62) or automated PD (N=63). Both groups had similar baseline characteristics, and PD treatment consisted of 25 L/day (2.0 L in each fill, with 70% tidal volume). Bicarbonate/lactate-buffered low glucose degradation product PD solutions were used. Those treated with PD had superior 28-day survival compared to those on CVVHDF (69.8% versus 46.8%, P<0.01). Secondary outcomes, including median time to resolution

Table 1. Randomized controlled trials comparing peritoneal dialysis for AKI treatment versus extracorporeal modalities

Study, Year	Comparison	Country, No. of Participants	PD Modality, Catheter Type	PD Prescription	APACHE II Score	Ventilatory Support (%)	UF Volumes (L/Day)	Median ICU Stay (Days)	Kidney Recovery (%)	Mortality at 30 Days (%)
Al-Hwiesh, 2018	PD versus CVVHDF	Saudi Arabia, 125	APD, flexible	24 h APD, 25 L/d (2.0 L fill volume, with 2 h dwell time, and 70% tidal)	22.1 versus 21.3	61.9 versus 69	0.95 versus 1.4	9 (7–11) versus 19 (13–20)	60.3 versus 35.5	30.2 versus 53.2
Gabriel, 2008	PD versus daily HD	Brazil, 120	APD, flexible	24 h APD, 36–44 L/d (2.0 L fill volume, with 35–50 min dwell time)	26.9 versus 24.1	68 versus 75	2.1 versus 2.4	NR	83 versus 77	58 versus 53
Ponce, 2013	PD versus daily 6–8 h HD	Brazil, 143	APD, flexible	24 h APD, 36–44 L/d (2.0 L fill volume, with 35–50 min dwell time)	27.5 versus 26.7	83 versus 87	1.4 versus 2.4	9 (5.7–19) versus 11 (5.7–20)	93.5 versus 90.3	63.9 versus 63.4
George, 2011	PD versus CVVHDF	India, 50	Manual, rigid	24 h manual PD with 1–2 L exchanges every 30 min	17.7 versus 18.4	60 versus 88	2.8 versus 2.9	NR	NR	72 versus 84
Phu, 2002	PD versus CVVH	Vietnam, 70	Manual, rigid	Manual PD with 2.5 L exchanges every 30 min	NR	NR	NR	NR	NR	47 versus 15

PD, peritoneal dialysis; UF, ultrafiltration; ICU, intensive care unit; CVVHDF, continuous venovenous hemodiafiltration; APD, automated peritoneal dialysis; HD, hemodialysis; NR, not reported; CVVH, continuous venovenous hemofiltration.

of AKI, ICU stay, and infectious complications were all statistically shorter/lower in the PD group.[20] Another RCT from Brazil compared the outcomes of 60 patients randomized to either automated PD or daily intermittent HD in patients with acute tubular necrosis requiring dialysis. PD prescriptions were continuous and consisted of 2.0-L exchanges, with 35–50 minutes dwell time (total of 36–44 L/day, and 18–22 exchanges per day). HD sessions were 6 days per week for a minimum of 3 hours. No differences between the groups were seen in the primary outcomes: survival after 30 days of treatment and kidney function recovery rates, and in the adequacy of metabolic control. The delivered dialysis dose was lower in the PD group compared to HD as measured by Kt/V urea per session (0.65 and 1.2, respectively). No differences were noted in terms of infectious complications, potassium levels, and ultrafiltration per session between the two groups. The time to recovery of kidney function was significantly shorter in the PD group (7.2±2.6 versus 10.6±4.7 days, $P=0.04$).[21] These findings were supported by another trial from two centers in Brazil comparing extended daily HD (6–8 hours/day, 6 days/week) to PD in patients with AKI. The study included 82 patients on extended HD and 61 on automated PD. PD prescriptions were like the previous study. The median ICU stay, recovery of kidney function, and mortality were similar in both groups.[26] In a study from India including critically ill patients with AKI-requiring dialysis, 50 patients were randomly allotted to CVVHDF ($N=25$) or to PD ($N=25$). No significant differences between the groups was noted in terms of mortality and the composite correction of metabolic parameters and fluid overload.[27] It should be noted that in this study, CVVHDF effluent doses were lower than current recommendations and rigid PD catheters were used. Lastly, an older study from Vietnam compared the outcomes of PD and continuous venovenous hemofiltration (CVVHF) in patients with severe infection-related AKI. The study was terminated early due to the higher mortality in the PD group compared to CVVHF (47% versus 15%). Study generalizability may be limited due to exclusive use of rigid PD catheters, acetate-buffered PD solutions with an open drainage system, and manual exchanges of 2.0 L of PD fluids every 30 minutes.[28] The exceptionally low mortality in the CVVHF arm (15%) also questions generalizability to other settings, raising the possibility of a type 1 error.

In summary, the majority of these RCTs suggest that the use of PD treatment in critical care settings is noninferior to other forms of extracorporeal KRT modalities for AKI treatment in terms of efficacy and patient survival. Importantly, these RCTs were conducted in largely single centers across middle-income countries. More robust and generalizable multicenter clinical trials are needed.

Contraindications to PD in AKI

Contraindications to PD in AKI treatment include recent breach of the peritoneal cavity, (*i.e.*, recent abdominal surgeries), the presence of extensive peritoneal adhesions or fibrosis, active peritonitis or other intra-abdominal infections, and severe lactic acidosis, where lactate-buffered PD solutions (versus bicarbonate-buffered solutions, currently not available in the United States) are the only available PD solution type (Figure 1). Of note, a previously published report has demonstrated that an elevated serum lactate level in critically ill PD patients does not itself indicate tissue hypoperfusion, but may result from delayed metabolism of the lactate buffer used in PD solutions.[29]

Another concern in using PD for AKI in critical care settings is the effect of intraperitoneal volume on respiratory biomechanics, particularly in mechanically ventilated patients, which is discussed later in this review. Other commonly cited concerns regarding PD use for AKI treatment are the unpredictable rates of fluid removal, particularly in volume overload states. In such cases, the ultrafiltration goals may be more rapidly achieved by HD. However, ultrafiltration volumes exceeding 2 L/day can usually be achieved with acute PD, especially if using high-concentration dextrose solutions and continuous, rapid exchanges. As with CKRT, the rate and efficacy of potassium removal is lower in PD, making HD a preferable option for life-threatening hyperkalemia. In settings where HD is not feasible, or may not be initiated quickly, potassium removal in PD may be maximized using hypertonic solutions, which can facilitate additional convective potassium removal above diffusive potassium removal. If the patient is hypo- or euvolemic, the additional ultrafiltration can be replaced with potassium-free IV fluid. Although PD has been used in the past for the treatment of toxic ingestions, it is less effective at elimination than HD and should only be used when other KRT options are unavailable.[30]

Effect of PD on Respiratory Mechanics

The rise in the intra-abdominal pressure because of dialysate infusion can be a barrier toward continuing PD in mechanically ventilated patients. This is related to the concern that such increases in intra-abdominal pressure from the installation of PD fluids could limit diaphragmatic movement, worsen lung volumes, and negatively affect respiratory mechanics. The intra-abdominal pressure may increase from normal values of 0.5–2.2 cm H_2O to as high as 10 cm H_2O following the infusion of 2 L of PD solution.[31,32] However, previous reports in intubated patients have shown that the increase in intra-abdominal pressure following dwell volumes of 2.0 L did not reach critical levels and were not associated with worsening in respiratory mechanics as measured by pulmonary static compliance, resistance of the respiratory system, and oxygenation index.[33,34]

Less clear is the effect of PD on nonintubated patients with respiratory compromise. Although some studies in healthy volunteers and maintenance PD patients have shown no change in forced expiratory volume, forced expiratory volume/vital capacity, and diffusion capacity of the lungs with intraperitoneal fluid instillation, the residual volume and functional residual capacity is reduced.[35,36] The clinical relevance of this is uncertain. Theoretically, in patients with respiratory compromise on the cusp of needing ventilatory support, the installation of intraperitoneal fluid may compromise lung volumes, expediting the need for intubation. These potential risks should be weighed against the speed with which mobilization of peritoneal ultrafiltration can be achieved to alleviate

pulmonary congestion and challenges in placing venous access for HD in those who cannot tolerate laying supine. Here, the decision to initiate or continue PD should be evaluated on a case-by-case basis by the entire care team.

During the recent COVID-19 pandemic, successful outcomes with use of PD in patients requiring prone positioning ventilation have been reported.[37,38] PD in prone individuals requires close monitoring and coordination between the ICU team, nephrologists, and nurses to do the PD exchanges (often manual) while the patient is supine, as proning is usually intermittent, occurring at intervals of 8–16 hours per day. In an experience from New York, PD had been continued while patients remained proned with tunneling of the PD catheter more laterally to facilitate ease of accessibility in the prone position—whether this is necessary is uncertain.

Challenges in Starting and Maintaining PD for AKI Program

Unique center-specific challenges in delivering PD in critical care settings exist for both AKI and maintenance dialysis patients based on local cultural factors, existing practices, care delivery models, and available resources. A closed model for ICU care may limit the effect of nephrologists' input on dialysis modality choices and willingness to even consider or continue PD. Additionally, many hospitals even struggle with delivering in-patient maintenance PD where dedicated staff to perform PD may be absent. When available, PD performance may be delegated to individuals with inadequate training and expertise as a secondary task, and the problem may be further compounded by the rapid turnover of these individuals. Health care settings already challenged by these issues will struggle to deliver PD for critically ill patients with AKI. In some settings, PD exchanges, or delivery of automated peritoneal dialysis (APD), could be performed by ICU nurses with advance training (akin to the performance of CKRT). In other models of care, nurses with PD expertise in other departments could support the ICU in delivering PD in the ICU. Alternatively, hybrid models may be feasible (setup of APD by a dedicated nurses but monitoring and surveillance of APD by ICU nurses). In terms of the recent New York experience with the use of PD for AKI, most of the centers preferred the use of automated PD as opposed to manual PD exchanges. In these cases, APD setup and/or manual exchanges were done by nephrologists themselves in some cases and coordinated by either nephrologists or PD nurses. Other health care staff including ICU nurses, physician assistants, and nurse practitioners were trained by the nephrology team to help in performing the PD exchanges. Given that PD for AKI is very commonly used in children and infants, the pediatric PD nurses played an invaluable role during the pandemic, providing hands-on training and arrangement of PD supplies in some circumstances.

In acute and critical care settings, technological advances in automated PD cycler technology, software development, and use of remote monitoring may be refined to aid in the delivery of PD in critical care settings. Refinements may include: the display of ongoing or cumulative ultrafiltration, the development of customized displays, and the relay of real-time treatment alarms or interruptions to facilitate live remote therapy, monitoring, and support.

PD Access Placement and Prescription for AKI

Flexible over rigid PD catheters are preferred, allowing for higher flow rates of dialysate with lower risk of leak, facilitating rapid escalation in dwell volumes, which is particularly important in catabolic patients.[6] Additionally, infection and bowel perforation risks are lower with flexible catheters.[6] The method of PD catheter insertion (laparoscopic versus percutaneous) should consider local experience, available resources, and the patient's surgical history and clinical status. Laparoscopic surgeries are usually not possible in critically ill patients in whom general anesthesia is often not tolerated. In such cases, having trained interventionalists (nephrologists/radiologists/surgeons) who can percutaneously insert PD catheters can facilitate rapid PD access placement.

The PD prescription for AKI therapy should be individualized depending on the metabolic and volume status of the patient. No consensus exists on the optimal PD dose in AKI patients. Based on studies from Brazil, the ISPD suggests that a weekly Kt/V urea of 2.2 may be acceptable for most patients with AKI. Yet, targeting higher Kt/V might be needed in hypercatabolic patients.[6,26,39,40] Of note, Kt/V may not be the ideal metric to measure the delivered dose of dialysis in PD patients with AKI. Dosing of PD is generally easier with automated PD than manual exchanges and should include fill volume, total therapy time, number of cycles, dwell time per exchange, dextrose concentration, and additives (heparin, insulin, potassium).

Intraperitoneal heparin at a dose of 500 u/L can be administered in all exchanges to prevent fibrin formation and maintain catheter patency. Heparin does not cross the peritoneal membrane and can be used without concern in patients with bleeding tendency. Intraperitoneal heparin administration should be avoided in patients with heparin-induced thrombocytopenia.[41] As frequent PD fluid dwells may result in hypokalemia, potassium can be supplemented IV, added to PD solutions, or alternatively can be given orally or enterally. Adding potassium to PD solutions prevents further potassium depletion but does not always obviate the need for concomitant oral/IV replacement. A sample PD prescription for AKI treatment is provided in Table 2.

Catheter exit-site care and bowel routine protocols should be in place like those endorsed among maintenance PD patients.[42] A 0.5% solution (currently not available in the United States) will facilitate intraperitoneal fluid absorption and should be considered in volume-depleted patients, particularly when IV access is not available. The 1.5% dextrose (1.36% anhydrous) concentration should be used in euvolemic patients, the 2.5% dextrose (2.27% anhydrous) for mild or moderate volume overload, and the 4.25% dextrose (3.86% anhydrous) should be reserved to those with severe volume overload. When the latter is used, particularly with rapid, frequent hypertonic exchanges, monitoring of sodium levels is warranted given the risk of hypernatremia because of sodium sieving. This phenomenon is characterized by increased free transperitoneal water transport through aquaporin-1 water

Table 2. Sample of automated peritoneal dialysis prescription for AKI therapy

Parameter	First 24 Hours	After 24–48 Hours (No Leaks)
Fill volume, ml	<60 kg: 1000–1200 >60 kg: 1500	<60 kg: 1500 >60 kg: 2000
Total therapy volume, ml[a]	<60 kg: 8000–24,000 >60 kg: 12,000–36,000	<60 kg: 6000–18,000 >60 kg: 8000–24,000
Total therapy time, h[a]	8–24	8–24
Number of exchanges[a]	8–24	4–12
Dwell time per exchange, min	60–120	120
Dextrose concentration	1.5% (1.36% anhydrous), 2.5% (2.27% anhydrous), 4.25% (3.86% anhydrous) as per patient's volume status	
Additives	Heparin 500 u/L in all exchanges [b]Potassium 3–4 mEq/L if serum levels are <4 mmol/L	

[a]As per patient's volume and metabolic demands.
[b]Potassium administration into peritoneal dialysis bags does not preclude the need of oral/IV replacement.

channels.[43,44] Although the glucose-based polymer PD solution (icodextrin) is commonly used to increase ultrafiltration during the long dwell in maintenance PD patients, its role in acute volume overload and in AKI therapy is limited, particularly with the use of continuous automated PD. Of note, icodextrin metabolites absorbed systemically can interfere with certain glucose monitors, making it important to use icodextrin-compatible glucometers to avoid erroneous capillary glucose measurements.[45,46]

Complications of PD in AKI Treatment

Mechanical and infectious PD complications are major concerns. Unlike elective PD initiation where 2 weeks of healing time is allowed, the PD catheter is typically used within 24–48 hours in acute-PD, resulting in higher risks of peri-catheter leaks. Leak risks can result from patient factors (*i.e.*, diabetes, obesity chronic steroid use) and modified by PD catheter insertion technique.[47,48] During surgical PD catheter insertion, the risk of leak can be reduced with the use of purse string sutures to secure the PD catheter deep cuff at the rectus muscle. Lower initial fill volumes (20 ml/kg) and performing PD while supine may decrease the risks of peri-catheter leaks, both of which lower abdominal pressure. However, the risk of leak following the use of acute high volume PD of 2.0 L in previous studies from Brazil was low and did not result in interruption of therapy.[21] As a result, initial dwell volumes should be individualized and the benefits of using higher initial fill volumes should be balanced against the risks of potentiating peri-catheter leaks. In the case of a peri-catheter leak, PD should be aborted for 24 hours before reintroducing smaller volumes, however, if not feasible, reduced volumes may facilitate continued therapy. Prone positioning did not lead to higher risk of leaks in a small case series of proned COVID-19–positive patients treated with PD for AKI.[37] Flow dysfunction is another concern following PD for AKI treatment. As with maintenance PD, constipation is the most frequent cause of flow dysfunction and aggressive laxative therapy is usually needed.

Early peritonitis is another possible complication during AKI treatment, with *Staphylococcus aureus*, *Pseudomonas aeruginosa* being the most frequently reported causative organisms along with fungal peritonitis.[49] In these settings, the use of antifungal prophylaxis should be strongly considered during broad spectrum antibiotic treatment.[50,51] Although it is not clear which antifungal prophylactic agent is best to prevent fungal peritonitis in critically ill patients, nystatin is more commonly used given its strong evidence base and safety profile in preventing antibiotic-associated fungal peritonitis.[52,53] In immunocompromised individuals and/or those on multiple broad-spectrum antibiotics, escalation to fluconazole can be considered but balanced against potential drug interaction risks, systemic side effects, and antimicrobial resistance.

The incidence of early peritonitis following PD initiation for AKI treatment has ranged between 12% and 15% in recent studies, yet a higher incidence may be seen with the use of rigid catheters and manual exchanges. As peritonitis signs might be masked in critically ill patients (abdominal pain and fever), the ISPD suggests peritonitis surveillance by daily diagnostic PD effluent leukocyte count and differential during AKI treatment.[6] Peritonitis can aggravate protein losses into the dialysate, making it important to maintain the nutritional status in these patients. Protein supplementation either orally or intravenously (1.2–1.5 g/kg per day) is suggested.[6,39,54]

Management of Maintenance PD Patients Following Cardiac Surgery

Rationale for Continuing Maintenance PD Following Cardiac Surgery

Many maintenance dialysis patients undergo cardiac surgeries every year. Following cardiac surgeries, PD avoids the need for vascular access, thus reducing the risk of access-related bacteremia, particularly salient following novel hardware, and prosthetic valve placement. Additionally, it is more hemodynamically tolerable, thereby minimizing cardiac stress following surgery.

Outcomes of Maintenance PD Following Cardiac Surgery

There is no evidence that intermittent HD is superior to PD when it comes to patients' outcomes following cardiac

surgeries. It is common in many centers to switch PD patient postoperatively to HD due to concerns regarding PD in critical care settings as previously discussed. In the postoperative period, adjustments of the patient's maintenance PD prescription should be considered, and if needed, continuous automated PD (over 24 hours) (analogous to CKRT and like PD AKI prescriptions) can be provided to address issues relating to additional clearance and volume removal. Kumar *et al.* conducted a case-control study to examine the perioperative outcomes and 2-year survival in 36 PD patients 2:1 demographic and comorbidity matched to HD patients who underwent coronary artery bypass grafting and cardiac valve replacement surgeries over 15 years. Both groups had similar survival perioperatively (PD: 89%, HD: 90%) and at 2 years (PD: 69%, HD: 66%). Although not significantly different, there were higher infection events in the HD group (19% versus 6%). The median critical care unit stay was longer in the HD group (4 versus 2 days). Two PD patients required conversion to HD, one for uncontrolled azotemia and another for dialysate leakage.[55] A Danish study compared the outcomes of 99 HD and 30 PD patients who underwent cardiac surgeries from 1998 to 2015. The 1-year and 5-year mortality were similar in both groups, with no between-group differences in postoperative complications.[56]

It is important for nephrologists to be involved early in the preoperative course and discuss with the surgical teams the importance of maintaining the integrity of the diaphragm, when possible, to minimize the risk of dialysate leak, and need for HD conversion. The routine practice of converting PD patients to HD following cardiac surgery is discouraged, lacking clear benefits, and could additionally result in greater risks.

Left Ventricular Assist Device and PD

Recently, there has been a significant increase in the use of left ventricular assist devices (LVAD) in patients with refractory heart failure, either as a bridge to heart transplantation or as destination therapy. However, AKI remains a major challenge that complicates up to 50% of LVAD implants, with up to 30% of these patients requiring KRT.[57–59] Although PD was initially contraindicated in these groups of patients due to the location of the drivelines in the peritoneal cavity, the drivelines in the newer smaller devices are now placed outside the peritoneum. Recently, PD was demonstrated to be a viable and preferable option than HD in patients on LVADs.[60–63] The cited advantages include a lower incidence of access-related bacteremia, the lower ultrafiltration rate, which offers greater hemodynamic stability, the preservation of residual kidney function, and possible better kidney recovery, particularly in cardiorenal syndrome.

Conclusions

In patients with AKI-requiring dialysis, PD is likely to be a cost-effective/less resources–intensive modality that has comparable outcomes to HD and CKRT in terms of efficacy and survival. Only few reasons exist to switch maintenance PD patients to HD or CKRT following cardiac surgery, as maintenance PD prescriptions can be intensified in the postoperative period and can provide several advantages and favorable outcomes compared to HD. Nephrologists should lead the discussions and play major roles in the selection of dialysis modality in collaboration with surgeons or intensivists facilitating changes in culture, which will be challenging and gradual. The choice of the AKI dialysis modality should take into consideration available resources, skills, and staff familiarity with different forms of KRT. PD has proven its efficacy and feasibility in critically ill patients during the COVID-19 era, yet the ongoing future role of PD as AKI therapy in the United States is unclear. Maintaining competencies in PD use for AKI therapy following the pandemic is important to overcome future challenges in rapidly and safely mobilizing this form of KRT if needed. Given that most of the evidence regarding PD for AKI emanates from low- and middle-income countries, more robust multicenter clinical trials inclusive of high-income countries are needed to assess the outcomes of PD for AKI treatment. Such investigation should optimally identify subgroups of patients (*i.e.*, the cardiorenal population) to study who may stand to benefit most from the purported advantages of PD for AKI therapy.

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References

1. Uchino S, Kellum JA, Bellomo R, et al. Acute renal failure in critically ill patients: a multinational, multicenter study. *JAMA.* 2005;294(7):813–818. doi:10.1001/jama.294.7.813
2. Andonovic M, Traynor JP, Shaw M, Sim MAB, Mark PB, Puxty KA. Short- and long-term outcomes of intensive care patients with acute kidney disease. *EClinicalMedicine.* 2022;44:101291. doi:10.1016/j.eclinm.2022.101291
3. Melo FdAF, Macedo E, Fonseca Bezerra AC, et al. A systematic review and meta-analysis of acute kidney injury in the intensive care units of developed and developing countries. *PLoS One.* 2020;15(1):e0226325. doi:10.1371/journal.pone.0226325
4. Strijack B, Mojica J, Sood M, et al. Outcomes of chronic dialysis patients admitted to the intensive care unit. *J Am Soc Nephrol.* 2009;20(11):2441–2447. doi:10.1681/ASN.2009040366
5. Manhes G, Heng AE, Aublet-Cuvelier B, Gazuy N, Deteix P, Souweine B. Clinical features and outcome of chronic dialysis patients admitted to an intensive care unit. *Nephrol Dial Transplant.* 2005;20(6):1127–1133. doi:10.1093/ndt/gfh762
6. Cullis B, Al-Hwiesh A, Kilonzo K, et al. ISPD guidelines for peritoneal dialysis in acute kidney injury: 2020 update (adults). *Perit Dial Int.* 2021;41(1):15–31. doi:10.1177/0896860820970834
7. Hyman A, Mendelssohn DC. Current Canadian approaches to dialysis for acute renal failure in the ICU. *Am J Nephrol.* 2002;22(1):29–34. doi:10.1159/000046671
8. Gaião S, Finkelstein FO, de Cal M, Ronco C, Cruz DN. Acute kidney injury: are we biased against peritoneal dialysis? *Perit Dial Int.* 2012;32(3):351–355. doi:10.3747/pdi.2010.00227
9. Ash SR. Peritoneal dialysis in acute renal failure of adults: the under-utilized modality. *Contrib Nephrol.* 2004;144:239–254. doi:10.1159/000078892
10. Rope RW, Pivert KA, Parker MG, Sozio SM, Merell SB. Education in nephrology fellowship: a survey-based needs assessment. *J Am Soc Nephrol.* 2017;28(7):1983–1990. doi:10.1681/ASN.2016101061
11. Mehrotra R, Blake P, Berman N, Nolph KD. An analysis of dialysis training in the United States and Canada. *Am J Kidney Dis.* 2002;40(1):152–160. doi:10.1053/ajkd.2002.33924
12. Struijk DG. Peritoneal dialysis in western countries. *Kidney Dis (Basel).* 2015;1(3):157–164. doi:10.1159/000437286
13. Khawar O, Kalantar-Zadeh K, Lo WK, Johnson D, Mehrotra R. Is the declining use of long-term peritoneal dialysis justified by outcome data? *Clin J Am Soc Nephrol.* 2007;2(6):1317–1328. doi:10.2215/CJN.02550607
14. Goldfarb DS, Benstein JA, Zhdanova O, et al. Impending shortages of kidney replacement therapy for COVID-19 patients. *Clin J Am Soc Nephrol.* 2020;15(6):880–882. doi:10.2215/CJN.05180420
15. Liu L, Zhang L, Liu GJ, Fu P. Peritoneal dialysis for acute kidney injury. *Cochrane Database Syst Rev.* 2017;12(12):CD011457. doi:10.1002/14651858.CD011457.pub2
16. Chionh CY, Soni SS, Finkelstein FO, Ronco C, Cruz DN. Use of peritoneal dialysis in AKI: a systematic review. *Clin J Am Soc Nephrol.* 2013;8(10):1649–1660. doi:10.2215/CJN.01540213
17. Chen W, Caplin N, El Shamy O, et al. Use of peritoneal dialysis for acute kidney injury during the COVID-19 pandemic in New York city: a multicenter observational study. *Kidney Int.* 2021;100(1):2–5. doi:10.1016/j.kint.2021.04.017
18. Karopadi AN, Mason G, Rettore E, Ronco C. Cost of peritoneal dialysis and haemodialysis across the world. *Nephrol Dial Transplant.* 2013;28(10):2553–2569. doi:10.1093/ndt/gft214
19. Liu FX, Ghaffari A, Dhatt H, et al. Economic evaluation of urgent-start peritoneal dialysis versus urgent-start hemodialysis in the United States. *Medicine (Baltimore).* 2014;93(28):e293. doi:10.1097/md.0000000000000293
20. Al-Hwiesh A, Abdul-Rahman I, Finkelstein F, et al. Acute kidney injury in critically ill patients: a prospective randomized study of tidal peritoneal dialysis versus continuous renal replacement therapy. *Ther Apher Dial.* 2018;22(4):371–379. doi:10.1111/1744-9987.12660
21. Gabriel DP, Caramori JT, Martim LC, Barretti P, Balbi AL. High volume peritoneal dialysis vs daily hemodialysis: a randomized, controlled trial in patients with acute kidney injury. *Kidney Int Suppl.* 2008;73(108):S87–S93. doi:10.1038/sj.ki.5002608
22. Rao VS, Turner JM, Griffin M, et al. First-in-human experience with peritoneal direct sodium removal using a zero-sodium solution: a new candidate therapy for volume overload. *Circulation.* 2020;141(13):1043–1053. doi:10.1161/circulationaha.119.043062
23. Kleinpeter MA, Norman LD, Krane NK. Disaster planning for peritoneal dialysis programs. *Adv Perit Dial.* 2006;22:124–129.
24. Johnson DW, Hayes B, Gray NA, Hawley C, Hole J, Mantha M. Renal services disaster planning: lessons learnt from the 2011 Queensland floods and North Queensland cyclone experiences. *Nephrology (Carlton).* 2013;18(1):41–46. doi:10.1111/nep.12008
25. Tamura H, Kuraoka S, Hidaka Y, Nagata H, Nakazato H. Pediatric peritoneal dialysis during the recent earthquakes in Japan and recommendations for future disaster preparation. *Kidney Int Rep.* 2020;5(7):1061–1065. doi:10.1016/j.ekir.2020.03.028
26. Ponce D, Berbel MN, Abrão JMG, Goes CR, Balbi AL. A randomized clinical trial of high volume peritoneal dialysis versus extended daily hemodialysis for acute kidney injury patients. *Int Urol Nephrol.* 2013;45(3):869–878. doi:10.1007/s11255-012-0301-2
27. George J, Varma S, Kumar S, Thomas J, Gopi S, Pisharody R. Comparing continuous venovenous hemodiafiltration and peritoneal dialysis in critically ill patients with acute kidney injury: a pilot study. *Perit Dial Int.* 2011;31(4):422–429. doi:10.3747/pdi.2009.00231
28. Phu NH, Hien TT, Mai NTH, et al. Hemofiltration and peritoneal dialysis in infection-associated acute renal failure in Vietnam. *N Engl J Med.* 2002;347(12):895–902. doi:10.1056/nejmoa020074
29. Trinh E, Saiprasertkit N, Bargman JM. Increased serum lactate in peritoneal dialysis patients presenting with intercurrent illness. *Perit Dial Int.* 2018;38(5):363–365. doi:10.3747/pdi.2017.00169
30. Bunchman TE, Ferris ME. Management of toxic ingestions with the use of renal replacement therapy. *Pediatr Nephrol.* 2011;26(4):535–541. doi:10.1007/s00467-010-1654-3
31. Gotloib L, Mines M, Garmizo L, Varka I. Hemodynamic effects of increasing intraabdominal pressure in peritoneal dialysis. *Perit Dial Int.* 1980;1(4):41–44. doi:10.1177/089686088000100406
32. Bargman JM. Complications of peritoneal dialysis related to increased intraabdominal pressure. *Kidney Int Suppl.* 1993;40:S75–S80.
33. Almeida CP, Balbi AL, Ponce D. Effect of peritoneal dialysis vs. haemodialysis on respiratory mechanics in acute kidney injury patients. *Clin Exp Nephrol.* 2018;22(6):1420–1426. doi:10.1007/s10157-018-1598-7
34. Almeida CP, Ponce D, de Marchi AC, Balbi AL. Effect of peritoneal dialysis on respiratory mechanics in acute kidney injury patients. *Perit Dial Int.* 2014;34(5):544–549. doi:10.3747/pdi.2013.00092
35. Gökbel H, Yeksan M, Dogan E, Gündogan F, Uzun K. Effects of CAPD applications on pulmonary function. *Perit Dial Int.* 1998;18(3):344–345.
36. Ulubay G, Sezer S, Ulasli S, Ozdemir N, Eyuboglu OF, Haberal M. Respiratory evaluation of patients on continuous ambulatory peritoneal dialysis prior to renal transplantation. *Clin Nephrol.* 2006;66(4):269–274. doi:10.5414/cnp66269
37. Soomro QH, Mukherjee V, Amerling R, Caplin N. Case series of acute peritoneal dialysis in the prone position for acute kidney injury during the COVID-19 pandemic: prone to complications? *Perit Dial Int.* 2021;41(3):328–332. doi:10.1177/0896860820983670

38. Bowes E, Joslin J, Braide-Azikiwe DCB, et al. Acute peritoneal dialysis with percutaneous catheter insertion for COVID-19-associated acute kidney injury in intensive care: experience from a UK tertiary center. *Kidney Int Rep.* 2021;6(2):265–271. doi:10.1016/j.ekir.2020.11.038
39. Ponce D, Berbel MN, Regina de Goes C, Almeida CTP, Balbi AL. High-volume peritoneal dialysis in acute kidney injury: indications and limitations. *Clin J Am Soc Nephrol.* 2012;7(6):887–894. doi:10.2215/CJN.11131111
40. Chitalia VC, Almeida AF, Rai H, et al. Is peritoneal dialysis adequate for hypercatabolic acute renal failure in developing countries? *Kidney Int.* 2002;61(2):747–757. doi:10.1046/j.1523-1755.2002.00177.x
41. Kaplan GG, Manns B, McLaughlin K. Heparin induced thrombocytopaenia secondary to intraperitoneal heparin exposure. *Nephrol Dial Transplant.* 2005;20(11):2561–2562. doi:10.1093/ndt/gfh989
42. Li PKT, Chow KM, Cho Y, et al. ISPD peritonitis guideline recommendations: 2022 update on prevention and treatment. *Perit Dial Int.* 2022;42(2):110–153. doi:10.1177/08968608221080586
43. Gomes AM, Fontan MP, Rodriguez-Carmona A, et al. Categorization of sodium sieving by 2.27% and 3.86% peritoneal equilibration tests-a comparative analysis in the clinical setting. *Nephrol Dial Transplant.* 2009;24(11):3513–3520. doi:10.1093/ndt/gfp319
44. Aanen MC, Venturoli D, Davies SJ. A detailed analysis of sodium removal by peritoneal dialysis: comparison with predictions from the three-pore model of membrane function. *Nephrol Dial Transplant.* 2005;20(6):1192–1200. doi:10.1093/ndt/gfh806
45. Perera NJ, Stewart PM, Williams PF, Chua EL, Yue DK, Twigg SM. The danger of using inappropriate point-of-care glucose meters in patients on icodextrin dialysis. *Diabet Med.* 2011;28(10):1272–1276. doi:10.1111/j.1464-5491.2011.03362.x
46. Schleis TG. Interference of maltose, icodextrin, galactose, or xylose with some blood glucose monitoring systems. *Pharmacotherapy.* 2007;27(9):1313–1321. doi:10.1592/phco.27.9.1313
47. Del Peso G, Bajo MA, Costero O, et al. Risk factors for abdominal wall complications in peritoneal dialysis patients. *Perit Dial Int.* 2003;23(3):249–254. doi:10.1177/089686080302300306
48. Singh N, Davidson I, Minhajuddin A, Gieser S, Nurenberg M, Saxena R. Risk factors associated with peritoneal dialysis catheter survival: a 9-year single-center study in 315 patients. *J Vasc Access.* 2010;11(4):316–322. doi:10.5301/jva.2010.5774
49. Ponce D, Buffarah MB, Goes C, Balbi A. Peritoneal dialysis in acute kidney injury: trends in the outcome across time periods. *PLoS One.* 2015;10(5):e0126436. doi:10.1371/journal.pone.0126436
50. Miles R, Hawley CM, McDonald SP, et al. Predictors and outcomes of fungal peritonitis in peritoneal dialysis patients. *Kidney Int.* 2009;76(6):622–628. doi:10.1038/ki.2009.202
51. Restrepo C, Chacon J, Manjarres G. Fungal peritonitis in peritoneal dialysis patients: successful prophylaxis with fluconazole, as demonstrated by prospective randomized control trial. *Perit Dial Int.* 2010;30(6):619–625. doi:10.3747/pdi.2008.00189
52. Lo WK, Chan CY, Cheng SW, Poon JFM, Chan DTM, Cheng IKP. A prospective randomized control study of oral nystatin prophylaxis for Candida peritonitis complicating continuous ambulatory peritoneal dialysis. *Am J Kidney Dis.* 1996;28(4):549–552. doi:10.1016/s0272-6386(96)90466-7
53. Campbell D, Mudge DW, Craig JC, Johnson DW, Tong A, Strippoli GF. Antimicrobial agents for preventing peritonitis in peritoneal dialysis patients. *Cochrane Database Syst Rev.* 2017;4(4):CD004679. doi:10.1002/14651858.CD004679.pub3
54. Kim SM, Kang BC, Kim HJ, et al. Comparison of hemodialysis and peritoneal dialysis patients' dietary behaviors. *BMC Nephrol.* 2020;21(1):91. doi:10.1186/s12882-020-01744-6
55. Kumar VA, Ananthakrishnan S, Rasgon SA, Yan E, Burchette R, Dewar K. Comparing cardiac surgery in peritoneal dialysis and hemodialysis patients: perioperative outcomes and two-year survival. *Perit Dial Int.* 2012;32(2):137–141. doi:10.3747/pdi.2010.00263
56. Bäck C, Hornum M, Møller CJH, Olsen PS. Cardiac surgery in patients with end-stage renal disease on dialysis. *Scand Cardiovasc J.* 2017;51(6):334–338. doi:10.1080/14017431.2017.1384565
57. Walther CP, Winkelmayer WC, Niu J, et al. Acute kidney injury with ventricular assist device placement: national estimates of trends and outcomes. *Am J Kidney Dis.* 2019;74(5):650–658. doi:10.1053/j.ajkd.2019.03.423
58. Silver SA, Long J, Zheng Y, et al. Outcomes after left ventricular assist device implantation in patients with acute kidney injury. *J Thorac Cardiovasc Surg.* 2020;159(2):477–486.e3. doi:10.1016/j.jtcvs.2019.03.064
59. Adegbala O, Olakanmi O, Akintoye E, et al. Trends, outcomes, and readmissions among left ventricular assist device recipients with acute kidney injury requiring hemodialysis. *ASAIO J.* 2020;66(5):507–512. doi:10.1097/mat.0000000000001036
60. Ajuria M, Franz DD, Morris JT 3rd, Abra G, Hussein WF. Peritoneal dialysis following left ventricular assist device placement and kidney recovery: a case report. *Kidney Med.* 2021;3(3):438–441. doi:10.1016/j.xkme.2020.12.009
61. Guglielmi AA, Guglielmi KE, Bhat G, Siemeck R, Tatooles AJ. Peritoneal dialysis after left ventricular assist device placement. *ASAIO J.* 2014;60(1):127–128. doi:10.1097/mat.0000000000000020
62. Koppel CJ, Jonker JT, Michels WM, Beeres SLMA. Peritoneal dialysis improves quality-of-life in a left ventricular assist device destination therapy patient-a case report. *Eur Heart J Case Rep.* 2021;5(10):ytab307. doi:10.1093/ehjcr/ytab307
63. Forcey DS, Manefield K, Wilson S. Peritoneal dialysis and LVAD bridge to successful heart-kidney transplant. *Perit Dial Int J.* 2022:8968608221126856. doi:10.1177/08968608221126856

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