Journal of Veterinary Emergency and Critical Care

Clinical Practice Review

*Journal of Veterinary Emergency and Critical Care* **21**(6) 2011, pp 605–617
doi: 10.1111/j.1476-4431.2011.00679.x

# A clinical review of peritoneal dialysis

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***Abstract***

**Objective** – To review the principles and practice of peritoneal dialysis in veterinary medicine.
**Data Sources** – Clinical and experimental studies and current guideline recommendations from the human literature; and original case studies, case reports, and previous reviews in the veterinary literature.
**Summary** – Peritoneal dialysis involves the exchange of solutes and fluid between the peritoneal capillary blood and the dialysis solution across the peritoneal membrane. It requires placement of a peritoneal dialysis catheter for repeated dialysate exchange. The ideal catheter provides reliable, rapid dialysate flow rates without leaks or infections. Catheter selection and placement are reviewed along with dialysate selection, exchange prescriptions, and overall patient management. PD does not require specific or complex equipment, and it can achieve effective control of uremia and electrolyte imbalances.
**Conclusions** – Peritoneal dialysis is a potential life-saving measure for patients with acute renal failure. Peritoneal dialysis results in gradual decline in uremic toxins. Previously low success rates have been reported. Improved success rates have been noted in dogs with acute kidney injury (AKI) secondary to leptospirosis. Cats also have a good success rate when PD is elected in patients with a potentially reversible underlying disease. Overall, PD remains a viable intervention for patients with AKI unresponsive to medical management. In select patients a favorable outcome is attained whereby PD provides temporary support until return of effective renal function is attained.

*(J Vet Emerg Crit Care 2011; 21(6): 605–617) doi: 10.1111/j.1476-4431.2011.00679.x*

***Keywords:*** acute kidney injury, AKI, cat, dog, renal replacement therapy

## *Introduction*

Peritoneal dialysis (PD) allows the removal of metabolites and water by the administration of a large amount of dialysis solution into the peritoneal cavity. It involves the exchange of solutes and fluid between the peritoneal capillary blood and the dialysis solution across the peritoneal membrane (Figure 1). The physical properties of diffusion, convection, and osmosis (ultrafiltration), apply to exchange fluid and solute in PD.[1] *Fluid exchange* occurs by osmosis, a process by which fluid moves from a solution of lower to a solution of higher osmolar concentration. The osmotic gradient is created by the presence of osmotic agents (ie, dextrose) in the dialysate that draws fluid across the peritoneal membrane. In PD, this movement of water as a result of osmotic gradients is referred to as ultrafiltration. *Solute exchange* occurs by way of diffusion and convection. Waste products in higher concentration in the blood diffuse across the peritoneum into the dialysate and are removed with each fluid exchange during PD. The rate of diffusion across the peritoneum depends on the size and the charge of the particles, as well as their concentration gradient. Urea (molecular weight 60 Daltons) is smaller and diffuses more rapidly than creatinine (113 Daltons).[2] However, clearance of low molecular weight solutes is lower with PD than with hemodialysis.[3] Convection is the movement of solute across a membrane simply because it is trapped in the flow of fluid.[1] This movement of solutes along with water through the peritoneal membrane by solvent drag is in quantities similar to the solutes plasma concentration. Convection allows for additional solute to be transferred beyond that achieved by diffusion alone.

In veterinary medicine, PD has traditionally been indicated for patients with acute kidney injury (AKI) associated with oliguria (<0.25 mL/kg/h) or anuria. It has also been recommended when the blood urea nitrogen (BUN) concentration >35 mmol/L (>100 mg/dL) or the serum creatinine concentration >884 μmol/L (>10 mg/dL) and medical management has failed to elicit a positive response.[4,5] These patients frequently have electrolyte and acid-base disturbances (eg, hyperkalemia,

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The author declares no conflict of interest.

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Submitted July 26, 2010; Accepted August 8, 2011.

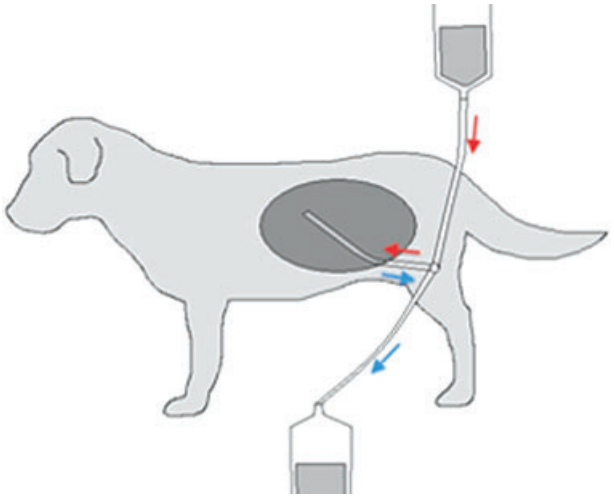

**Figure 1:** Diagrammatic representation of fill and drain phases in PD.

metabolic acidosis), plus or minus volume overload, that can be corrected with PD. PD can also be used for the accelerated elimination of certain dialyzable toxins, for example, ethylene glycol, ethanol, barbiturate overdose, sodium monofluoroacetate poisoning and to address severe hepatic encephalopathy, and hypo- or hyperthermia.[6–8] Similarly, PD can be used for presurgical management of patients with uroabdomen or urinary tract obstruction.[5]

In human medicine, the classical indications for PD are similar to veterinary medicine: azotemia: BUN >35 mmol/L (>100 mg/dL), volume overload, electrolyte imbalance, uremic symptoms, or acid-base disturbances.[9] However, for human AKI patients, PD has been largely replaced by veno-venous renal replacement therapies (ie, intermittent hemodialysis or continuous renal replacement) and optimal timing for initiating renal replacement therapy (RRT) is currently under serious investigation and re-evaluation.[10–12] From the human literature, solute clearance via veno-venous RRT is higher than with PD and PD is considered less effective in treating emergency situations (eg, acute pulmonary edema, drug intoxication) including the AKI patient. Regardless, the timing of veno-venous RRT remains uncertain and there is wide variation in clinical practice. Data from recent human observational and retrospective analyses have suggested improved survival with early initiation of renal support.[10,11] Suggested earlier criteria in these different studies have included BUN > 27 mmol/L (>75 mg/dL), or creatinine > 442 μmol/L (>5 mg/dL) in the asymptomatic patient, or oliguria defined as < 100 mL of urine/8 h with diuresis (~0.17 mL/kg/h over 8 h for the average person).[11] Currently in human medicine, without a consensus, different parameters are considered, including absolute and relative indications such as BUN concentration, oliguria, and volume overload. More than any numerical values, the progression of the disease and the clinical condition and prognosis of the patient should be considered.[11] These same ideas are likely also appropriate for the veterinary patient, regardless of the type of dialytic therapy under consideration.

Although venovenous RRT has largely replaced PD for AKI patients, PD remains a viable option and is widely used in the medical profession throughout the third world. It offers several advantages over venovenous RRT such as technical simplicity, excellent cardiovascular tolerance, absence of an extracorporeal circuit, and decreased bleeding risk.[9] PD results in a gradual decline in uremic toxins, and patients are less likely to develop dialysis disequilibrium syndrome when compared to intermittent hemodialysis. Human studies have demonstrated that continuous PD can provide adequacy in urea control and volume balance.[13–15]

Several case reports have documented the successful use of PD in veterinary patients.[7,16–21] One research study reported support of an anephric dog for 54 d with ambulatory PD.[2] PD can achieve effective control of uremia and electrolyte disturbances. Full replacement of kidney function cannot be achieved, but the basic goals of PD in veterinary medicine are to remove enough solutes and excess fluid, and to control acid-base balance in order to temporarily maintain homeostasis in an animal until sufficient return of renal function is achieved. The availability of different dialysis modalities plays an important role in treatment choice, and PD can be readily performed in any 24-h veterinary intensive care unit.

PD does have some limitations. It is not recommended for patients with severe coagulopathy, or peritoneal fibrosis or adhesions that preclude solute exchange or prevent fluid distribution throughout the abdomen. It is contraindicated in peritonitis, and vascular leak states, or severe hypoalbuminemia. Other relative contraindications include recent surgery or the presence of hernias (diaphragmatic, inguinal, or abdominal).[4,5]

## PD Therapy

### Dialysate selection

Various solutes and water can be added or removed from plasma by altering the electrolyte composition and osmolality of the dialysate fluid.[4] Conventional PD solutions contain glucose, lactate, sodium, potassium, and calcium in differing concentrations. In general, these solutions tend to have a high concentration of lactate and glucose, a high osmolarity, and a low pH. Some human patients react to infusion of the standard PD solution suggesting a component of pain, the latter is thought to be associated with the low pH. The application of new, pH neutral solutions containing lactate, bicarbonate, or

**Table 1:** Composition of conventional peritoneal dialysis solutions* versus lactated Ringer's solution[d] in SI units and US units

| | SI units | | US units | |
|---|---|---|---|---|
| | Conventional PD solution* | LRS | Conventional PD solution* | LRS |
| Sodium | 132–134 mmol/L | 130 mmol/L | 132–134 mEq/L | 130 mEq/L |
| Calcium | 1.25–1.75 mmol/L | 1.4 mmol/L | 2.5–3.5 mEq/L | 2.8 mEq/L |
| Magnesium | 0.25–0.75 mmol/L | – | 0.5–1.5 mEq/L | – |
| Chloride | 96–104 mmol/L | 109 mmol/L | 96–104 mEq/L | 109 mEq/L |
| Lactate | 35–40 mmol/L | 28 mmol/L | 315–360 mg/dL | 252 mg/dL |
| Glucose | 83–236 mmol/L | – | 1,500–4,250 mg/dL | – |
| Osmolarity | 340–512 mOsm/L | 272 mOsm/L | 340–512 mOsm/L | 272 mOsm/L |
| pH | 4–6.5 | 6.5 | 4–6.5 | 6.5 |
| Potassium | – | 4 mmol/L | – | 4 mEq/L |

*Conventional dialysis solution, ie, Dianeal.[c]

a combination of the 2 has shown better preservation of peritoneal cells and better tolerance in adult and pediatric human patients.[22–24] Use of acetate as a buffer has been discontinued in human medicine because it is associated with loss of ultrafiltration and sclerosing peritonitis.[3] Acetate is present in several balanced electrolyte solutions (eg, Plasmalyte A,[a] Normosol R[b]) which are therefore not recommended for PD therapy.

Glucose is the most commonly used osmotic agent and draws fluid across the peritoneal membrane. The standard dialysis fluid glucose concentrations are 1.5% (1,500 mg/dL), 2.5% (2,500 mg/dL), and 4.25% (4,250 mg/dL). The use of glucose makes the solution hyperosmolar; the osmolality of the solutions are 346 mOsm/L, 396 mOsm/L, and 405 mOsm/L, respectively.[1] Increasing the glucose concentration of the dialysis fluid enhances the osmotic gradient favoring the movement of fluid from the blood to the peritoneal cavity containing the dialysis fluid and increases fluid removal. When selecting a PD solution, it is advisable to select a solution with the lowest level of osmolarity consistent with the fluid removal requirements for that exchange to avoid the risk of severe dehydration and hypovolemia and to minimize the loss of protein. Glucose is safe and inexpensive, however, its absorption across the peritoneal membrane leads to short-lived ultrafiltration and metabolic complications reported in human medicine include hyperglycemia, hyperinsulinemia, a decrease in plasma glucagon concentrations, hyperlipidemia, and potential weight gain.[23,25] In the long term, high concentrations of glucose are deleterious to the peritoneal membrane;[23] this is only relevant for the patient on chronic PD. The degradation of large concentrations of glucose in PD solutions give rise to cytotoxic glucose degradation products (GDPs), and GDPs react with amino acids to produce advanced glycosylation end products (AGEs) which cause fibrosis of the peritoneal membrane and contribute to ultrafiltration failure.[26]

In human patients receiving long-term PD, alternative osmotic agents to dextrose have been evaluated. Icodextrin, a glucose polymer, has limited absorption across the peritoneal membrane, and induces colloid osmosis, which contributes to a slow but sustained ultrafiltration.[3,22] A 7.5% solution is iso-osmolar (286 mOsm/L). It is indicated, in human PD patients, for once daily use during a long dwell time (8–16 h/overnight) and is alternated with standard dextrose solutions. This combination maintains solute removal using the dextrose solution, and optimizes ultrafiltration with the icodextrin solution. More recently, amino acids have been used as an osmotic agent mainly because of an assumed positive effect on nutritional status.[25] A total of 1.1% amino acid solutions can only be used in a single daily exchange or mixed with glucose solutions, since they tend to worsen acidosis and increase urea load.[27,28] They also have a high osmolarity and a low pH. To the author's knowledge, icodextrin and amino acid containing PD solutions have not been clinically evaluated in veterinary medicine.

Commercial dialysates (ie, Dianeal[c]) are available and considered ideal for PD use. If a commercial dialysate is not available, lactated Ringer's solution[d] (LRS) can be used in its place with additional dextrose, and appropriate additions based on the patient's metabolic presentation.[4–6,16,17,29] (Table 1). Normal saline (0.9% NaCl) is another short-term, potassium-free alternative; however, 0.9% NaCl predisposes to the formation of peritoneal adhesions and fibrosis and is not recommended for human patients who frequently require long-term PD for chronic renal failure.[30]

If a commercial dialysate is not available, preparation of a dialysate solution in-house must follow strict aseptic techniques. Dextrose should be added to these solutions to make approximate 1.5%, 2.5%, or 4.25% solutions (1.5% solution – add 30 mL 50% dextrose to 1 L fluid, 2.5% solution – add 50 mL 50% dextrose to

 

1 L fluid, 4.25% solution – add 85 mL to 1 L fluid). The concentration of dextrose depends on the hydration status of the patient with higher dextrose concentrations achieving improved ultrafiltration and water removal. A 4.25% solution should only be used when patients are fluid overloaded, and a 1.5% solution is generally adequate in normovolemic patients. Although infrequently required, potassium, magnesium, and calcium can be added to the dialysate based on the patient's electrolyte status.[6,24] The potassium concentration in LRS[d] is 4 mmol/L (4 mEq/L), this is generally low enough to be used in hyperkalemic patients while still correcting moderate-to-severe hyperkalemia. If normal saline is used, sodium bicarbonate should be added as a buffer solution at 30–45 mmol/L (30–45 mEq/L).[6,23] The addition of heparin to the dialysate solution has previously been recommended to decrease clot formation and improve dialysate outflow; however, commercial dialysate does not contain heparin. The recommended dose of unfractionated heparin in veterinary medicine has ranged from 250 U/L to 1,000 U/L.[4,5,31] The most recent recommendations suggest 500 U heparin/L added during the initial exchanges and up to 5 d thereafter.[5,6] Heparin is minimally absorbed at this dose range.[5] Antibimicrobials are not routinely added to dialysate. Addition of electrolytes or medications to the dialysate should always be from a new/uninvaded vial and all injection ports should be cleaned with alcohol prior to injection. Ideally, a mask and sterile gloves should be worn while preparing dialysate. Dialysate should be warmed to body temperature (preferably 38°C, [100.4°F]) prior to infusion.

### *Peritoneal Access*

#### Catheter selection

The ideal catheter provides reliable, rapid dialysate flow rates without leaks or infections.[32] A multitude of PD catheters and insertion techniques have been evaluated; however, no consensus in human medicine regarding optimal catheter type or implantation method has been reached.[32–37] An ideal catheter type has not been established in veterinary medicine. Most catheters are manufactured of silicone elastomer or polyurethane and have numerous side holes to allow for the influx and outflow of dialysis fluid. Catheter options are numerous, but include simple tube catheters with stylet/trocar (multipurpose catheters), Tenckhoff[e] catheters, the Blake silicon fluted drain,[f] the fluted T catheter,[g] the acute PD catheter with coaxial design,[h] and Jackson Pratt surgical suction drains.[i] Early outflow failure is often noted in veterinary PD patients, this may be due to improper catheter placement (kinking, obstruction), omental entrapment, or clot formation. Despite many newer catheter designs, the conventional straight Tenckhoff catheter remains the most widely used catheter in human PD patients.[37] This catheter is a straight or coiled, multifenestrated silicon catheter (Figure 2). The Tenckhoff catheter has not been widely evaluated in veterinary patients. Previous reports have noted that when these catheters were used for dogs and cats, the catheters often obstructed by the mesentery or omentum.[19] The coiled catheter design provides increased bulk of tubing to separate the parietal and visceral layers of the peritoneum. Flow in and out of the tip of the catheter is more protected and there are more sideholes for outflow. In human medicine, it is believed that this design allows for better flow and less propensity for catheter migration and omental wrapping; however, conclusive evidence for this is lacking.[32] Placement of the Tenckhoff catheter can be performed by mini-surgical approach, via laparotomy, or by percutaneous blind or fluoroscopy-guided placement. A recent report evaluating PD in cats used Blake silicon drains[f] that were attached to a closed intermittent negative pressure collection system.[j,21] These drains use fluted channels to replace the distal drainage holes of the Tenckhoff catheter. This set up achieved successful PD in all cats with an average PD duration of 75 h.[21] The T-fluted catheter,[g] like the Blake drain, uses long, inverted T-shaped channels. It has both a cranial and a caudal segment from the point of abdominal insertion (T-shaped), and is designed to drain the cranial peritoneal space and avoid omental attachment. In veterinary medicine, the T-fluted catheter[g] has shown good results,[38] and is favored by some veterinary PD users. In human medicine it is suggested that the fluted T catheter may be a useful alternative for patients at high risk of catheter failure or for standard PD patients.[35,37] The T-fluted catheter[g] requires surgical placement (or a specialized peritoneoscope for mini-laparoscopic placement). Another option is the acute PD catheter with a coaxial design[h] that must be placed surgically. A historical alternative was the column-disc catheter. This catheter was effectively used in veterinary medicine[2,7,18,39] and has experimentally maintained PD in an anephric, omentectomied dog for 54 d.[2] Despite its experimental long-term use, its

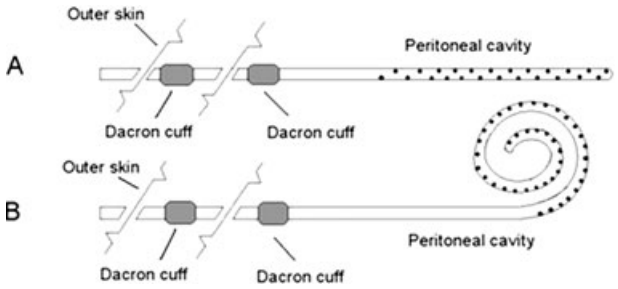


**Figure 2:** Tenckhoff peritoneal dialysis catheters (A) straight and (B) coiled.

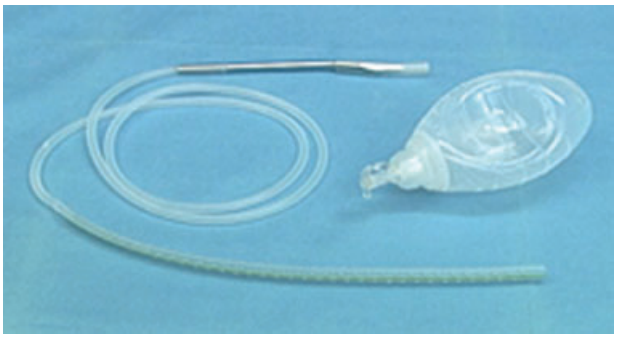

**Figure 3:** Jackson Pratt surgical suction drain and active collection system evacuator. Image provided by B. Brisson and reprinted with permission.

clinical use has not been further reported on, and the catheter has been discontinued. Other multipurpose catheters, percutaneous cystotomy tubes (ie, Malecot or Stamey catheters), or a pneumothorax catheter,[k] have been attempted in veterinary medicine when PD catheters have not been readily accessible;[4,17,19] outflow failure seriously limits their use. The author has also used a 14-G chest tube[l] placed via Seldinger technique for percutaneous peritoneal access for interim management (<24 h), until a more "permanent" catheter can be placed. These catheters invariably kink and become obstructed within 12–24 h. Currently, Jackson Pratt surgical suction drains[i] have been used in several institutions with less occlusion than noted by other multipurpose straight tube catheters. These catheters are very similar to the straight Tenckhoff catheter and are placed by mini surgical approach. Several days of successful PD have been achieved using these catheters and the author recommends these catheters to other alternatives if commercial PD catheters are not readily accessible. When these catheters are used, they can be adapted to active continuous suction collection evacuators (bulbs)[m] (Figure 3) or to a passive closed collection system (ie, IV line and empty sterile IV bag). Some users feel that the active suction helps minimize catheter occlusion. Larger collection system reservoirs[j,n] are available for use in medium-to-large size dogs that require the collection of larger effusate volumes.

Most chronic commercial PD catheters have attached Dacron cuffs that serve to anchor the catheter in place and provide a barrier to infection. Current human guidelines recommend the use of catheters with 1 or 2 cuffs.[33,34] Cuffs are positioned in the musculature ± the subcutaneous space, 2–3 cm prior to skin exit.[37,40] Over several days, fibroblast ingrowth anchors the Dacron cuff(s) however, the utility of the Dacron cuff is lessened with immediate catheter use in acute PD management. Dacron cuffs make catheter removal more difficult, as surgical excision is needed. Alternative catheters to commercial PD catheters routinely do not have Dacron cuffs.

**Catheter placement**

Techniques described for insertion of the PD catheter include: mini-surgical approach, blind percutaneous placement using a trocar or using a guidewire (Seldinger technique), or direct visualization by laparoscopic placement. No method has proven to be more advantageous in human medicine.[32,33,37] Laparoscopic catheter placement has not been evaluated in veterinary medicine. Catheter selection may dictate placement as previously discussed. Omentectomies have been recommended due to omental entrapment of the PD catheter. This procedure requires a more extensive laparotomy than necessary for catheter insertion. Omentectomies are strongly advised if a patient is already undergoing exploratory laparotomy. In addition, in veterinary medicine, omentectomies have been recommended when PD is anticipated for greater than 3 d when using simple tube catheters or the Tenkhoff catheter.[5,19,40] However, new peritoneal catheter designs may make this procedure unnecessary.[5]

Catheter placement is performed using strict aseptic technique preferably in a surgery suite. A urinary catheter should always be placed prior to PD catheter placement to prevent bladder trauma on PD catheter insertion. Most veterinary patients needing PD are mentally very depressed secondary to AKI, and mild sedation and local anesthesia are frequently sufficient regardless of technique for catheter placement (percutaneous or mini-surgical approach). Sedation protocols with minimal cardiovascular depression are recommended and include IV opioids (eg, hydromorphone, fentanyl) ± benzodiazepines if necessary.[41,42] Alternatively general anesthesia using inhalant anesthesia can be utilized for more alert animals. With the patient in lateral or dorsal recumbency, the abdomen is clipped from the xiphoid to the pubis and surgically prepared. It is essential that the animal be draped and aseptic technique maintained to prevent contamination of the peritoneal catheter and system. Administration of a prophylactic dose of a first generation cephalosporin (ie, cefazolin) is recommended prior to PD catheter insertion in human medicine;[37,43,44] this practice should be extended to veterinary patients. Human medicine, has also strongly suggested a subcutaneous tunnel for all types of catheter placement to decrease the incidence of peritonitis and to decrease the risk of dialysate leak;[34] this practice should also be encouraged in veterinary patients. Lidocaine is infused, for analgesia, at the skin, and abdominal entry sites, and over the length of the planned subcutaneous tunnel.

Percutaneous placement of a PD catheter can be performed using a catheter with trocar, or via a modified

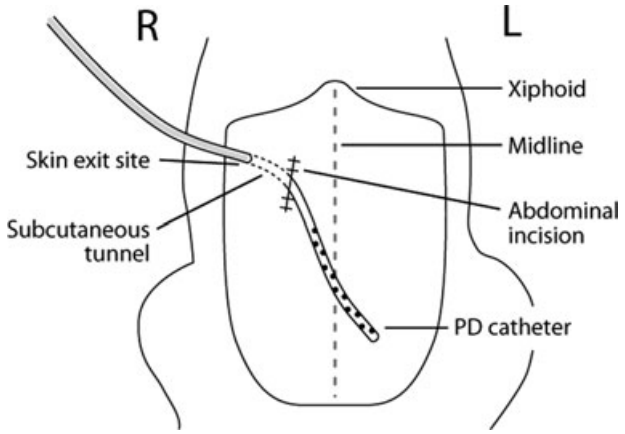


**Figure 4:** Catheter placement via mini-surgical paramedian approach. A skin incision, to the right of midline, is extended into the peritoneal cavity. The PD catheter is positioned extending into the pelvis. The opposite (distal) end of the PD catheter is tunneled through the subcutaneous tissues to exit the skin approximately 5 cm from the abdominal incision.

Seldinger technique, with a system developed specifically for placement of intraabdominal PD catheters. The catheter can enter the abdomen on midline or via a paramedian approach, at the level of the umbilicus.[33] In human medicine, a midline approach through the linea alba has been recommended for trocar insertions.[32] The human literature recommends prefilling the abdomen with sterile saline prior to blind puncture.[24] A small skin incision (<0.4 cm) is made with a scalpel (ensure a small incision such that a tight seal is maintained around the catheter after its insertion). A fair amount of pressure is required to advance the trocar into the abdomen, use the gloved nondominant hand as a guard and allow only 1–2 cm of the trocar to penetrate the abdomen to avoid accidental laceration of abdominal organs. Once in the abdomen, the PD catheter is advanced off the stylet, into the abdomen, and directed caudally and positioned in the lower pelvis, in an unobstructed location. Once the intraabdominal portion of the catheter has been placed, tunneling of the distal tip of the catheter within the subcutaneous tissues is performed. Ensure catheter patency prior to securing the catheter by instilling a small volume of dialysate (5 mL) and ensuring easy retrieval. The catheter can be secured with a purse-string suture or with fixation provided in the PD kit (if available).

When a mini-surgical approach is chosen for PD placement, abdominal penetration should be approximately 3–5 cm to the right of midline through the rectus muscle, at the level of the umbilicus (Figure 4). With the patient in dorsal recumbency, a small, 3–5 cm "primary" paramedian skin and subcutaneous incision is made immediately over the planned, blocked, abdominal entry site. A stay suture may be placed in the rectus sheath to allow manipulation of the body wall, and a 2–3 cm incision through the rectus muscle is made into the abdominal cavity. The parietal peritoneum is identified and incised. The surgeon must ensure that full penetration into the abdominal cavity is achieved as the parietal peritoneum is discrete from the body wall off midline and accidental placement of the PD catheter between the muscular body wall and the parietal peritoneum is possible. Once definitive access to the abdomen is achieved, the catheter (with stylet if available) should be directed caudally and positioned in the lower pelvis in an unobstructed location.[37]

As the PD catheter exits the abdominal incision, it can be secured to the rectus sheath using a purse-string suture;[43,45] this has improved early catheter use and has reduced the risk of dialysate leakage in human medicine. Additional measures include a 3 purse-string approach reported in human medicine where a purse-string suture is placed in each of the following layers: parietal membrane, inner, and outer sheet of the rectus fascia.[43] Alternatively, reports in human pediatric medicine document the application of fibrin glue[o] (1 mL), at the peritoneal Dacron cuff, if present, to prevent dialysate leak and offer early catheter use; no secondary adverse effects were noted.[46] Subsequently, the distal tip of the PD catheter is tunneled through the subcutaneous tissues to exit the skin approximately 5 cm from the abdominal incision.

Alternatively, for snug abdominal wall closure, once the PD catheter exits the abdominal incision, the author recommends tunneling the sterile distal end of the PD catheter immediately *under* the external sheath of the rectus abdominus muscle (Figure 5), through a segment of the muscle, prior to its exit through the subcutaneous tissues and skin. The trocar is angled enough to prevent

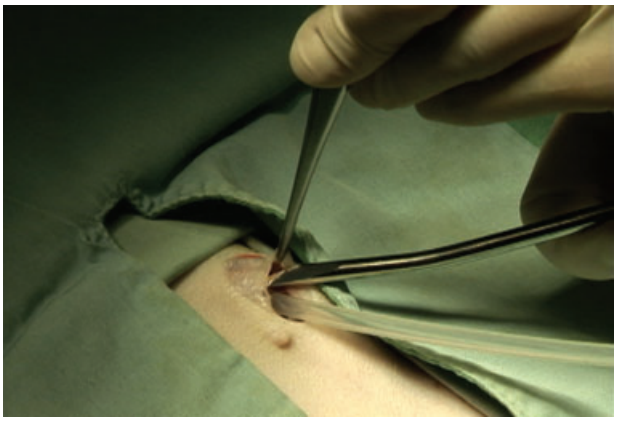

**Figure 5:** Example of isolating the external sheath of the rectus abdominus muscle, and tunneling, with a trocar, the distal end of the PD catheter under the external rectus sheath through a segment of the muscle prior to its exit through the subcutaneous tissues and skin. The trocar is angled enough to prevent accidental abdominal penetration.

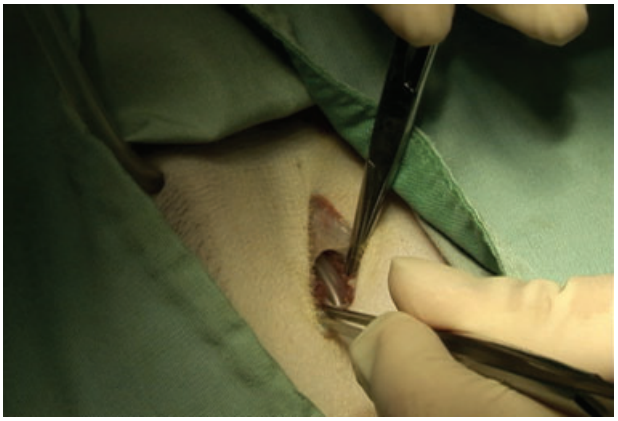

**Figure 6:** PD catheter after tunneling under the rectus sheath. For complete abdominal wall closure, the visible overlying edges of the rectus sheath are completely closed over the underlying PD catheter.

accidental abdominal penetration. This method allows complete closure of the external rectus sheath of the rectus abdominus muscle, at the abdominal entry site, over the underlying PD catheter (Figure 6). The rectus sheath is closed with a simple continuous or simple interrupted suture pattern using an absorbable monofilament suture (eg, PDS,[p] Maxon[q]). Similar tunneling within the rectus sheath has shown improved early PD success in a recent human report.[45]

Regardless of method of catheter placement, prior to final closure of the abdominal entry site, catheter flow should be checked. The catheter is connected to the dialysate solution in a sterile fashion and a small volume of dialysate (2–5 mL) is infused into the abdomen. This small volume of dialysate should easily be retrieved via the collection system to ensure unoccluded catheter placement or the catheter should be redirected. Subsequently, the skin is closed routinely over the abdominal insertion site. Table 2 summarizes the key points involved in PD catheter placement.

Catheters can be secured at the skin exit site with a purse-string suture and fingertrap suture. Reports in human medicine discourage the use of external suture fixation to decrease the risk of exit-site infection, such a recommendation would be ideal in veterinary medicine; however, fixation may be warranted if Dacron cuffs are not present on the catheter, and giving consideration to the noncompliant nature of some veterinary patients, particularly as clinical improvement is noted. A nonocclusive sterile dressing (ie, Opsite[r]), including several layers of sterile gauze, is applied over the catheter exit site. Catheter movement should be prevented at the exit site to allow healing and decrease the risk of exit-site infections. The surgical dressing should ideally not be changed for several days unless there is obvious bleeding or evidence of infection.[32]

During PD insertion, reported human complications can include hemorrhage, perforation of the intestine, kinking of the catheter with drainage problems, catheter malplacement within fascial planes, leakage of dialysate, peritonitis, and wound infection.[43]

**Table 2:** Recommendations for PD catheter placement

- Prophylactic use of a first generation cephalosporin at the time of PD catheter placement.
- Catheter placement using a subcutaneous tunnel.
- Use of a catheter with 1 or 2 Dacron cuffs.
  - Deep cuff placed at an intramuscular location.
- Catheter directed caudally and positioned in the lower pelvis.
- Dialysate flow ensured/confirmed at time of catheter placement.

### Postimplantation dialysis

Once placed, the PD catheter is attached to a commercial closed Y connection system.[5] Alternatively, a closed Y-system can be achieved using a 3-way stopcock and IV fluid sets. The PD catheter is attached to the 3-way connector, with one luer lock adapter attached to the dialysate line, and the second line attached to a sterile collection system (empty sterile IV bag or active evacuator). A "flush before fill" technique is recommended where by on each occasion that a new dialysate bag is attached, a portion of the dialysate is first flushed into the collection system, to allow the line to be flushed free of any bacterial contamination, before dialysate infusion into the patient is begun.[5] Aseptic technique should be followed for all bag exchanges.[19]

### Dialysate exchanges

To initiate PD, warmed dialysis fluid is placed into the peritoneal cavity where it remains for a predetermined time (ie, dwell time). This dwell time in human medicine ranges anywhere from 20 min to 6 h depending on the renal status of the patient.[1] During the dwell time, solute and fluid are exchanged across the peritoneal membrane. At the conclusion of the dwell time, the dialysis fluid, containing the solutes and fluid removed from the blood, is drained and discarded. Once the dialysis fluid is drained, the process is repeated with fresh dialysis fluid. Each cycle of fill, dwell, and drainage is an "exchange" and must be accurately recorded.[1] Ideally, a dialysis-free period of 10–15 d is recommended after catheter insertion, when possible.[47] This is impractical in the setting of AKI where hemodialysis is unavailable. In reality, immediate use of PD catheters is much more extensive and several human studies have tried to identify catheter insertion techniques that allow more rapid initiation of abdominal exchanges while decreasing dialysate

**Table 3:** Approach to early catheter use

- Snug catheter placement.
- Good abdominal closure.
  - Three purse-string suture technique.
- Catheter placement using a subcutaneous tunnel.
- Use of Dacron cuff(s).
- Smaller initial infusion volumes.
- Patient positioning.

leakage.[43] Table 3 summarizes recommendations for successful early catheter use.

Initially infusion volumes are small, approximately 10–20 mL/kg to decrease the risk of dialysate leakage and to minimize cardiovascular complications. Warmed dialysate is infused into the abdominal cavity by gravity flow or using an IV infusion pump over a 5- to 10-min period. Throughout the dialysate infusion and dwell time, the patient is monitored for any signs of discomfort, nausea, or respiratory compromise, which would necessitate smaller infusion volumes. Initially, the author recommends that infused dialysate remains in the abdomen for approximately 45 min. Others have recommended shorter (30–40 min) dwell times.[4] For dialysate retrieval, the collection system is placed below the patient and the fluid is allowed to drain by gravity over approximately 15 min. Drain as much fluid as possible. The procedure is repeated hourly until the patient improves and stabilizes. After the first 24 h, the infusion volume can be increased to 30–40 mL/kg if this is tolerated by the patient. In the author's experience, patients often display signs of discomfort once greater than 20 mL/kg of dialysate is infused; should signs of discomfort/respiratory compromise be noted, smaller volumes (eg, 20 mL/kg) are continued indefinitely.

The amount of solute and fluid removed during PD depends on the volume and tonicity of the dialysis fluid, the amount of time the fluid is left in the peritoneal cavity before it is exchanged, and the intrinsic solute transport characteristics of the peritoneal membrane.[1] The rate of *fluid* removal is greatest at the beginning of each exchange and becomes less effective with time as the osmotic gradient dissipates due to the absorption of glucose from the dialysis fluid and due to the dilution of the glucose by the movement of fluid from the blood to the dialysis fluid. Therefore, the amount of fluid removed during PD can be enhanced by increasing the glucose concentration of the dialysis fluid and/or maintaining a maximally effective osmotic gradient by increasing the frequency and decreasing the dwell time of the exchanges. *Solute* exchange during PD results primarily from diffusion of solutes from the blood to the dialysis fluid. The most important determinant of solute exchange is the volume of the dialysis fluid instilled into the peritoneal cavity. As the fill volume increases, more surface of the highly vascularized peritoneal membrane is available for solute exchange.[48] Optimizing PD efficiency includes increasing the fill volume to the maximal tolerable volume and if this does not achieve anticipated improvement in patient status and/or renal parameters, then increasing the number of exchanges to enhance solute clearance.[1] A continuous around-the-clock PD regime is preferred to an intermittent schedule whenever possible.[49] Once patient improvement is noted, and target values are met, dialysis can be extended to every 4–6 h but should continue throughout the 24-h day. For these later fluid exchanges, the dialysate should remain in the abdomen between exchanges (4–6 h).

As a general rule of thumb, dialysate (effusate) volume should equal infused volume if a 1.25% dextrose solution is used, and effusate volume should be more than infused volume if a 2.5% or 4.25% dextrose solution is used for correction of over-hydrated patients. Should effusate be less than infusate at any given cycle, consider patient hydration or catheter occlusion. Patient repositioning may allow successful drainage. Ultimately, if the patient is well hydrated, the author recommends that a single attempt at dialysate re-infusion be performed, without alteration, and frequently the difference in volume is recovered at the next effusion. Records should be kept and the volume of fluid filled and drained is carefully recorded to allow close monitoring of patient fluid balance.[1,4]

**Analgesia, postoperative care**

Patients undergoing PD should be monitored closely and require 24-h care, preferably in an acute critical care setting. Analgesia is essential and should be administered as necessary. Opioids are generally the preferred analgesics due to minimal cardiovascular effects; nonsteroidal anti-inflammatory drugs (NSAIDs) are contraindicated. Ketamine is renally excreted in cats, and its duration of action may be prolonged in cats with renal injury.[50] Nausea may be encountered and antiemetics are strongly recommended. Catheter immobilization is imperative to allow healing at the catheter exit site and to decrease the risk of dialysate leakage. Other requirements include excellent nursing care and particular attention to nutritional status and hydration of the animal. Therapy for the underlying disease process is also necessary. If systemic antibimicrobials are indicated, adjustments in antimicrobial dosage and frequency must be considered. Renally compromised patients may have decreased antimicrobial elimination but PD can lead to subtherapeutic antimicrobial concentrations.[51] For patients in renal failure, antimicrobial dose adjustment are based on pharmacokinetic and pharmacodynamic profiles. For

example, the half-lives of beta-lactams are prolonged in patients with renal failure, but beta-lactams exhibit time-dependent antibacterial activity; consequently, maintenance doses should be smaller but given at the same interval.[51] However, when incorporating PD, antimicrobial elimination is increased and these adjustments cannot be relied upon. Ultimately the use of serum drug concentration is ideal but not frequently possible.

Serial body weight measurements are recommended to assess patient hydration (body weight should be recorded a *minimum* of twice daily). Continuous ECG, blood pressure, and central venous pressure monitoring is also suggested. Packed cell volume, total plasma protein, colloid osmotic pressure, blood glucose, blood gases, and electrolytes are monitored a minimum of every 12–24 h; electrolyte abnormalities (eg, hypo-, hyperkalemia, hypomagnesemia, hyper-hypophosphatemia) are addressed as needed. Creatinine is initially monitored daily. On initiating PD, a measured osmolality should also be monitored daily to help guide the dextrose concentration/osmolality of the dialysate selected to approximate the osmolality of the patient. A complete blood cell count should be evaluated routinely, and repeated if any indication of patient deterioration is noted. Finally, dialysate effusate should be evaluated at each exchange. Should a cloudy dialysate develop, cytology, gram stain, and culture of the dialysate should be performed.

The adequacy of dialysis is evaluated by interpreting all relevant clinical data including both the patient status (eg, hydration status, appetite, energy level) and laboratory status (eg, electrolyte and acid-base status, and renal parameters [urea and creatinine]).[49] Response to therapy and an increase in urine production are signs of some renal recovery. For additional prognostication, renal biopsy can determine the severity of the lesion and the integrity of the tubular basement membrane in patients with AKI.[52] Renal biopsy may also aid in establishing an accurate histologic diagnosis. Contraindications to renal biopsy include the presence of an uncorrectable coagulopathy, severe anemia, hydronephrosis, uncontrolled hypertension, large or multiple renal cysts, perirenal abscess, extensive pyelonephritis, and end-stage renal disease.[52] The decision to pursue renal biopsy must consider the risks and benefits to the patient. Concerns include complication from renal biopsy (eg, hemorrhage, clot obstruction of the renal pelvis or ureter, renal infarction, loss/worsening of renal function),[53] and delay in histopathological results where response to therapy may precede histopathology findings. Hemorrhage has been reported post renal biopsy in 9.9% and 16.9% of dogs and cats, respectively;[53] and it is reported to be more likely in dogs weighing less than 5 kg, and in patients with severe azotemia (creatinine > 442 μmol/L [5 mg/dL]), uncontrolled systemic hypertension, or coagulopathy (thrombocytopenia [platelet count $< 80 \times 10^9$/L [$80 \times 10^3/\mu$L]] [cats and dogs], prolonged prothrombin time [dogs], and a prolonged activated partial thromboplastin time [cats]).[53,54] These findings are frequently identified in the severe oliguric to anuric AKI patient; strict monitoring for perirenal hemorrhage post biopsy and availability of blood products is suggested should the patient require transfusion.

**Discontinuing dialysis**

Dialysis should be continued until urine production is noted, renal function is adequate, and the patient is clinically improving. A specific creatinine value cannot be suggested as animals will differ in their response to azotemia. For patients with temporary renal failure, urine production may return over several days (3–5 d), over which time dialysis can be reduced, and intermittent dialysis performed, with less frequent exchanges extended to every 4–6 h. As urine production returns, animals generally become polyuric, and renal dysfunction can thereafter be treated medically without continued PD use.

**Complications**

Complications associated with PD include catheter obstruction and migration, dialysate leak, inadequate dialysis, the development of hypoalbuminemia, electrolyte abnormalities, pelvic limb edema, pleural effusion, catheter exit-site infections, and peritonitis.

**Noninfectious problems**

Hypoalbuminemia may readily develop in patients during PD. Hypoalbuminemia may be caused by low dietary intake, gastrointestinal or renal protein losses, loss of protein in the dialysate, and uremic catabolism.[5] Ensuring nutritional supplementation is key. Enteral feeding is ideal, either by nasoesophageal feeding tube or esophagostomy tube; however, patients are frequently nauseous and/or vomiting and enteral feeding by these routes may not be possible. In these circumstances, a naso-jejunal feeding tube is ideal. Conversely, gastrostomy and jejunostomy tubes are contraindicated with PD because of increased risk of infection and dialysate leak.[5] Patients may require parenteral nutrition (PN). This can be difficult to institute in oliguric patients where volume overload is readily encountered. Also, should hyperglycemia ensue post PN initiation, diffusion/ultrafiltration ratios change and solute clearance by PD can be diminished.

Catheter malfunction is one of the most frequent complications of PD leading to the failure of therapy. No reports have examined PD catheter malfunction in

veterinary medicine; therefore, the following discussion reviews findings in human medicine. These findings are likely similar in veterinary medicine and human interventions may apply. Common extraluminal causes of catheter malfunction are malposition of the catheter (catheter kinking or catheter migration out of the pelvis), fibrous adhesions, omental wrapping, and fibrin or blood clots (which can cause extra- or intraluminal obstruction).[55]

Once the catheter has been placed, passive filling should take no more than 10 min, drainage no more than 15 min.[56] Two different types of slowing of the dialysate flow may be observed: 1-way or 2-way obstruction. The outflow obstruction is characterized by a slow drainage flow making it impossible to drain the peritoneal cavity of the patient properly. Most of the time, this is a sign of catheter displacement.[56] Outflow obstruction is more common and the author has clinically noted similar findings in veterinary patients. Inflow obstruction is generally due to catheter kinking intraperitoneally or at the catheter tunnel or exit site. Other causes of inflow obstruction include intraluminal blood or fibrin clots. Basic rules for preserving catheter integrity suggest that one should never try to aspirate liquid out of an occluded catheter with a syringe (unless very gentle aspiration is used and immediately stopped if any resistance is noted) as this is likely to cause definite obstruction.[56] In human medicine, radiographs are recommended and/or dynamic catheterography for early diagnosis of malfunction.[55,56] Solutions for catheter malfunction depend on the underlying cause – extraluminal occlusion may be relieved by a change in patient position. For catheter kinking, catheter repositioning can be performed surgically or fluoroscopically. Several human observational studies and reports allude to the usefulness of catheter manipulation under fluoroscopic control with up to a 60% success,[37] but no reports have been published in the veterinary literature. Catheters may require replacement, and the frequent occurrence of catheter occlusion suggests the consideration for omentectomy. Intraluminal, 2-way occlusion, is usually due to partial obstruction of the catheter by fibrin or tissue ingrowth inside the lateral holes.[56] If fibrin clotting is responsible, human recommendations include introducing 10–20 mL of dialysate or saline solution several times into the catheter vigorously, at high pressure (using a 20-mL syringe, prefilled with 20 mL solution).[56]

If a mechanical maneuver does not work, fibrinolytic agents have been used in human medicine. Catheter occlusion occurs most often in pediatric patients (ie, smaller lumen PD catheter), shortly after catheter placement, although later occlusions can occur.[47] Fibrinolytics are utilized despite recent catheter implantation; however, increased risk for hemorrhage in the early postoperative period must be considered. In human patients, tissue plasminogen activator (tPA), urokinase and heparin administration into the PD catheter have been recommended.[47,55,57] Thrombolytic therapy with heparin has included the use of 250–500 U/L in the instilled peritoneal solution or 5,000 IU instilled into the catheter for 2–4 h.[55,57] More recently, the use of tPA has been reported in both pediatric and adult human medicine;[47,57] tPA doses in pediatric medicine (age of 3 wk to 16 y) have ranged from 1–10 mg, total dose, using different tPA concentrations (1 mg/5 mL up to 2 mg/mL, with 1 mg/mL being used most frequently) diluted in normal saline, in a volume sufficient to fill the catheter.[47] The tPA dilution is allowed to dwell for 1–2 h (or longer), and then is aspirated, and an attempt is made to drain by gravity. If the occlusion is resolved, the catheter is flushed with heparinized solution before resuming routine dialysis.[47] To the author's knowledge, clot dissolution via these methods has not been reported in veterinary medicine.

Dialysate leakage may be noted. Care in placing PD catheters is critical to decreasing the likelihood of dialysate leakage. If dialysis is required immediately, it should be initiated with small exchange volumes (~10 mL/kg) with gradual increase in fill volumes, patients should be kept immobile, and patient positioning may help to minimize the leak.

Pleuroperitoneal communication has been reported in human PD therapy.[55] The increased intraabdominal pressure may result in a leak of PD fluid from the peritoneal cavity, through the diaphragm, into the pleural space. The pathogenesis probably depends on a localized absence of muscle fibers in the hemidiaphragm. The incidence is very low (<5% in human medicine),[55] but should be a differential for patients that develop pleural effusion during PD treatment.

Inadequate dialysis may also be noted. PD may not provide adequate solute removal, especially in larger patients and in patients with declining residual renal function. PD is ultimately limited by the surface area and permeability characteristics of the peritoneal membrane as well as the volume it can contain.[58]

#### Infectious problems

Adequate care is required to prevent exit site and tunnel infections. The catheter should be immobilized to avoid traumatic lesions and the exit site and subcutaneous tunnel should be inspected and palpated regularly.

### *Peritonitis*

Prevention is the most important method for dealing with peritonitis in PD patients. Aseptic technique should be followed at all times when dealing with the PD

catheter, the exchange set, connections, and while spiking new dialysate bags. Turbidity of effluent is the earliest sign of probable infection.[3] Diagnosis is based on the presence of cloudy fluid with inflammatory cells, presence of organisms on cytology, and positive bacterial growth on culture. The main sources of infection are through the lumen of the PD catheter or around the outside of the catheter. In human medicine, infection is predominantly caused by gram positive skin contaminants such as *Staphylococcus*.[3,32] The veterinary literature also reports that *Staphylococcus spp*. is the most common organism,[5,19,31] but gram negative infections have also been reported and include *Escherichia coli*, *Klebsiella pneumoniae*, *Acinetobacter*, *Proteus*, and *Pseudomonas aeruginosa*.[16] Empiric treatment in human and veterinary medicine involves the addition of antimicrobials to the dialysate;[31,43,59] current evidence states that the intraperitoneal route is more effective than the IV route in preventing treatment failure.[60] In veterinary medicine, a first generation cephalosporin is added to the dialysate as a loading dose of 1,000 mg/L dialysate and is followed by a maintenance dose of 250 mg/L of dialysate, with appropriate dialysate volumes delivered based on body size (proportion of drug to dialysate remains unchanged).[40] Treatment should be continued for 10 d based on culture and sensitivity results. Gram negative and mixed infections are suggestive of intraabdominal pathology and intestinal contamination; surgical exploration is recommended.[44] Pseudomonas and fungal peritonitis are the most serious infectious complications.[3,31,44,55] Culture and sensitivity results should dictate use of other antimicrobials. Unsuccessful management of peritonitis necessitates catheter removal.

**Prognosis**

The prognosis for dogs treated with PD for AKI is relatively discouraging. In a study of 27 dogs and cats treated with PD for AKI or azotemia, only 22% (6 of 27 patients) survived to discharge from hospital.[16] More recently, 4 out of 5 dogs (80%) treated for AKI secondary to leptospirosis survived to discharge from hospital suggesting that PD is effective for the management of uremia in dogs with acute renal failure caused by leptospirosis.[18] Isolated case reports also document successful treatment of patients with acute ischemic renal failure, and ethylene glycol intoxication.[7,17] More recently, a case series evaluating PD in cats revealed a good success rate (5 of 6 cats discharged from hospital) when PD was elected in patients with a potentially reversible underlying disease.[21] Patients recovering from oliguric/anuric kidney injury will frequently require several days (3–7 d) of PD before a positive response in urine production can be noted/assessed. Several more days of hospitalization for ongoing IV fluid support should be anticipated as renal recovery typically involves severe polyuria in the recovery process. Owners of patients willing to undertake PD should be forewarned of a protracted hospital stay and significant expense. Ultimately, the success of PD relies on the intrinsic solute transport characteristics of the peritoneal membrane, and recovery depends on the residual renal function of the patient. Despite low success rates, PD can be an effective tool for treatment of AKI. Owners must be well appraised of the commitment, cost, and prognosis associated with PD. If elected, PD does not require complex equipment, and it can achieve effective control of uremia and electrolyte disturbances in select cases. Therapy results in a gradual decline in uremic toxins, and can provide a temporary measure to control fluid and acid-base balance to maintain homeostasis in an animal until sufficient return of renal function is achieved.

## Acknowledgements

The author would like to thank Drs. Judy Brown and Brigitte Brisson for providing the images.

## Footnotes

[a] Plasma-Lyte A Injection, Baxter, Mississauga, Ontario.
[b] Normosol R, Abbott, Abbott Park, IL.
[c] Dianeal, Baxter Healthcare, Deerfield, IL.
[d] Lactated Ringer's Injection USP, Baxter.
[e] Tenckhoff catheter, Quinton, Kendall, Covidien, Mansfield, MA.
[f] Hubless Blake silicon (fluted) drain (7 or 10 mm), Ethicon, Markham, Ontario.
[g] T-style fluted catheter, Ash Advantage, Medigroup Inc, Aurora, IL.
[h] Acute PD Catheter with Coaxial Design, SurgiVet, Smiths Medical, Dublin, OH.
[i] Hubless Silicon Flat Drain (7 or 10 mm width), Bard, Covington, GA.
[j] J-VAC Reservoir (300 or 450 mL), Ethicon.
[k] Pneumothorax catheter, Cook Medical, Bloomington, IN.
[l] Mila Chest Tube 14-G, Mila International Inc, Erlanger, KY.
[m] Silicone Closed Wound Suction Evacuator, Bard.
[n] Snyder Hemovac wound drainage device (400 mL), Zimmer, Dover, OH.
[o] Fibrin glue Tissucol; Baxter, Deerfield, IL.
[p] PDS*II Suture, Ethicon.
[q] Maxon, Syneture, Covidien.
[r] Opsite, Smith & Nephew, St. Laurent, Quebec.

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