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*Special Series/Guidelines*

PERITONEAL DIALYSIS INTERNATIONAL

Peritoneal Dialysis International
2021, Vol. 41(2) 139–157
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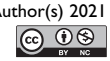
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# ISPD guidelines for peritoneal dialysis in acute kidney injury: 2020 Update (paediatrics)

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## Abstract

Peritoneal dialysis (PD) for acute kidney injury (AKI) in children has a long track record and shows similar outcomes when compared to extracorporeal therapies. It is still used extensively in low resource settings as well as in some high resource regions especially in Europe. In these regions, there is particular interest in the use of PD for AKI in post cardiac surgery neonates and low birthweight neonates. Here, we present the update of the International Society for Peritoneal Dialysis guidelines for PD in AKI in paediatrics. These guidelines extensively review the available literature and present updated recommendations regarding peritoneal access, dialysis solutions and prescription of dialysis.

***Summary of recommendations*:**

1.1 Peritoneal dialysis is a suitable renal replacement therapy modality for treatment of acute kidney injury in children. (**1C**)

2. Access and fluid delivery for acute PD in children.

2.1 We recommend a Tenckhoff catheter inserted by a surgeon in the operating theatre as the optimal choice for PD access. (**1B**) (**optimal**)

2.2 Insertion of a PD catheter with an insertion kit and using Seldinger technique is an acceptable alternative. (**1C**) (**optimal**)

2.3 Interventional radiological placement of PD catheters combining ultrasound and fluoroscopy is an acceptable alternative. (**1D**) (**optimal**)

2.4 Rigid catheters placed using a stylet should only be used when soft Seldinger catheters are not available, with the duration of use limited to <3 days to minimize the risk of complications. (**1C**) (**minimum standard**)

2.5 Improvised PD catheters should only be used when no standard PD access is available. (**practice point**) (**minimum standard**)

2.6 We recommend the use of prophylactic antibiotics prior to PD catheter insertion. (**1B**) (**optimal**)

2.7 A closed delivery system with a Y connection should be used. (**1A**) (**optimal**) A system utilizing buretrols to measure fill and drainage volumes should be used when performing manual PD in small children. (**practice point**) (**optimal**)

2.8 In resource limited settings, an open system with spiking of bags may be used; however, this should be designed to limit the number of potential sites for contamination and ensure precise measurement of fill and drainage volumes. (**practice point**) (**minimum standard**)

2.9 Automated peritoneal dialysis is suitable for the management of paediatric AKI, except in neonates for whom fill volumes are too small for currently available machines. (1D)

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3. Peritoneal dialysis solutions for acute PD in children
   3.1 The composition of the acute peritoneal dialysis solution should include dextrose in a concentration designed to achieve the target ultrafiltration. (**practice point**)
   3.2 Once potassium levels in the serum fall below 4 mmol/l, potassium should be added to dialysate using sterile technique. (**practice point**) (**optimal**) If no facilities exist to measure the serum potassium, consideration should be given for the empiric addition of potassium to the dialysis solution after 12 h of continuous PD to achieve a dialysate concentration of 3–4 mmol/l. (**practice point**) (**minimum standard**)
   3.3 Serum concentrations of electrolytes should be measured 12 hourly for the first 24 h and daily once stable. (**practice point**) (**optimal**) In resource poor settings, sodium and potassium should be measured daily, if practical. (**practice point**) (**minimum standard**)
   3.4 In the setting of hepatic dysfunction, hemodynamic instability and persistent/worsening metabolic acidosis, it is preferable to use bicarbonate containing solutions. (**1D**) (**optimal**) Where these solutions are not available, the use of lactate containing solutions is an alternative. (**2D**) (**minimum standard**)
   3.5 Commercially prepared dialysis solutions should be used. (**1C**) (**optimal**) However, where resources do not permit this, locally prepared fluids may be used with careful observation of sterile preparation procedures and patient outcomes (e.g. rate of peritonitis). (**1C**) (**minimum standard**)
4. Prescription of acute PD in paediatric patients
   4.1 The initial fill volume should be limited to 10–20 ml/kg to minimize the risk of dialysate leakage; a gradual increase in the volume to approximately 30–40 ml/kg (800–1100 ml/m$^2$) may occur as tolerated by the patient. (**practice point**)
   4.2 The initial exchange duration, including inflow, dwell and drain times, should generally be every 60–90 min; gradual prolongation of the dwell time can occur as fluid and solute removal targets are achieved. In neonates and small infants, the cycle duration may need to be reduced to achieve adequate ultrafiltration. (**practice point**)
   4.3 Close monitoring of total fluid intake and output is mandatory with a goal to achieve and maintain normotension and euvolemia. (**1B**)
   4.4 Acute PD should be continuous throughout the full 24-h period for the initial 1–3 days of therapy. (**1C**)
   4.5 Close monitoring of drug dosages and levels, where available, should be conducted when providing acute PD. (**practice point**)
5. Continuous flow peritoneal dialysis (CFPD)
   5.1 Continuous flow peritoneal dialysis can be considered as a PD treatment option when an increase in solute clearance and ultrafiltration is desired but cannot be achieved with standard acute PD. Therapy with this technique should be considered experimental since experience with the therapy is limited. (**practice point)**
   5.2 Continuous flow peritoneal dialysis can be considered for dialysis therapy in children with AKI when the use of only very small fill volumes is preferred (e.g. children with high ventilator pressures). (**practice point)**

**Keywords**
AKI, children, dialysis, intensive care, peritoneal dialysis

## Introduction

Acute kidney injury (AKI) is a common complication amongst sick hospitalized children. In studies using modern definitions, AKI prevalence ranges from 5% to 25% in both non-critical and critical patients. It is independently correlated with increased mortality and morbidity across all age groups.[1–4] In regions where dialysis is required, but not available, the mortality of these children is vastly increased.[5] Peritoneal dialysis (PD) was the first renal replacement therapy (RRT) modality used for the management of AKI in children of all ages. Its practice has declined in favour of the new extracorporeal blood purifying technologies in some parts of the world. A recent Internet survey of dialysis modalities used for AKI in children in high-income countries (HIC) (mainly from North America) and low- and lower middle-income countries (LLMIC) showed that in HIC countries, haemodialysis (HD) (72%) and continuous RRT (CRRT) (24%) were the preferred modalities, whereas in LLMIC 68% of infants were dialysed with PD.[6] In contrast, a recent survey of 35 European paediatric nephrology centres showed that PD and CRRT were the most frequently reported dialysis modalities, accounting for 39.4% and 38.2% of treatments, respectively, followed by intermittent HD (22.4%). In centres treating post cardiac surgery, PD was the most commonly chosen modality.[7] The choice of treatment modality seems to be affected by the geographical region and socioeconomic conditions, as well as the clinical characteristics of the patient. Despite the technological advancements, refinement and the development of safety procedures for

extracorporeal techniques, the application of these therapies in children remains expensive, complex, technology-dependant and requires experienced specialized nursing personnel, rendering it rather difficult to be introduced in areas with limited resources.

PD has also undergone technological improvement with new machines (PD cyclers) with better safety profiles, fewer connections and the potential for a greater variety of PD prescriptions. Manual techniques are, however, still more commonly used in LLMIC. In premature and small neonates for whom automated PD (APD) cycler systems are unable to deliver small enough volumes, PD can be performed manually with closed manual exchange systems. These manual exchange systems are inexpensive and can be applied to the smallest infants, including extreme and very low birthweight infants.[8–10] Children and infants undergoing cardiac surgery are at high risk of AKI as a result of nephrotoxic drugs, cardiopulmonary bypass and poor cardiac output, all of which can lead to fluid overload (FO). In turn, many paediatric cardiac centres in highly resourced countries insert PD catheters routinely during complex cardiac surgery, especially in the smallest infants. Early PD (on the day of surgery or post-operative day 1) has been commenced as part of post-operative care using either PD or passive drainage via the PD catheter. Studies on the outcomes of these practices have shown earlier time to negative fluid balance, shorter time on mechanical ventilation and fewer electrolyte imbalances.[11]

### *Methods*

These guidelines have been developed under the auspices of the International Society for Peritoneal Dialysis (ISPD). The committee has been carefully selected to include paediatric and adult nephrologists, as well as intensive care specialists from around the world, with a bias towards including practitioners from those countries where the provision of PD for treatment of AKI is routinely practiced. Each section was written by at least two authors who performed a review of the literature in that area. The section was reviewed by the co-chairs (BC, FF and BW), with the recommendations and their grading made by consensus of the whole committee. The final guidelines were subsequently reviewed by all authors. The authors of each section can be found in Appendix 2. The recommendations are based on the GRADE system, a well validated structure which matches the strength of the recommendation to the level of evidence.[12] Grade 1 is a strong recommendation, and grade 2 is a weak recommendation. The letters (A to D) indicate the level of evidence used to make the recommendations. Where no evidence exists, but there is enough clinical experience for the committee to make a recommendation, this was categorized as a practice point.

These guidelines have been developed for practitioners working in very different conditions. In some cases, what is felt to be optimal care may not be practical due to resource limitations. It is, therefore, important to define a minimum standard which needs to be achieved to ensure that the benefits of PD treatment for AKI outweigh the risks; this minimum standard may not, however, be deemed optimal treatment. There will, therefore, be recommendations made for '**minimum standard'** or '**optimal**', but practitioners should always strive to achieve the latter. There is no validated method of defining these two standards, and they are based on consensus by the authors, using the best available evidence and extensive clinical experience.

These are guidelines and as such should be used to direct practice patterns. It is important to keep in mind, however, that the guidelines may not be applicable to all clinical situations; clinicians should use the information to offer the best possible care to patients understanding that deviation from the guidelines may be necessary.

**1.1 Peritoneal dialysis is a suitable renal replacement therapy modality for treatment of acute kidney injury in children. (**1C**)**

## Rationale

### *Ease of implementation*

In regions with poor infrastructure, PD is particularly useful as it requires less technical skill and is cheaper than both continuous extracorporeal therapies or HD.[13–15] Retrospective studies have shown that PD can be safely performed in children with hemodynamic instability and multi-organ failure requiring vasopressors.[16,17] Dialysis catheters placed at the bedside[18] allow the rapid and safe institution of therapy without the need for anticoagulation. This also potentially eliminates the need for an intensive-care unit (ICU) environment for patients whose condition is stable. Whereas severe fluid restriction in small babies runs the risk of hypoglycaemia, the use of glucose-containing PD solutions and the subsequent absorption of glucose by the treated patients permits severe fluid restriction in small babies with AKI without the risk of hypoglycaemia.[19]

### *Comparison with other RRT modalities*

Observational studies comparing modalities have shown no difference in mortality between children treated with PD and those receiving CRRT as treatment for AKI. In 1995, a retrospective review of 34 children post cardiac surgery by Fleming et al. showed that CRRT was associated with better fluid control and nutritional support compared to PD.[20] There was, however, no difference in mortality. A retrospective analysis of 226 children with AKI from various causes published in 2001[16] showed no difference in mortality when comparing PD to CRRT. In this study, HD had a higher survival than CRRT or PD for all disease states. The better survival rate for HD was attributed by the

authors to the preselection of more hemodynamically stable patients for HD. A retrospective study from India comparing the efficacy and safety of continuous PD versus daily intermittent HD in 136 children aged 1 month to 16 years found the risk of death for patients treated with HD was 75% higher than those who received PD.[21] Children treated with HD in this study had frequent hypotensive episodes during treatment and a risk analysis of cause of death suggested fluid and electrolyte changes as possible causes. In another retrospective analysis from Israel of 115 children requiring dialysis for AKI, Krause et al. found intermittent HD to be associated with a significantly better outcome compared to PD or hemodiafiltration (HDF).[22] As possible reasons for this outcome, the authors cited that patients on PD and HDF had higher vasopressor support and thus were likely to have had more severe illness. The patients on PD and HDF were also younger and the size of the PD group was significantly larger than the other groups, which could also have affected the outcome. As is characteristic of many paediatric investigations, these studies were all hampered by the small number of patients, a lack of standardization of the therapy provided, variability in terms of the modalities available and additional variability regarding expertise and experience with the different modalities. These factors probably explain the variable outcomes. A problem encountered in many LLMIC is that often the only dialysis modality easily available for children is HD in adult units. Consequently, non-paediatric circuits and filters lead to large intravascular volume shifts and too rapid clearances. PD would be advantageous in these cases.

In conclusion, there is at present no clear benefit of one dialysis modality over another for the treatment of AKI. PD is a suitable modality for treatment of AKI in children of all ages and sizes.

## *Choice of modality*

In regions where all modalities of RRT are available, the choice of modality often depends on local expertise and preference as there is currently no proven advantage of one modality over another as discussed above. However, in the following situations, PD may be favoured over other modalities:

a) In low birthweight babies, PD is frequently the dialysis option utilized because of the difficulty in inserting large enough vascular catheters to allow extracorporeal techniques.[8–10]
b) Post cardiac surgery in small babies.[11,23]
c) Presence of bleeding diatheses which contraindicate the placement of large central venous catheters.
d) Cardiovascular instability in small babies where specialized paediatric CRRT equipment is not readily available to allow for low extracorporeal blood volumes.

There are a variety of contraindications to PD (relative and absolute), which consist of the following:

a) recent abdominal surgery (relative) and specifically, an open abdomen (absolute);
b) paralytic ileus (relative);
c) open chest post cardiac surgery (relative);
d) abdominal compartment syndrome (absolute);
e) difficulty ventilating patient (relative);
f) pleuroperitoneal connection allowing dialysate in the chest (relative);
g) diaphragmatic hernia (relative);
h) inguinal hernia (relative);
i) hypercatabolic renal failure where clearance of small solutes may be insufficient (relative);
j) clinical situations where precise removal of large volumes of fluid are required (relative);
k) abdominal wall cellulitis or abdominal wall burn (relative); and
l) fungal peritonitis (absolute).

2. Access and fluid delivery for acute PD in children

2.1 We recommend a Tenckhoff catheter inserted by a surgeon in the operating theatre as the optimal choice for PD access. (**1B**) (**optimal**)
2.2 Insertion of a PD catheter with an insertion kit and using Seldinger technique is an acceptable alternative. (**1C**) (**optimal**)
2.3 Interventional radiological placement of PD catheters combining ultrasound and fluoroscopy is an acceptable alternative. (**1D**) (**optimal**)
2.4 Rigid catheters placed using a stylet should only be used when soft Seldinger catheters are not available, with the duration of use limited to <3 days to minimize the risk of complications. (**1C**) (**minimum standard**)
2.5 Improvised PD catheters should only be used when no standard PD access is available. (**practice point**) (**minimum standard**)
2.6 We recommend the use of prophylactic antibiotics prior to PD catheter insertion. (**1B**) (**optimal**)
2.7 A closed delivery system with a Y connection should be used. (**1A**) (optimal) A system utilizing buretrols to measure fill and drainage volumes should be used when performing manual PD in small children. (**practice point**) (**optimal**)
2.8 In resource limited settings, an open system with spiking of bags may be used; however, this should be designed to limit the number of potential sites for contamination and ensure precise measurement of fill and drainage volumes. (**practice point**) (**minimum standard**)
2.9 Automated peritoneal dialysis is suitable for the management of paediatric AKI, except in neonates for whom fill volumes are too small for currently available machines. (**1D**)

## Rationale

### 2.1-2.6 Catheter types and insertion

Catheter implantation techniques used for acute PD catheter insertion include surgical (open dissection or laparoscopic), blind percutaneous using a Seldinger technique, interventional radiological placement and rigid catheters placed using a stylet. The method of catheter implantation is usually based on patient factors and locally available skills.

*Surgically placed catheters.* A Tenckhoff catheter inserted by a surgeon in the operating theatre is the optimal choice for children receiving acute PD.[17,24–26] This has been successful even in small babies. Laparoscopic insertion of Tenckhoff PD catheters in children has been shown to be as successful as open surgical procedures, with no differences in complication rates.[27] Laparoscopic salvage of migrated or blocked catheters is also useful.[28] Suturing of port sites reduces leakage and this may be an argument for laparoscopy over laparotomy. In many centres, the cardiac surgeons will place a Tenckhoff catheter at the time of operation. There are a number of techniques used for the placement of these catheters.[29] Catheters placed in this way generally have a low complication rate.[23,30,31] Children with a sternotomy have an increased chance of a breach occurring between the peritoneum and the pleural space. Depending on the specific catheter insertion technique used by the cardiac surgeon, this complication may occur more or less frequently.

*Catheters placed by Seldinger technique.* Bedside catheter insertion by the Seldinger technique in children of all sizes, using soft flexible Cook or Tenckhoff catheters, is an acceptable alternative to surgical placement. The Cook catheters used are either the temporary Cook PD catheters which have been used successfully for many years[16,20,32–34] or the Cook Mac-Loc™ Multi-purpose Drainage Catheters (CMMDC). These multipurpose catheters were used in 21 infants and children with a mean age of 6.9 months. There were only three complications in two patients precluding continuation of PD. The remainder of the patients used the catheter until recovery from AKI or non-renal death. Good target fluid and solute removal were achieved with no catheter-related infections. The mean complication free days were 10.5 (range 2–29 days) with 90% catheter survival at 14 days. In this experience, there were no significant differences between the CMMDC and the historical Tenckhoff catheter usage with respect to complication free survival and catheter-related complications ($p = 0.057$).[18] In a much earlier study from Belgium, pigtail Cook catheters were also used with low complication rate.[35] Bedside placed Tenckhoff PD catheters using the Seldinger technique with peel-away technology, with either non-tunnelled[36,37] or tunnelled approaches, have been used successfully. A study from Turkey describing 108 cases of bedside inserted tunnelled Tenckhoff catheters done by paediatric nephrologists, using a Seldinger technique, showed this to a be a safe and cost-effective method of insertion. Of note, there were no cases of bowel perforation despite using a blind Seldinger technique.[38] This is a well-established technique in the adult literature (see adult guidelines). Step-by-step insertion guidelines are available on the Saving Young Lives Website – https://www.theisn.org/programs/saving-young-lives-project.

*Interventional radiological placement.* Interventional radiological placement of PD catheters combining ultrasound and fluoroscopy *in adults* is a cost saving, safe, less invasive, and at least as effective option when compared with traditional surgical placement.[39] Consensus protocols (adults) are available[40] which facilitates urgent-start PD in cases who present late in ESKF needing dialysis. This also allows a single procedure which may suffice for acute and chronic dialysis access. While there is no data regarding this approach in children, its application could potentially avoid the need for temporary vascular access catheters using vessels which can be difficult to access, and which may be damaged with resultant long-term implications. In less well-resourced countries, there may a deficiency of fluoroscopy machines, but ultrasound machines are becoming increasingly available in paediatric centres worldwide.

*Rigid stylet insertion PD catheters.* If soft Seldinger placed catheters are not available, rigid stylet PD catheters can be used. Rigid stylet catheters are associated with a high risk of leakage, dislodgement, viscus injury and peritonitis and are not advised to be used beyond 2–3 days.[25,41] These catheters are, however, inexpensive and typically readily available. A study from Sudan reported on the care of 659 children with AKI over 7 years where the most common dialysis modality used was PD (343 children (52.4%)). A rigid catheter (Peritocat; peritoneal dialysis catheter, B. Braun Melsungen AG, Melsunge, Germany) was successfully placed at the bedside using a blind technique. On average, PD was continued for 4.5 days (range: 2–9 days). When dialysis was needed for a longer period, a soft PD catheter was inserted, or the patient was switched to HD. Peritonitis was reported in 53 (15.4%) patients in addition to bowel, bladder and vessel injury in 7 cases due to the rigid stylet. However, recovery from AKI was achieved in 450 (68.9%) children overall, with recovery after PD in 205/343 (65.4%).[42]

*Alternatives where no PD catheters are available.* In cases where no PD catheters are available, alternative catheters have been used to serve as PD catheters. These include central venous or dialysis lines (adult or paediatric) inserted via the Seldinger technique. Alternatively, intercostal chest drains, nasogastric tubes (with extra side holes cut) or Foley's urethral catheters inserted via a mini laparotomy

**Table 1.** Peritoneal dialysis catheters and delivery systems.

**Seldinger insertion technique – soft catheters**

**1. Cook catheters**

- Cook multipurpose drainage pigtail catheters

Fuhrman drainage catheters – Pigtail catheter with 6 side ports and 15 cm length.
Set comes with an 18 gauge needle 5 cm length with a dilator and guidewire for Seldinger technique.

| Catheter size | Age | Pigtail catheters less likely to obstruct |
|---|---|---|
| 5 Fr | Premature infant | Obstructs easily as small drainage holes |
| 6 Fr | Neonate | Obstructs easily as small drainage holes |
| 8.5 Fr | 1 month to 1 year | Most frequently used, even in neonates |
| 10.2 Fr | 6 months to 2 years | |
| 12 Fr | 1 year to 5 years | |

- Peritoneal dialysis straight catheter

Straight, soft catheter; 8 Fr; 5 cm length

- Peritoneal lavage straight catheter

Straight, firm catheter; 9 Fr with 90 side ports; 20 cm length

2. **Arrow multipurpose cavity drainage catheter**

Curled catheter, multiple large drainage holes

**Seldinger insertion technique – with peel away sheath Tenckhoff technology**

- Kits (Kimal/Covidien/Medcomp/Cook/KWay) primarily 16 Fr sheath. Different lengths are available depending on the size of the child.
- Tenckhoff catheters used can be straight or curled, double or single cuff and can be used tunnelled or non-tunnelled.

| Tenckhoff catheter size 15 Fr approx. guide | Age |
|---|---|
| 31–32 cm | <6 months |
| 37–38 cm | 6 months to 5 years |
| 40–42 cm | Older than 5 years |

**Rigid stylet PD catheter (Stick catheter) – inserted via a sharp removable trochar device**

Peritocath/Romsons which protrudes at right angle to abdomen if patient in a supine position; easy dislodgement.

**Manual PD delivery systems**

Buretrols are very important in these delivery systems to measure fill and drain volumes accurately.
Commercially available systems:

- Fresenius PD paeds system
- Baxter systems
- Dialy-Nate system/Gesco Dialy-Nate (Utah Medical Products, Midvale, Utah, USA); older children

These are generally used for infants under 3 kg (ideally < 5 kg). Where commercially available systems are not available then improvised systems should be used.

**Automated peritoneal dialysis machines**

Commercially available systems:

- Homechoice Pro. This machine can be programmed to a fill volume of 60 ml.
- Fresenius sleep safe harmony device. This machine can be programmed down to a fill volume of 25 ml.

It is generally not recommended that a fill volume of less than 100 ml be used because of the dead-space involved which could compromise dialysis efficiency.

in the operating theatre can serve as a catheter for dialysis. These have been very effective, although no formal comparative data are available. It should be noted that none of these options are recommended as first line; however, they have been shown to be life-saving and so it is suggested that they be used if no other option exists.[43,44] In a study from Esezobor et al. in Nigeria, intercostal chest drains were used in 14 of 17 children requiring PD for treatment of AKI, with complications of blockage of catheters and peritonitis occurring in 4 (23.5%) and 2 (11.8%) patients, respectively. Resolution of AKI and discharge from the hospital occurred in 8 (47.1%) of the cases.[43]

*Available acute PD catheters.* Please see Table 1 for the range of PD catheter available for children of different sizes for acute PD. There are a range of Tenckhoff PD catheters, with differences in the configuration of the intraperitoneal portion (straight or coiled). The number and type of cuffs also varies, and catheters may have a single, dual or disc ball cuffs. Until further data are available, relating

specifically to acute PD, the use of a double-cuff Tenckhoff catheter with a downward or lateral subcutaneous tunnel configuration, as recommended in the chronic PD literature, is the preferred Tenckhoff access.[45] The preference at different units may vary widely according to surgical preference and local expertise.

*Location for catheter insertion.* Even in the most sophisticated countries, the most appropriate place for insertion of the catheter will depend on the clinical setting. For example, in a patient with multi-organ failure and shock, the most appropriate place may be at the bedside in the ICU, whereas a stable patient should be transferred to a surgical theatre, radiology suite or dedicated procedure room. There are no trials answering this question; however, the experience of many clinicians is that bedside insertion is safe and does not lead to increased peritonitis risk if strict sterile technique is adhered to.

*Anatomical insertion site.* Recommended insertion sites for bedside percutaneous placement of a PD catheter are in the midline in the mid-rectus abdominis sheath below the umbilicus or midpoint between the umbilicus and the anterior superior iliac spine of the hip. The inferior epigastric artery, which runs along lateral aspect of rectus abdominal sheath, should not be punctured using these landmarks. Recommendations are also available which demonstrate the use of bedside ultrasound to avoid inadvertent puncturing of bowel by identifying a site on the anterior abdominal wall where there is maximum separation between the abdominal wall and the bowel.[40]

*Sedation and analgesia.* Sedation and analgesia for bedside insertion in children can be the greatest hazard in this situation and it is imperative that facilities and staff are available to administer and deal with the consequences of these agents.

*Training.* Health disparities in various LLMIC have resulted in difficulties in providing acute PD for children and infants in terms of both equipment and staff training.[46] Recent efforts by organizations supporting the Saving Young Lives (SYL) program, such as the ISPD, ISN, IPNA and EuroPD, have facilitated the training of staff (medical and nursing) in the insertion of PD catheters in children and small infants. Placement of PD catheters in LLMIC is often perceived as technically difficult, resulting in a lack of uptake of this potentially life-saving treatment. Contrary to this belief, bedside insertion of PD catheters in children can be achieved safely, even by non-surgically trained clinicians, where paediatric surgeons and theatre facilities may be limited.

*Sterile technique.* Peritonitis is a major limiting factor in acute PD. Although there is little evidence to recommend best practice in acute PD, methods to reduce infection can be extrapolated from the chronic PD literature.[45]

The following sterile technique is recommended when inserting a bedside PD catheter:

(a) sterile garments worn by staff – mask, hat, gown and sterile gloves;
(b) sterile drapes;
(c) all components including saline bag for artificial ascites and connections must be opened on the sterile tray;
(d) add povidone iodine dressing to PD connections;
(e) closed sterile system of tubing, PD fluid and PD catheter; and
(f) train staff extensively on sterile procedures for all components of PD.

McCulloch et al. showed that with the use of this aseptic technique and trained acute dialysis staff, low peritonitis rates are possible.[36] A recent study of 32 children with AKI from the Democratic Republic of Congo showed that following SYL training, the use of locally manufactured PD fluid and bedside insertion of cuffed PD catheters by paediatric residents resulted in survival in 70% of cases. There was a total complication rate of 18%, including a low peritonitis rate of 6.2%, blocked catheters 6.2% and leakage 3.1%.[47]

## 2.5 Prophylactic antibiotics

Colonization of the Tenckhoff catheter and/or contamination at the time of insertion increases the risk of subsequent peritonitis and needs to be avoided through strict sterile technique. Whereas prophylactic antibiotics do not always prevent infections if sterile technique is not followed, when used in conjunction with sterile technique, there is a decrease in the incidence of peritonitis. In the absence of data pertaining to the use of prophylactic antibiotics in the setting of acute PD, guidelines regarding the use of this therapy for chronic PD catheter insertion are best followed.[45] The decision of which antibiotic to use is dependent on local bacterial susceptibilities, timing of the procedure and availability. It is generally accepted that the most important organisms to protect against are the gram-positive organisms. However, given the small risk of bowel injury, some clinicians use an agent which would also cover gram-negative bacteria. The ISPD paediatric guidelines recommend that the prophylactic antibiotics should be provided within 60 min prior to PD catheter insertion to have adequate tissue levels prior to the initial incision. It therefore makes agents which require a long infusion time unsuitable for patients who need emergent dialysis.

## 2.6-2.7 Manual PD delivery systems

PD for infants and children with AKI may be implemented with a manual gravity-based system. A closed system is associated with lower peritonitis rates compared to the standard spiking system in chronic patients and there is

no reason to suspect this would not be the case in acute PD.[48,49] Strict fluid balance, which is of utmost importance in the very young, is assisted by the use of buretrols which permit the precise measurement of inflow and drainage. This technique also minimizes the number of connections and therefore, the risk of touch contamination. Systems that are now available commercially include the PD-Paed system (Fresenius Medical Care, BadHomburg, Germany), the Baxter manual PD system and the Dialy-Nate system/Gesco Dialy-nate (Utah Medical Products, Midvale, Utah, USA) set for older children. A twin-bag system (as used by chronic PD patients) can be used to ensure a closed system.

In resource limited settings, a closed system may not be available and an open system may need to be utilized. This should be designed to minimize the potential sources of contamination at the point of the spike and connection to the catheter and drainage bag. The circuit should consist of a single dialysis fluid bag attached to a buretrol and an infusion set which is then attached to the dialysis catheter through a three-way tap. The drainage tubing can then be inserted into an empty, sterile 200-ml fluid bag or catheter bag. A buretrol is essential in neonates and infants where exact volumes need to be delivered to reduce the risk of overdistension which can result in respiratory embarrassment or leakage.

In the case of older children and/or if buretrols are not readily available, a scale may be used to weigh the PD bag while fluid flows into and out of the patient.

## 2.8 Automated PD systems

APD employing a cycling device was introduced into clinical practice in the 1980s, decreasing the frequency of peritonitis and providing efficient metabolic and electrolyte control in AKI patients.[50,51] APD offers a wide selection of highly efficient treatment schedules obtained using short dwell times, high dialysate flow rates and customized intraperitoneal volumes (IPVs). APD has the advantage of requiring less intensive nursing care but comes with a financial burden.

Components of the APD system

Cycler: treatment settings, such as the amount of solution to be infused and the length of time the solution remains in the peritoneal cavity (dwell time), are programmed into the cycler. The cycler then automatically performs the treatment. As is the case with manual PD, the APD exchange has three phases: fill, dwell and drain. The prescription of these phases if using the APD machine to deliver PD, should be the same as if using manual PD, as described in the prescription section below. Total time on therapy in a day should also be as described in the prescription section.

APD options for treatment of AKI include the following:

CCPD/IPD: Total volume of PD solution used for the therapy includes the total fill volume for all cycles and the last fill volume. The last fill volume is usually set at zero when the child is getting PD continuously in a 24-h period. This may change if the child is on acute PD for some time when the prescription may start to resemble that of a chronic PD prescription. The PD solution used for the 'Last Fill Volume' can have the same dextrose concentration as the solution used throughout the dialysis session, or it can be different.

TIDAL: In this modality, only a portion of the dialysis solution within the peritoneal cavity is drained and replaced with new solution during each therapy cycle; this leaves a residual volume of fluid in the abdomen. This is beneficial in two ways: (a) the residual volume continues to facilitate water and solute removal even during filling and draining of the abdomen, thus increasing effective dialysis time, which may be beneficial in removing slow moving molecules, and (b) it can be helpful when there is difficulty completely draining the dialysis solution or there is drainage pain, as the catheter does not directly oppose the peritoneum.

A recently published study randomizing 125 critically ill *adult* patients to tidal APD or continuous veno-venous hemodialysis (CVVHD) showed a significantly lower mortality in the tidal APD group (30.2 vs. 53.2% – $p = 0.0028$).[52] This is the first study to demonstrate superior outcomes compared with extracorporal therapies. The study was, however, underpowered to show this outcome and needs to be repeated. The results can also not necessarily be extrapolated to children. Currently, the only indication for acute tidal PD in children remains outflow pain.

For tidal PD, cycler programming needs to include the following:

- tidal volume percentage (volume of fluid drained and refilled during each cycle, expressed as a percentage of the initial fill volume);
- total ultrafiltration (UF) (total UF expected for the entire dialysis session); and
- number of FULL peritoneal drain cycles during the dialysis session.

The cycler calculates the number of cycles, the dwell time, the tidal volume and the ultrafiltration volume per cycle.

Adult machines usually have settings for cycles ranging from 100 ml to 3000 ml. The limiting factor for using APD equipment in infants and children is the availability of low-fill mode option for paediatric patients and the minimum accepted fill volume. Cycling machines adapted for paediatric use have fill volumes reduced to as low as 25–60 ml

per cycle (Table 1). Because of the dead space involved however, it is generally recommended not to use a fill volume of less than 100 ml. If fill volumes less than this are required as a result of the small size of the child, manual PD should be used

**3. Peritoneal dialysis solutions for acute PD in children**

3.1 The composition of the acute peritoneal dialysis solution should include dextrose in a concentration designed to achieve the target ultrafiltration. (**practice point**)

3.2 Once potassium levels in the serum fall below 4 mmol/l, potassium should be added to dialysate using sterile technique. (**practice point**) (**optimal**) If no facilities exist to measure the serum potassium, consideration should be given for the empiric addition of potassium to the dialysis solution after 12 h of continuous PD to achieve a dialysate concentration of 3–4 mmol/l. (**practice point**) (**minimum standard**)

3.3 Serum concentrations of electrolytes should be measured 12 hourly for the first 24 h and daily once stable. (**practice point**) (**optimal**) In resource poor settings, sodium and potassium should be measured daily, if practical. (**practice point**) (**minimum standard**)

3.4 In the setting of hepatic dysfunction, hemodynamic instability and persistent/worsening metabolic acidosis, it is preferable to use bicarbonate containing solutions. (>**1D**) (**optimal**) Where these solutions are not available, the use of lactate containing solutions is an alternative. (**2D**) (**minimum standard**)

3.5 Commercially prepared dialysis solutions should be used. (**1C**) (**optimal**) However, where resources do not permit this, locally prepared fluids may be used with careful observation of sterile preparation procedures and patient outcomes (e.g. rate of peritonitis). (**1C**) (**minimum standard**)

## Rationale

### *3.1 Dextrose concentrations of acute PD fluids*

PD solutions for acute PD are generally commercially available with dextrose concentrations of 1.5%, 2.5% and 4.25% (1.36%, 2.27% or 3.86% are equivalent if glucose is measured). The osmolality of the 1.5%, 2.5% and 4.25% solutions are 346, 396 and 485 mosmol/l, respectively, and their use results in an osmotic gradient between dialysate and plasma that promotes fluid removal.[53] Glucose absorption occurs across the peritoneal membrane continuously and is enhanced by small exchange volumes that are typically used for acute PD and which result in a gradually diminished osmolar gradient and less efficient ultrafiltration. In turn, acute PD is usually initiated with a 2.5% dextrose solution in order to achieve effective ultrafiltration when FO exists, and the prescribed fill volume is small to avoid dialysate leakage. Initial use of a 1.5% solution may be appropriate when euvolemia or only mild FO exists. The use of a 2.5% or 4.25% solution in a PD prescription characterized by frequent exchanges can result in hyperglycaemia, especially in young infants, and may necessitate insulin therapy or a modification of the dextrose concentration used. The latter can be achieved by mixing equal volumes of 1.5% and 2.5% dextrose solutions infused through two buretrols connected via a Y-set. Intravenous insulin infusion should be use preferentially (see Table 4). If, however, insulin is to be used by placing it in the dialysis solution, the dose should be appropriate for the dialysis dextrose concentration. Typical initial doses are as follows, with adjustment based on frequent blood glucose monitoring, which should only be used in event of hyperglycaemia, not routinely in all patients[53]:

4–5 units/l for 1.5%;
5–7 units/l for 2.5%; and
7–10 units/l for 4.25%.

Caution should be used when using insulin because of the risk of hypoglycaemia (see Table 4, for initial dose of IVI insulin).

### *3.2-3.3 Dialysate and serum electrolytes*

The potassium concentration of the dialysis solution should be negligible (0–2 mmol/l) at treatment initiation as many patients will present with hyperkalaemia, often accompanied by metabolic acidosis. Once a normal serum potassium concentration is achieved, as typically occurs over the initial 6–12 h of dialysis, the concentration of potassium in the dialysis solution can be gradually increased to a concentration of $\leq$4 mmol/l with ongoing modification dependent on factors that influence the serum potassium level (e.g. dialysate dextrose concentration, serum $CO_2$, medications, parenteral nutrition, etc.). If no facilities exist to measure the serum potassium, consideration should be given for the empiric addition of potassium to the dialysis solution after 12 h of continuous PD to achieve a dialysate concentration of 3–4 mmol/l. Losses of potassium can be high in acute PD and its removal may cause serious potassium depletion and cardiovascular instability. Hypokalaemia might be prevented or corrected by adding potassium to the dialysis solution (4 mmol/l).[54,55]

If supplemental calcium is needed (see below), it must be given by a route other than in the PD solution to prevent precipitation. Serum ionized calcium levels must be closely monitored when the dialysate contains a high concentration of bicarbonate to facilitate interventions designed to prevent the development of tetany. It should also be noted that bicarbonate loss from dialysate is increased in association

with high ultrafiltration rates as a result of convective clearance.[56] The dialysate sodium concentration is typically 132–134 mmol/l. With only a small concentration gradient between dialysate and plasma, the transport of sodium is primarily by convection. As often occurs with acute PD, rapid cycling with hypertonic dialysis solutions to promote ultrafiltration can result in hypernatremia as a result of enhanced free water clearance secondary to sodium sieving and transport of water through aquaporin channels.[57,58] The removal of free water is greatest during the initial 30–60 min of each exchange. If hypernatremia develops, consideration should be given to extending the dwell time if solute clearance allows or lowering the concentration of glucose in the dialysis solution. If rapid cycling is needed for solute removal and fluid balance is neutral or negative, a hypotonic fluid such as 0.45% saline can be infused intravenously to match the net ultrafiltration from PD.

### 3.4 Bicarbonate-based PD fluids

The inclusion of alkali in the dialysate helps to correct the acidosis that may accompany AKI. Whereas many commercially prepared dialysis solutions for acute PD are lactate based with a concentration of 35–40 mmol/l, more biocompatible solutions (e.g. bicarbonate or lactate/bicarbonate-based) are available in countries other than the United States and have been used for the provision of acute PD in children.[59] On occasion, infants and young children do not tolerate the lactate absorbed from the dialysis solution in the setting of hepatic dysfunction, hemodynamic instability and persistent/worsening metabolic acidosis. In these situations, use of a commercial or pharmacy prepared bicarbonate-based solution is preferable. Whereas there are no specific paediatric data on this topic, the adult literature does not provide strong evidence of an advantage using a bicarbonate versus a lactate-based solution in clinically important outcomes such as mortality and adverse events. However, in the one randomized, controlled trial in adult patients, those patients in shock who were treated with bicarbonate-based PD fluids, had a significantly better lactate level, bicarbonate level and pH compared to those using lactate-based solutions.[60]

### 3.5 Locally mixed fluids

Commercially available solutions are produced to high standards with strict asepsis and careful monitoring for bacterial and endotoxin contamination. On the other hand, locally prepared solutions carry the potential risks of contamination and mixing errors which may be life-threatening. The use of hospital pharmacy prepared solutions has previously been reported in children to be associated with low peritonitis rates and good patient outcomes.[16,61] More recent publications from Africa have also demonstrated good outcomes using the beside preparation of PD fluids made from commercially available intravenous fluid. Palmer et al. performed a retrospective review of all acute PD patients and showed no difference in peritonitis rates between those treated with commercial solutions and those using a locally mixed solution.[62,63] A retrospective survey based on the care of 49 children from Cape Town, South Africa using bedside prepared PD solutions, made from intravenous fluids, showed a low frequency of peritonitis (4.1% of patients) and no complications.[36] It should be emphasized that commercial solutions often have closed drainage systems to prevent accidental contamination, in contrast to the makeshift connections which may be needed for locally prepared solutions. Finally, cost is often a factor which may limit utilization of commercially produced solutions in low-resource settings, particularly if patients are paying for their own care. The costs include both the cost of purchasing the solutions and the costs for transportation, taxes and bureaucratic assessments.

The ISPD recommends the following types of fluid in order of preference:

1. Commercially prepared solutions.
2. Locally prepared solution made in an approved and certified aseptic unit/pharmacy. These products would have a limited expiration time as approved by the manufacturing unit (see http://www.ashp.org/DocLibrary/BestPractices/PrepGdlCSP.aspx, for guidelines on standards for compounding pharmaceuticals).
3. Solutions prepared in a clean environment with a minimum number of punctures and the least number of steps. This fluid should be used immediately.

Appendix 1 provides examples of how to mix PD solutions using commonly available intravenous fluids to approximate commercially prepared solutions (Tables 2 and 3). It should be noted that in making solutions using the above-mentioned approach, calcium and magnesium may be present. In general, this is not a problem for acute PD, which is usually of short duration. Many of the plasma expanders that are used to make PD solutions contain potassium. In situations where hyperkalaemia is a problem, this is not ideal. After the first 24 h, however, it may be beneficial as potassium is often added to the PD solution to prevent hypokalaemia.

General rules when preparing dialysis solutions:

- The concentrations of the well-known IV solutions may vary from country to country, so check concentrations before mixing.
- Maintain absolute strict sterile technique when mixing solutions.
- The fewer components added to the solution, the lower the risk of infection and error.
- Avoid mixing bicarbonate and calcium as they will precipitate.

**Table 2.** Commercially available intravenous fluids.

| Type of fluid | Na+ | K+ | $Ca2^+$ | Mg | $Cl^-$ | $HCO_3-$ | Lactate | pH | Osmolality |
|---|---|---|---|---|---|---|---|---|---|
| Hartmann's solution | 131 | 5[a] | 2.0 | | 111 | | 29 | 7.0 | 278 |
| Ringer's lactate | 131 | 5[a] | 1.8 | | 112 | | 28 | 6.5 | 279 |
| Plasmalyte B | 130 | 4[a] | 0 | 1.5 | 110 | 27 | | 7.4 | 273 |
| ½ Normal saline | 77 | | | | 77 | | | 5.0 | 154 |

[a]Potassium concentrations vary in different countries.

**Table 3.** Typical compositions of some commercially available PD fluids.

| Type | Na+ | K+ | Ca2+ | Mg | $Cl^-$ | $HCO_3^-$ | Lactate | pH | Osmolality |
|---|---|---|---|---|---|---|---|---|---|
| Fresenius Balance 1.5%$^{tm}$ | 134 | | 1.25 | 0.5 | 100.5 | | 35 | 7.0 | 356 |
| Baxter Dianeal 1.5%$^{tm}$ | 132 | | 1.25 | 0.25 | 95 | | 40 | 5.2 | 344 |
| Baxter Physioneal 1.5%$^{tm}$ | 132 | | 1.75 | 0.25 | 101 | 25 | 10 | 7.5 | 345 |
| Fresenius Bicavera 1.5%$^{tm}$ | 134 | | 1.75 | 0.5 | 104.5 | 34 | | 7.4 | 358 |

PD: peritoneal dialysis.

### *Further additives to PD fluid*

Common practice is to add heparin (500 IU/l) to the dialysis fluid to prevent fibrin clots,[64,65] however this practice does vary between centres. In cases of hypernatremia in conjunction with AKI, in which the patient requires dialysis, hypertonic sodium (3% or 5%) can be added to the PD fluid to increase the sodium concentration in the PD fluid to within 15 mmol of the patient's serum sodium. This will allow for a more gradual reduction in the serum sodium. Antibiotics are commonly added to the peritoneal fluid in order to treat peritonitis.[45]

*Note:* Peritoneal dialysate effluent may harbour viable infectious microorganisms including infectious viruses and should therefore be disposed of in an appropriate manner.

4. Prescription of acute PD in paediatric patients
   - 4.1 The initial fill volume should be limited to 10–20 ml/kg to minimize the risk of dialysate leakage; a gradual increase in the volume to approximately 30–40 ml/kg (800–1100 ml/m$^2$) may occur as tolerated by the patient. (**practice point**)
   - 4.2 The initial exchange duration, including inflow, dwell and drain times, should generally be every 60–90 min; gradual prolongation of the dwell time can occur as fluid and solute removal targets are achieved. In neonates and small infants, the cycle duration may need to be reduced to achieve adequate ultrafiltration. (**practice point**)
   - 4.3 Close monitoring of total fluid intake and output is mandatory with a goal to achieve and maintain normotension and euvolemia. (**1B**)
   - 4.4 Acute PD should be continuous throughout the full 24-h period for the initial 1–3 days of therapy. (**1C**)
   - 4.5 Close monitoring of drug dosages and levels, where available, should be conducted when providing acute PD. (**practice point**)

## Rationale

### *4.1 Fill volumes*

Small fill volumes are generally recommended at the initiation of acute PD and soon after PD catheter placement to decrease the risk of dialysate leakage that may arise because of the PD solution-induced rise in intraperitoneal pressure (IPP).[64] If no leakage occurs, the fill volume can be gradually increased to enhance solute and fluid removal since larger volumes result in more prolonged maintenance of the concentration and osmolar gradients.[66] In general, the fill volume should not exceed 800 ml/m$^2$ in patients <2 years because of the associated rise in IPP that can occur and the resultant reabsorption of ultrafiltrate through lymphatics.[67] Fill volumes > 40 ml/kg (1100 ml/m$^2$) are rarely required if PD is prescribed using a continuous schedule and may result in respiratory compromise in the ICU setting.[68] Morris et al. studied the intra-abdominal pressure (IAP) of six infants undergoing PD within 24 h of cardiac surgery. The IPP was measured at fill volumes of 10, 20 and 30 ml/kg and although there was considerable variation between the patients, the pressures remained low and there were no deleterious cardiac or respiratory effects.[69] It is worth noting that elevated IAP is an independent predictor of mortality among critically ill children. Paediatric ICU protocols recommend measuring IAP in patients who are at risk for abdominal compartment syndrome. Among others, one of the risk factors is a patient receiving PD.[70] IAP can be measured via a bladder transducer or directly from the peritoneal cavity.

### *4.2 Exchange duration*

The use of short exchange times initially aims to accomplish the desired ultrafiltration and solute removal while the gradients between serum and dialysate are preserved. Although even shorter (<60 min) exchange times have been used on

**Table 4.** Suggested prescription modulation to achieve outcomes.

| | |
|---|---|
| Initial prescription | Fill volume: 10–20 ml/kg<br>Total cycle: 60–90 min. Fill: 5–10 min; dwell: 30–60 min; drain: 10–20 min<br>Initial glucose concentration: 2.5%<br>Heparin 500 IU/l<br>PD over a full 24-h for 1–3 days |
| *Problem* | *Modification to prescription* |
| Poor ultrafiltration | (1) Rule out access issues or peritoneal leak<br>(2) Increase glucose concentration (1.5%→2.5%→4.25%) (or 1.36, 2.27 and 3.86% in some areas)<br>(3) Decrease exchange duration by reducing dwell time by ± 25% (reduce fill and drainage times to a minimum)<br>(4) Increase fill volumes 30–40 ml/kg (800–1100 ml/$m^2$)<br>(5) Consider CFPD |
| Hyperkalaemia (emergency treatment required) | (1) Reduce dwell time to 15–30 min (reduce fill and drainage times to a minimum)<br>(2) Monitor potassium levels regularly |
| Serum potassium < 4 mmol/l | Add 4 mmol/l of potassium to PD fluid |
| Difficulty with ventilation/increased intra-abdominal pressure | (1) Reduce fill volume incrementally by 5 ml/kg.<br>(2) Position patient in semi fowlers position (30° head up)<br>(3) Consider measuring intra-abdominal pressure to guide fill volume (either intravesical pressure with a transducer via a urinary catheter or directly from the PD catheter with a manometer)<br>(4) Consider CFPD with very low fill volumes |
| High phosphate | (1) Tolerate if not problematic and limited duration expected. If problematic:<br>(2) Increase dwell times to > 60 min<br>(3) Increase fill volumes 30–40 ml/kg (800–1100 ml/$m^2$) |
| Hypernatraemia secondary to rapid cycling | (1) Increase dwell time to >60 min<br>(2) Reduce dialysate glucose concentration, if possible |
| Hypernatraemia, AKI and requiring dialysis | (1) Add hypertonic sodium (3% or 5%) to PD fluid to within 15 mmol of patient's sodium to allow a gradual reduction in the serum sodium |
| Lactic acidosis AND hepatic dysfunction OR shock OR neonate AND/OR not responding to lactate-based fluids | Use bicarbonate-based PD fluids |
| Hyperglycaemia > 20 mmol/l | (1) Reduce glucose concentration in PD fluid if possible and/or increase exchange duration<br>(2) If not working or not possible:<br>Insulin infusion (start 0.05 IU/kg/h) OR<br>(3) Add insulin to PD bags (see text section 3.1) |
| Development of new pleural effusion | (1) Consider extracorporeal dialysis modality if available<br>(2) Insert chest drain and check fluid for glucose<br>(3) Position patient in semi fowlers position (30° head up)<br>(4) Reduce volume of PD per cycle<br>(5) Measure volume of fluid coming from chest drain and add to fluid balance |

PD: peritoneal dialysis; AKI: acute kidney injury; CFPD: continuous flow peritoneal dialysis.

occasion, such as described in a recent review of the literature of PD in extreme low birthweight (<1000 g) and very low birthweight (<1500 g) premature babies in whom lower fill volumes (7–14 ml) and shorter dwell times (10–20 min) were utilized successfully.[8] Solute removal is often compromised because of the substantial period of time that is spent filling and draining the patient.[71] In general, the inflow time should be 5–10 min (or less) and depends on the amount of fluid to be infused, the height of the bag of dialysis solution relative to the patient and the resistance created by the PD catheter and the associated tubing. The dwell time, that period of the exchange when the dialysis solution remains in the peritoneal cavity, is approximately 30–60 min. Rapid small solute equilibration rates in small children on acute PD support these short exchange durations.[72] The drain time should typically be 10–20 min and is dependent on the volume of fluid to be drained, the resistance of the catheter and tubing and the height difference between the patient and the drainage bag. As noted previously, frequent exchanges increase the risk for hypernatremia and mandates close monitoring for these

laboratory abnormalities.[57] Finally, the exchange duration can gradually be prolonged in association with an increasing fill volume to a regimen comparable to what is used for chronic dialysis, dependent on the tolerance of the patient and the ability of the regimen to meet the solute and fluid removal goals.

### 4.3 Fluid balance

Paediatric patients with AKI are frequently hypervolemic and substantial FO has been associated with an increased risk for morbidity and mortality.[73] Fluid removal is an important treatment goal for many patients and it is vital to closely monitor fluid balance. In most cases, the ability to achieve a targeted fluid goal should be reassessed no less frequent than every 2–3 h initially, with subsequent modification of therapy as deemed necessary.

Methods to assess fluid balance include the following:

- Weights conducted every 12–24 h. This is often impractical in an ICU setting where babies are attached to ventilators and other equipment. Some newer ICU beds come fitted with scales.
- Strict monitoring of input and output and calculation of daily fluid balance.
- Determination of cumulative percentage fluid overload (%FO) calculated daily. A useful formula to calculate FO is as follows: $\%FO = (\text{Fluid in} - \text{Fluid out})/(\text{PICU Admission weight}) \times 100\%$.[74]

Ideally, the successful generation of ultrafiltrate with each exchange (plus any urine output that might exist) will result in resolution of the fluid overloaded state, while permitting the fluid needs of the patient for medications, blood products, nutrition and maintenance of hemodynamic stability. The ability to regularly achieve positive ultrafiltration and meet the patient's needs will often require hypertonic dialysis solutions (2.5%/4.25%) and frequent exchanges early in the course of acute PD when the fill volumes are small; modification of the ultrafiltration needs will mandate adjustment of the dialysis prescription.

Ideally, once the patient is euvolemic, the dextrose concentration of the dialysate and the frequency of exchanges can be decreased. Early during therapy, the use of frequent exchanges of hypertonic dialysate can result in substantial fluid removal and on occasion, intravascular volume depletion. Failure to address this issue by decreasing ultrafiltration or increasing the provision of enteral or parenteral fluid can potentially slow kidney recovery. Conversely, monitoring of all sources of intake (e.g. medications, nutrition and blood products) is equally important. Sometimes overlooked is the recognition that a decrease in a patient's insensible fluid loss typically occurs in association with use of a respirator/oscillator and can substantially influence the fluid balance of the small infant. Gradual prolongation of the time interval between assessments can occur once stability of the fluid management has been achieved. These assessments should not occur less often than daily.

### 4.4 Time on PD

In most cases, the use of acute PD with frequent exchanges should be continuous during the initial period of stabilization in order to meet the patient's needs for solute and fluid removal. The frequency of exchanges should be determined by the clinical status of the patient. The small fill volume that typically characterizes the initial prescription limits the efficacy of PD for treatment of AKI and therefore PD typically needs to be continued over a full 24-h period in the acute setting to achieve adequate clearances and fluid removal. Currently, there is no data correlating clearances to outcomes in children on acute PD; therefore, no target dose of dialysis can be set. In two paediatric studies of AKI caused by a wide variety of aetiologies, use of a fill volume of 20 ml/kg and a dwell time of 60 min, resulted in a weekly average creatinine clearances of 75 l/week/1.73 m.[75,76] McNiece et al. measured the clearance in five post cardiac surgery neonates using a fill volume of 10 ml/kg and a dwell time of 20 min. The median weekly creatinine clearance were found to be 74 l/week/1.73 $m^2$ and the median $Kt/V$'s were 4.84.[77] Finally, Ricci et al. determined the creatinine clearance of 20 post cardiac surgery neonates to be 34 l/week/1.73 $m^2$ when using a PD fill volume of 10 ml/kg and variable dwell times.[78] These studies show that despite the low fill volumes and frequent cycles used in paediatrics, clearances are achieved that surpass what is recommended in the adult literature (see adult ISPD guidelines). Reassessment of the patient's needs should occur at least daily. Once the immediate needs of the patient have been met, and most commonly with gradual recovery of kidney function and the achievement of solute/fluid stability, the provision of dialysis during only a portion of each 24 h using an increased fill volume is usually sufficient. It should be emphasized that the use of PD continuously does not inhibit the resolution of AKI.

### 4.5 Medication dose adjustment

Clearance of many drugs may be altered once the patient transitions from AKI with oliguria to PD. This may result in inadequate serum levels, especially with agents such as antibiotics and anticonvulsants and dosing should be adjusted accordingly.

For suggested advice on prescription modulation to achieve desired outcomes, please refer to Table 4.

5. Continuous flow peritoneal dialysis (CFPD)

5.1 Continuous flow peritoneal dialysis can be considered as a PD treatment option when an increase in solute clearance and ultrafiltration is desired but cannot be achieved with standard acute PD. Therapy with this technique should be considered

experimental since experience with the therapy is limited. (**practice point**)

5.2 Continuous flow peritoneal dialysis can be considered for dialysis therapy in children with AKI when the use of only very small fill volumes is preferred (e.g. children with high ventilator pressures). (**practice point**)

## Rationale

Continuous flow PD has been shown in chronic adult PD patients to increase the clearance of small solutes threefold to eightfold and to significantly increase ultrafiltration compared to conventional PD.[79–81] In one of the few studies of this dialysis technique in adult patients with AKI, 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 200–500 ml/h.[54] In two separate studies in children with AKI using CFPD, an approximately fourfold increase in small solute clearance and ultrafiltration was achieved compared to conventional PD.[75,76] In another study in children, successful ultrafiltration was achieved in fluid-overloaded children with acute respiratory distress syndrome using gravity-assisted CFPD.[82]

Practically, single-pass CFPD is what has been described in children. As small volumes of fluid are used in paediatric patients, this is felt to be reasonably cost-effective. To carry out the procedure, a second catheter should be placed in the peritoneal cavity to allow continuous flow. A catheter can be placed on either side of the umbilicus at a position midway between the superior iliac crest and the umbilicus. Alternatively, one of the catheters can be placed below the umbilicus. After filling the abdomen, with the conventional fill volume as described above, dialysis fluid flows continuously through the abdomen. The exact technique differs according to the method used and the reader should refer to the above articles.

Prescription:

- Fill volume of 10–20 ml/kg (can be lower if raised IAP).
  - Dialysate flow rate of 50–100/1.73 $m^2$/min (i.e. flow rate = 50–100 ml min× patients' BSA (body surface area) in $m^2$/1.73 $m^2$).
- Ultrafiltration flow: This can initially be set at 2.5 ml/1.73 $m^2$/min but may have to be adjusted according to actual ultrafiltration.
- Dialysis solution: Adequate ultrafiltration can usually be achieved using 1.5% dialysis solution; however, on occasion an increased dialysis dextrose concentration may be necessary.
- Ultrafiltration: After an initial dialysis period of 2 h, ultrafiltration should be assessed after draining the abdomen completely. After that, a 4-h dialysis session can be prescribed, with modification as needed following re-evaluation of the patient.
- Once the serum potassium falls below 4 mmol/l, potassium (4 mmol/l) should be added to the dialysate solution.

Safety:

- Monitor specifically for blocking of the outflow tubing. Transducers or careful observation of fluid flow are essential.
- Monitoring for raised IAP due to excessive ultrafiltration or blockage in the outflow tubing is recommended. This can be done via a bladder transducer or directly from the peritoneum. Increased ventilatory pressures can be used as surrogate for rising IAP.
- Monitor for excessive ultrafiltration and potassium removal.

### *Managing complications of PD for AKI*

There are a number of potential complications associated with the use of PD for management of AKI in children. Although an in-depth discussion on these is beyond the scope of these guidelines, the following will be discussed briefly:

- peritonitis;
- mechanical complications;
- protein loss; and
- hyperglycaemia.

*Peritonitis.* Peritonitis is a major complication of acute PD. Infection rates vary widely from different centres.[37,83–86] Recommendations that are specific to acute PD (section P2) are given in these guidelines to reduce the rate of infection. Until further data exist that are specific to acute PD, further measure to diagnose, prevent and treat acute peritonitis should be as contained in the paediatric chronic PD guidelines.[45] It should be emphasized that the clinical signs of peritonitis may be masked by the patient's overall illness and additionally, the overall inflammatory state of the patient may influence the likelihood of meeting the chronic PD peritonitis diagnostic criteria. It is therefore reasonable to consider performing a leukocyte count daily for peritonitis surveillance in patients on acute PD. In resource limited settings, this may not be feasible and an alternative method is use of a urine leukocyte esterase dipstick test daily, which if >2+ should prompt treatment while awaiting a confirmatory leukocyte count and culture results. Whereas this approach has shown good sensitivity and specificity in small adult studies, other features such as abdominal pain and fever should also prompt further investigation and possibly empiric treatment.[87,88] Patients in the critical care environment have a high incidence of systemic

candidiasis and there needs to be a high index of suspicion for fungal peritonitis in these patients as well.

*Mechanical complications in Seldinger placed catheters (Cook).* Access dysfunction occurs in Seldinger placed catheters in 10–50% of cases.[16,24,36] When using the soft coiled multipurpose catheters, the occurrence of access dysfunction has been found to be significantly less common.[18,35] The most common described access related complications are catheter obstruction and peri catheter leakage.

If obstruction of the catheter occurs, the following sequential steps can be taken in an attempt to address the blockage:

- Make sure bladder is empty.
- Treat constipation if present.
- Flush catheter with heparinised saline.
- Instillation of tissue plasminogen activator into the catheter can be attempted if fibrin clot suspected; 2.5 mg (1mg/ml) is mixed in 10-ml normal saline and slowly injected into the catheter. The volume to be injected will be determined by the volume of the lumen of the catheter. This is left for 1 h and followed by gentle aspiration and flushing of the catheter.[89,90] Once the catheter is cleared then 500 units of heparin should be added to each litre of PD solution.
- Replace the catheter over a guidewire in the same position.
- Insert a new catheter in a different position.

Peri catheter leak. If this occurs, the following steps can be followed:

- Reduce fill volumes, if possible.
- Consider a period of time off dialysis (vs. continuous for 24 h) in addition to a reduction in fill volume if possible.
- Replace the catheter over a guidewire in the same position with a larger gauge catheter. Multipurpose Cook catheters come in a range of sizes (see Table 1).
- Infuse fibrin glue between the catheter and the tunnel wall.[91,92] (Some clinicians use fibrin glue in this way to prevent catheter leak.)
- Insert a new catheter in a different position.

Insertion of catheter into bladder or bowel. If the catheter is inserted into the bladder, there will be an increase in urethral output on filling the abdomen with PD solution. Similarly, if the bowel is punctured, there may be diarrhoea in association with filling the abdomen or patient may develop clinical signs of peritonitis. Surgical opinion should be sought in suspected cases. If bowel injury is suspected but there are not clinical signs of peritonitis, close monitoring for signs of peritonitis should be carried out with the addition of antibiotics, to cover for presumed intra-abdominal sepsis, for 72 h. If the need for PD is still deemed necessary, after the necessity for surgical repair of a perforation has been ruled out, then a new catheter can be inserted, and PD commenced. Antibiotics commonly used intravenously for intrabdominal sepsis are augmentin (first line) piperacillin + tazobactam and amikacin (second line) or ertapenem (third line). Amikacin use IVI in kidney failure is controversial and should be accompanied by Amikacin drug levels if used. The choice of antibiotic will depend on local bacterial susceptibilities and availability

*Mechanical complications in tunnelled Tenckhoff catheters.* Access dysfunction can occur in 3–30% of cases of children with a tunnelled Tenckhoff PD catheter.[16–18,26,61] Management of access dysfunction of tunnelled Tenckhoff catheters in children is the same as for adults. (See adult ISPD guidelines, for PD in AKI and ISPD guidelines on creating and maintaining optimal PD access.[93,94])

*Pleural effusion.* The development of a pleural effusion following the initiation of acute PD is a relative contraindication to continuing PD. If however clinicians choose to continue PD, the following steps can be followed:

- Insert chest drain.
- Check glucose concentration in fluid to confirm the presence of PD fluid.
- Monitor fluid removal from chest drain and include it in the daily fluid balance.

*Loss of protein from peritoneal membrane.* Protein loss from the peritoneal membrane during acute PD may compromise the patient's nutrition and immune status.[19,95] It is essential that adequate nutrition, specifically extra protein supplementation is given during treatment, preferably with the help of a dietician. In general, patients should receive the dietary reference intakes for protein, in addition to that quantity lost per dialysis. The average amounts lost daily as a result of chronic PD are included in the KDOQI paediatric nutrition guidelines.[96]

*Ventilation problems/raised intra-abdominal pressure.* Children with pulmonary involvement as a component of their acute illness may develop respiratory compromise during PD because of compromised diaphragmatic movement during the dwell phase.[68] This, in turn, may be a relative contraindication to PD. If ventilation problems occur because of PD, this will usually manifest as a decrease in tidal volume when a child is on pressure ventilation or an increase in peak inspiratory pressure when using volume ventilation. If this occurs, the pulmonary compromise may improve by reducing the fill volume by increments 5 ml/kg until the situation improves. If possible, measurement of the IAP after a fill, using either a bladder transducer or directly from the PD catheter using a manometer, may assist in titrating the most appropriate IPV.

*Hyperglycaemia.* Due to the high glucose concentration in PD fluid, there is a tendency to develop hyperglycaemia in acute PD. This decreases the osmotic gradient between PD fluid and serum and should be treated to enable optimal ultrafiltration. Maintenance of normoglycaemia has also been shown to significantly improve survival in critically ill patients. See Table 4, for specific recommendations regarding the management of elevated serum glucose levels.

Potential topics for future research in acute PD:

- Peritoneal transport characteristics
- Comparison of patient outcomes using different PD dosing strategies
- Clearance studies, including cytokine clearance and sodium removal
- Metabolic implications of acute PD in children
- Intraperitoneal pressure studies in children
- Comparison of dialysis efficiency and metabolic changes associated with biocompatible versus standard PD solutions
- Catheter design for neonates, infants and small children
- PD dosing/prescription strategies for neonates
- Strategies to decrease the risk for peritonitis
- Risk factors for non-infectious complications
- Pharmacokinetic and clearance studies of commonly administered medications
- Use of CFPD in children
- Delphi type survey to seek global consensus regarding acute PD recommendations
- Treatment of catheter malfunction in acute PD
- Assessment of pain and discomfort in older children on acute PD

## Acknowledgement

We would like to thank Francis Lalya for his assistance with these guidelines.

## Author contributions

Introduction: Peter Nourse, Mignon McCulloch, Fred Finkelstein and Brett Cullis; Access and fluid delivery for acute PD in children: Mignon McCulloch, Peter Nourse, Sampson Antwi, Alp Numanoglu, Fredrick Finkelstein and Brett Cullis; Peritoneal dialysis fluids for acute PD in children: Bradley Warady and Peter Nourse; Prescribing acute PD in children: Bradley Warady and Peter Nourse; Continuous flow PD: Peter Nourse and Mignon McCulloch; and all authors reviewed and edited the manuscript and approved the final version of the manuscript.

## Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Brad Warady has received previous research support in terms of support of the International Pediatric Peritoneal Dialysis Network (IPPN) from Baxter and the ISPD.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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## Appendix 1

**Table 1A.** Locally mixed peritoneal dialysis fluids.[a]

Dialysis fluid can be made by adding 50% dextrose to either Ringers Lactate, plasmalyte B or Hartmann's solution

- 1 l Ringers Lactate + 30 ml 50% dextrose will make a 1.5% solution
- 1 l Ringers Lactate + 90 ml 50% dextrose will make a 4.5% solution
- 1 l Plasmalyte B + 30 ml 50% dextrose makes a 1.5% dialysis solution
- 1 l Plasmalyte B + 90 ml 90% dextrose makes a 4.5% dialysis solution
- 1 l Hartmann's + 30 ml 50% dextrose makes a 1.5% dialysis solution
- 1 l Hartmann's + 90 ml 50% dextrose makes a 4.5% dialysis solution

Using 0.45% saline then:

- 1 l ½ Normal saline + 40 ml 50% dextrose + 40 ml 8.4% Na Bic + 60 ml 3% NaCl will make a 1.5% dialysis solution
- 1 l ½ Normal saline + 60 ml 50% dextrose + 40 ml 8.4% Na Bic + 60 ml 3% NaCl will make a 2.5% dialysis solution

Using 0.9% saline and 5% dextrose

- 1 l Normal saline + 1 l 5% dextrose + 100 ml 8.4% $NaHCO_3$ makes a 2.5% dialysis solution

Please note the final electrolyte and glucose concentrations of the above solutions:

- 1 l Plasmalyte B/Ringers Lactate/Hartmanns' + 30 ml 50% dextrose (15 g) will generate a solution with the following concentrations: glucose 1.45%, Na 126 mmol/l, $HCO_3-$ 27 mmol/l, K 3.8 mmol/l, Mg 1.45 mmol/l and osmo = 342 mmol/l
- 1 l ½ Normal saline + 40 ml 8.5% Na Bic (40 mmol) + 40 ml 50% dextrose (20 g) + 60 ml 3% NaCl (30 mmol) will generate a solution with approximately the following concentrations: Na ± 130 mmol/l, Bicarb 35 mmol/l, glucose 1.7%, osmo = 345mmol/l
- 1 l Normal saline + 1 l 5% dextrose + 100 ml 8.4% $NaHCO_3$ makes a 2.5% dialysis solution will generate a solution with the following concentration: glucose 2.38%, Na 121 mmol/l, $HCO_3-$ 48 mmol/l, osmo = 374mmol/l

[a]When adding more glucose, the electrolyte concentrations will change slightly but not significantly.