

Peritoneal Dialysis for Acute Kidney Injury Treatment in the United States: Brought to You by the COVID-19 Pandemic

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic has created unprecedented strain on health care resources in the United States. Initial reports of AKI rates from Wuhan, China ranged between 3% and 9%, although rates as high as 15% have been reported (1,2). For AKI requiring RRT, intermittent hemodialysis (HD) and continuous RRT (CRRT) have been mainstays of therapy in the United States. However, shortages in supplies, staffing, and available equipment among critically ill patients with COVID-19, particularly in the New York City area, have demanded alternative strategies such as acute peritoneal dialysis treatment for AKI (AKI-PD) that are being implemented. Here, we will review the rationale for the use of AKI-PD and describe potential advantages, criteria for patient selection, and practical considerations on the basis of initial experiences to consider when prescribing and delivering peritoneal dialysis (PD).

Rationale for Acute PD in Patients with COVID-19 and Potential Advantages

PD was routine for AKI treatment worldwide well into the 1980s. However, by the 1990s with the development of the central venous catheter for HD and the advent of CRRT, PD became rarely used in higher-resource countries to treat adult patients with AKI (3). The utility and efficacy of PD to treat patients with AKI were re-examined after the publication of a series of articles from Brazil, including a randomized trial, demonstrating that PD provided acceptable care, was not inferior to daily HD in treating acutely ill patients with AKI in terms of patient mortality, and was associated with a shorter duration of AKI and need for RRT (4,5). These findings were confirmed in a randomized trial from Saudi Arabia comparing PD with hemodiafiltration (6). AKI-PD expanded dramatically in lower-resource countries with the advent of the Saving Young Lives Program in 2012, which promoted the use

of PD because of minimal infrastructural requirements, including a lack of need for water or electricity, the ease of training staff, and low costs (7–10). With the expanded PD use, the International Society for Peritoneal Dialysis (ISPD) developed guidelines for the use of PD to treat patients with AKI (3). The recommendation that PD was an acceptable form of RRT for AKI in these guidelines was supported by two meta-analyses (including a Cochrane analysis), both of which concluded that PD is not inferior to extracorporeal therapies in the management of patients with AKI (11,12).

Because PD is the original CRRT, it may be particularly suitable for hemodynamically unstable patients and for those who face challenges in establishing a reliable vascular access or with limited vascular access sites. Furthermore, unlike HD therapies, there are no concerns regarding the need for systemic anticoagulation. Emerging issues regarding a hypercoagulable state in critically ill patients with COVID-19 may pose challenges in the consistent delivery of HD or CRRT, with repeated dialysis circuit clotting making PD an attractive strategy (13). If automated acute PD prescriptions are delivered, there is a potential for reducing nursing contact with patients with COVID-19 during treatment compared with HD treatments, particularly with the use of extension tubing that allows the PD cyclor and troubleshooting to take place at a distance from the patient. A recent review underscores the utility of PD to manage patients with AKI in austere environments and under conditions of duress and conflict, emphasizing the ease of implementing treatment with acceptable outcomes (14).

Concerns Regarding Acute PD and Patient Selection

At the start of PD, solute transport characteristics and ultrafiltration (UF) capacity remain unknown, which may necessitate aggressive initial empirical

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prescriptions with more frequent exchanges using hypertonic dialysate to maximize peritoneal UF. This is germane to patients with COVID-19 in whom greater initial fluid removal may be often warranted (15). Unlike HD or CRRT where fluid removal rates are visible in real time, UF often remains unknown until the end of a PD treatment, providing an additional source of unease among critical care team members. Maintaining enough solute clearance is an additional concern particularly among patients who are hypercatabolic, but using high-volume PD seems to be able to mitigate these concerns and may be the preferable modality particularly in patients who are mechanically ventilated (5). Among experienced centers and using appropriate PD catheter placement techniques (discussed below), starting dwell volumes of 2.0 L have been used as suggested by the ISPD to allow for higher earlier PD doses (3,5). Programs with limited experience in AKI-PD or an operator new to percutaneous PD access insertion (as may be the case with the experience during the COVID-19 pandemic in the United States) may first wish to have an initial test period using lower PD dwell volumes to start.

In general, lack of knowledge and familiarity with the performance of PD exchanges and use of automated PD by critical care nursing staff remains a major barrier. Online or virtual education and training support from centers with expertise may help overcome these immediate challenges. In particular, pediatric nurses may be an excellent resource given the greater use of PD in children. Under extreme cases, attending nephrologists have resorted to learning to set up the ambulatory peritoneal dialysis (APD)ycler for their patients with adjunct offsite nursing support. Arguably, among staff with no acute dialysis expertise, training for acute PD is likely more straightforward than *de novo* training in HD or CRRT delivery, and consideration should be given as such. Similar to CRRT, potassium removal is slower and less efficient, and acute PD may not be an initial option for patients with life-threatening hyperkalemia.

A list of potential absolute and relative contraindications for acute PD is in Table 1. Of special note in patients with COVID-19 is concerns of use of acute PD in patients who are mechanically ventilated, which is not a contraindication to acute PD. The primary concern is that increases in intra-abdominal pressure (IAP) via PD fluid installation may

theoretically limit diaphragmatic excursion on compromise respiratory biomechanics. Noninvasive measurement of intraperitoneal pressure has been described after the PD catheter is in place, with typical values ranging from 10 to 16 cm H₂O. Pressures should not exceed 18 cm H₂O and can be lowered by lowering exchange dwell volumes (16,17). Yet despite these concerns, initial reports suggest that despite modest increases in IAP, compared with HD, PD has a minimal effect on respiratory biomechanics in patients who are mechanically ventilated even at dwell volumes of 2 L (18,19). Given that many patients with COVID-19 require prone mechanical ventilation (although there are some reports of successful PD in patients who are prone ventilated), we would suggest that an alternative dialysis modality be considered for these patients due to practical considerations and in individuals with severe respiratory distress where increases in IAP may potentially accelerate the need for intubation (20,21).

In AKI-PD, the time between PD catheter placement and initial use is short, and PD fluid leaks represent a complication seen with higher frequency compared with elective PD starts, which usually have at least 2 weeks of healing time from catheter insertion to first use (22,23). Nevertheless, the leak rates in the Brazilian and Saudi experiences using high-volume PD therapy immediately after catheter placement were extremely low (5,6). Other patient-related leak risk factors include patients with diabetes, increased body mass index, and patients on chronic immunosuppression (24). Strategies to minimize the risk of leaks include (1) selection of initial acute PD candidates with few/no patient-related leak risk factors, (2) optimization of PD catheter insertion techniques to reduce the risk of leaks (discussed below), (3) lower initial dwell volumes in the supine position (particularly in an initial AKI-PD experience) to reduce IAP (25), and (4) using PD as a bridge therapy from another dialysis modality and placing the catheter early in anticipation of a switch to PD to allow for a longer healing period.

PD Access Placement

In acute PD, similar to urgent start PD, use of the catheter within 24–48 hours demands the optimal placement technique to maximize a successful exchange, minimize the risk of leaks, and allow for rapid escalation in dwell volumes. In the United States, PD access is predominantly provided by surgeons using a laparoscopic approach (26). Because of considerations of preservation of hospital resources for the anticipated surge of patients with COVID-19 and for the safety of the operating room team performing laparoscopic procedures, PD access has become difficult to arrange despite Centers for Medicare and Medicaid Services designation of dialysis access procedures as essential (27,28).

Therefore, percutaneous catheter insertion with or without image guidance may be considered for peritoneal access (29,30). Although experience with percutaneous placement is not as widespread, it is a technique that can be performed at bedside or in the radiology suite by surgeons, interventional radiologists, or interventional nephrologists who have learned these techniques for the first time during the COVID-19 pandemic. In addition, many surgeons have also reverted to bedside mini-laparotomy procedures for PD access insertion. They may be performing these procedures

Table 1. Absolute and relative contraindications for peritoneal dialysis in AKI

Factors
Recent breach of peritoneum (abdominal surgery)
Peritonitis
Bowel compromise/inflammation
Severe hyperkalemia
Toxic ingestion
Severe respiratory failure and pulmonary edema
Shock liver and/or severe lactic acidosis ^a
Ascites and high intra-abdominal pressure
Prone ventilation

^aOnly a relative contraindication with lactate-buffered (not bicarbonate-buffered) peritoneal dialysis solutions. Bicarbonate-buffered solutions are not currently available in the United States.

Table 2. Peritoneal dialysis treatment for AKI dialysis orders: dialysis prescription—automated peritoneal dialysis order (first 24-hour prescription)

Parameter	Weight (≤70 kg)	Weight (>70 kg)
Fill volume, ml	1000	1500
Time, h	8–24	8–24
No. of cycles	8–24	8–24
Total therapy volume, ml	8000–24,000	12,000–36,000
Dwell time per exchange, h	1	1

For intensive care unit, 16–24 hours. For patients on floor, start with 8–12 hours.

using this method for the first time who would have traditionally exclusively placed PD catheters *via* a laparoscopic technique. During access placement, leak risk is minimized with (1) the use of a purse-string suture to secure the deep cuff, which should be placed in the rectus muscle (31). (2) A paramedian over a midline incision into the peritoneal cavity may further reduce leak risk by providing better adherence of the deep cuff to the lateral rectus muscle laterally compared with the thinner medial tissues of the linea alba, although this remains controversial (32). For all procedures, prophylactic antibiotics at the time of PD access insertion should be used in keeping with ISPD guidelines to reduce early peritonitis risk (33). Local expertise and operator experience with the technique being considered should be the main drivers for the method of PD access insertion. One of the main advantages for acute PD is that the PD catheter may also serve as a long-term access should the patient fail to recover from the AKI episode.

Acute PD Protocol and Prescription Considerations

An acute PD prescription must carefully balance the metabolic and UF needs of the patient while minimizing the risk of treatment-related complications. What dose to be delivered is controversial and has been poorly studied. The Brazilians targeted daily Kt/V of approximately 0.6/d, which may be necessary in very catabolic patients, but the ISPD has suggested that daily Kt/V_{urea} of 0.3 may be adequate for many patients with AKI (3,5). A dose estimation guide is provided in Tables 2–4, although Kt/V_{urea} in PD may not be the appropriate metric for the dose of dialysis in AKI. Furthermore, consideration must be given to local resources available, including nursing capability, familiarity with both manual and automated PD, cyclers supply, dialysate supply, and nephrologists' ability to identify and manage complications.

A sample PD prescription and protocol are provided in Figure 1. Bowel hygiene is important to optimize catheter function, with a bowel routine protocol in place from the time of placement and over the course of therapy. Both automated and manual PD exchanges are possible with an acute PD prescription in the supine position to minimize the risk of increased IAP and leaks. If manual exchanges are performed, continuous APD systems can be used with standard equipment or using the manifold and clamps to minimize the number of connections and disconnections

Table 3. Peritoneal dialysis treatment for AKI dialysis orders: prescription—after 24–48 hours (no leaks), increase dwell volume and time

Parameter	Weight (≤70 kg)	Weight (>70 kg)
Fill volume, ml	1500	2000
Time, h	8–24	8–24
No. of cycles	4–12	4–12
Total therapy volume, ml	6000–18,000	8000–24,000
Dwell time per exchange, h	2	2

For continuous automated peritoneal dialysis, consider 2-hour dwell time per exchange.

needed. Automated PD prescriptions need not be necessarily prescribed for overnight treatments alone; they may be set up for continuous (24-hour) treatments and have been largely used for bed-bound patients and patients who are mechanically ventilated. In these patients, the PD cycler can be set up for one 24-hour treatment and 60- to 240-minute exchanges used as clinically indicated. With excessively short APD dwell times and hypertonic dialysate, there is a greater risk of sodium sieving, particularly with hypertonic solutions leading to excessive free water loss (in the absence of sodium removal), and biochemistry should be reviewed for rises in serum sodium (5,34). With frequent automated PD cycling, hypokalemia may also ensue, necessitating intraperitoneal and/or intravenous potassium supplementation. More frequent cycling may also promote a greater risk of APD alarms overnight, and as a result, less frequent cycles and using tidal PD may be advantageous overnight with fewer/no staff available to troubleshoot these alarms. If a leak develops, temporary cessation of PD may be needed and has been introduced as early as within 24 hours of rest using lower dwell volumes. If persistent, catheter replacement may be necessary using the techniques described above to reduce the risk of leaks. Drug dosing in AKI-PD has not been well established in particular for antimicrobials and could be potentially extrapolated from the CRRT literature. Where possible, antibiotic drug levels should be measured and followed.

For all PD exchanges, intraperitoneal heparin supplementation (500–1000 μl) has been given either prophylactically to prevent intraperitoneal fibrin formation or as needed on

Table 4. Peritoneal dialysis treatment for AKI dialysis orders: dextrose concentration (is on the basis of volume status and ultrafiltration requirement)

Dextrose Concentration	No. of Liters
1.5% (if no fluid overload)	
2.5% (if mild or moderate fluid overload)	
4.25% (if severe fluid overload)	4.25% solution can remove up to 1 L of fluid in 4 h

Stable patient on floor can transition to standard continuous cyclic peritoneal dialysis regimen after 1 week.

PD Prescription for Acute Kidney Injury - Sample Protocol

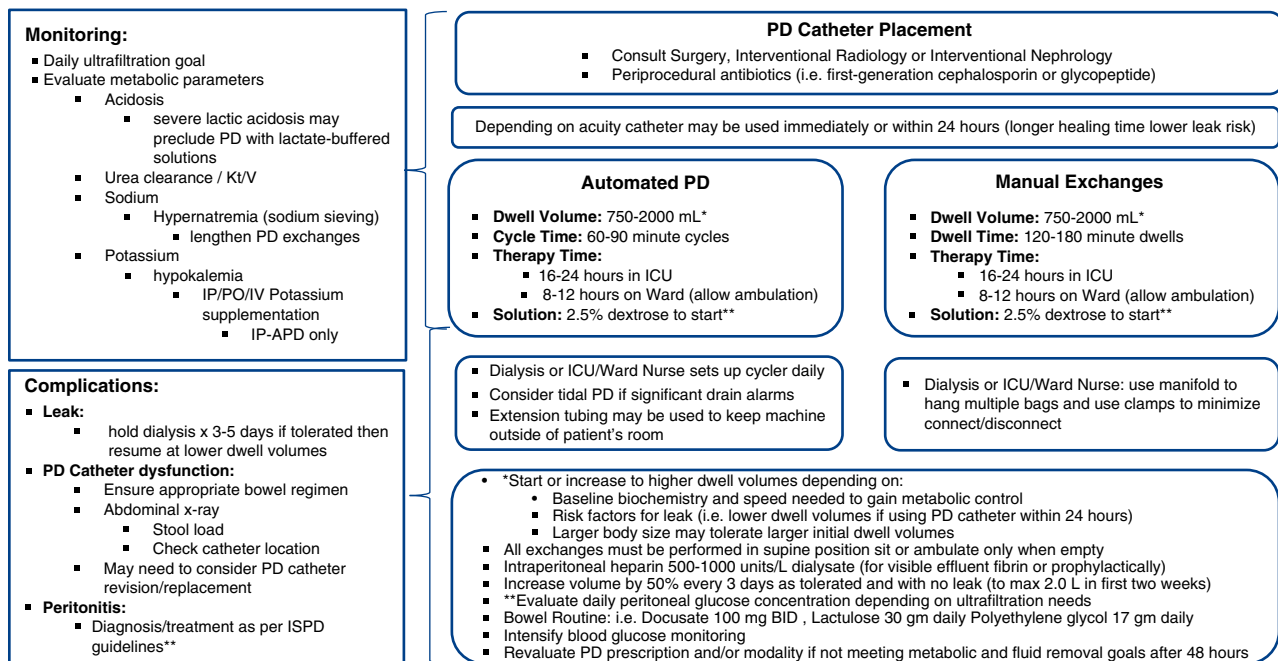


Figure 1. | Considerations in the prescription, monitoring, and complications for delivery of PD for AKI (33). APD, ambulatory peritoneal dialysis; BID, twice a day; ICU, intensive care unit; IP, intraperitoneal; ISPD, International Society of Peritoneal Dialysis; IV, intravenous; PD, peritoneal dialysis; PO, oral.

the basis of appearance of effluent fibrin to maintain PD catheter patency. Heparin is too large to cross the peritoneal membrane, and therefore, it is not contraindicated in patients with bleeding diatheses but is contraindicated in patients with heparin-induced thrombocytopenia, where intraperitoneal heparin has been reported to elicit an immunologic response (35). With sluggish PD catheter function, drain pain, prolonged inflow or outflow times, or excessive automated PD cycler low drain alarms, tidal PD (leaving a fixed residual volume of dialysis solution) during each exchange may be required. Spent dialysis fluid can be discarded with the same precautions as used for other bodily fluids (i.e., urine) among patients who are COVID-19 positive, although viral replication of COVID-19 has been recently identified in PD effluent (36).

PD for AKI is an established RRT with acceptable outcomes in pediatric patients with AKI and in adult patients outside of the United States (37). It is our hope that the renewed interest in the treatment of PD for AKI in adult patients in the United States during the COVID-19 pandemic is accompanied by increased proficiency and comfort with providing and offering this treatment modality and encouraging initial reports. For programs with established expertise in managing patients on maintenance PD or with expertise in using PD for urgent starts in the late-referred patient with ESKD, PD for AKI may be less of a leap compared with programs with little experience in maintenance PD where such an endeavor may be more challenging and perhaps ill advised. In such patients or where there is reluctance among the critical care team, use of urgent start PD in the late-referred patients with ESKD or greater use of

PD in sub-AKI or as a bridging therapy from HD may offload HD and CRRT resources reserved for critically ill patients. For an AKI-PD program to be successful, it will require a team approach centered around support from the critical care team, tenets of PD access insertion reliability and speed, nursing expertise, standardization and implementation of protocols, and evidence-based practice (where available). Initial candidates may want to be considered carefully and more restrictively, particularly in initially choosing lower acuity candidates and from a PD access perspective, candidates with no prior major abdominal surgery or scarring. If PD is not meeting the patient's goals for RRT for AKI after two treatments, it is important to swiftly consider an alternate dialysis modality. As patients are ready for discharge from the hospital with ongoing AKI requiring RRT, discharge planners will need to work with outpatient dialysis facilities to transition the patient to outpatient PD. Currently, in the United States, few insurance providers pay for AKI-PD; therefore, the patient management team will need to be involved so that coverage can be guaranteed prior to discharge via the health plan or through an agreement between the hospital and the dialysis provider. This safe transition should also include an in-home assessment to ensure the patient's long-term success on the modality after discharge.

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Author Contributions

F.O. Finkelstein, M. Naljayan, and J. Perl conceptualized the study; J. Perl was responsible for resources; and V. Aggarwal, J.H. Crabtree, F.O. Finkelstein, M. Naljayan, J. Perl, and V. Srivastana wrote the original draft and reviewed and edited the manuscript.

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V. Aggarwal has received speaking honoraria from Nxstage Medical Inc. J.H. Crabtree has received consultancy fees from Baxter Healthcare and Merit Medical and speakers' honoraria from Baxter Healthcare, Merit Medical, Fresenius Medical Care, DaVita, and Medtronic. F.O. Finkelstein reports research grants from Fresenius Medical Care (Renal Research Institute). M. Naljayan has received speaking honoraria from DaVita Kidney Care and served on advisory boards for DaVita Kidney Care and Baxter Healthcare. J. Perl has received speaking honoraria from AstraZeneca, Baxter Healthcare, DaVita Healthcare Partners, Fresenius Medical Care, Dialysis Clinics Incorporated, and Satellite Healthcare and has served as a consultant for Baxter Healthcare, DaVita Healthcare Partners, Fresenius Medical Care, and LiberDi. V. Srivastana has received speaking honoraria from Baxter Healthcare.

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