Peritoneal Dialysis in Veterinary Medicine

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KEYWORDS

• Peritoneal dialysis • Acute kidney injury • Anuria • Urea kinetic

Peritoneal dialysis is a modality of renal replacement therapy that is commonly used in human medicine for treatment of chronic kidney disease and end-stage kidney failure. Peritoneal dialysis employs the same principle as other forms of renal replacement therapy: the removal of uremic solutes by diffusion across a semipermeable membrane. In hemodialysis and continuous renal replacement therapy, blood is passed through straw-like semipermeable membranes, which are bathed in a dialysate. By contrast, peritoneal dialysis uses the peritoneum as a membrane across which fluids and uremic solutes are exchanged. In this process, dialysate is instilled into the peritoneal cavity and, through the process of diffusion and osmosis, water, toxins, electrolytes, and other small molecules are allowed to equilibrate. The dialysate is then removed and discarded, carrying with it uremic toxins and water. This process is repeated continuously as needed to achieve control of uremia.

Although peritoneal dialysis is used primarily for the treatment of chronic kidney disease in people, reports from as early as 1923 demonstrate its role in treating acute kidney injury.[1] Its use has also been described for removal of dialyzable toxins and to treat pancreatitis, electrolyte and acid base abnormalities, refractory congestive heart failure, and inborn errors of metabolism. In veterinary medicine, the most common use of peritoneal dialysis is to treat acute kidney injury, though it can be used for any of the aforementioned indications as well.

PHYSIOLOGY OF PERITONEAL DIALYSIS

The peritoneum is the serosal membrane that lines the abdominal cavity. The parietal peritoneum lines the abdominal cavity and is continuous with the visceral peritoneum, which lines the abdominal organs. The visceral peritoneum accounts for 80% of the peritoneal surface area; with the parietal peritoneum making up the remaining 20%.[2] The peritoneum has a surface area that is approximately the same as that of a normal

body surface area; typically 1 to 2 m^2 in an adult.[2] Children have a disproportionately larger peritoneal surface area than adults.[2] Arterial circulation to the peritoneum is supplied by the cranial mesenteric artery for the visceral peritoneum and by the lumbar, intercostal, and epigastric arteries for the parietal peritoneum. The portal system provides drainage for the visceral peritoneum while the caudal vena cava drains the parietal peritoneum. One important clinical implication of this anatomic variant is that drugs that are absorbed via the visceral peritoneum undergo first-pass clearance by the liver. Lymphatic drainage is provided through stomata in the diaphragmatic peritoneum.

Microscopically, the peritoneum is made up of a single layer of mesothelial cells overlying an interstitial layer. The mesothelial cells are covered by microvilli, which contribute greatly to the large overall surface area of the peritoneum. These mesothelial cells are ultrastructurally similar to the type II pneumocytes of the lung, producing a film of glycosaminoglycans that function to lubricate and protect the abdominal viscera.[3] The interstitial layer is made of a mucopolysaccharide matrix with collagenous fibers, peritoneal capillaries, and lymphatics. A basement membrane composed of type IV collagen lies between the mesothelial cells and the interstitium. The interstitium has been described as a 2-phase system, consisting of a balance between a water-rich colloid-poor phase and a colloid-rich water-poor phase.[3] All of these structures act as barriers between fluid instilled into the peritoneal cavity and the endothelial surface of capillaries (**Fig. 1**).

The 3-pore model of peritoneal transport treats the capillary as the limiting factor in solute and water transport across the peritoneum (**Fig. 2**). This model proposes that pores of 3 different sizes mediate this transport. Large pores are present in small numbers, contributing less than 0.1% of total number of pores; they are significantly larger than the other pores, with a radius of 20 to 40 nm. These pores transport macromolecules such as proteins via convection. Small pores have a radius of 4 to 6 nm and are present in large numbers, accounting for 90% to 93% of total pore area.[4] These pores are thought to be involved in transport of small solutes such as urea, creatinine, sodium, and potassium in association with water.[2] The amount of transport is limited by the total number of small pores. Ultrasmall pores have a radius of less than 0.8 nm. These pores are involved in water transport only, and are thought to represent the same aquaporin-1 molecules that are present in the renal proximal tubules and red blood cells.[2] Ultrasmall pores account for 40% of total capillary ultrafiltration.[4] The rate of transport through the ultrasmall pores is determined
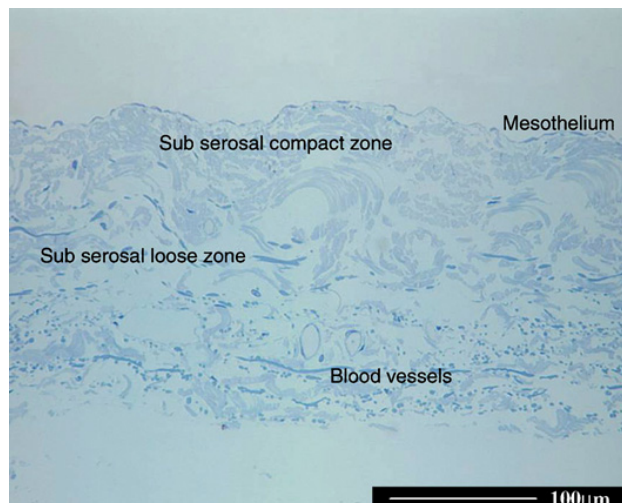

Fig. 1. Histology of the peritoneal membrane. (*Courtesy of* JD Williams, Cardiff University, Cardiff, Wales.)
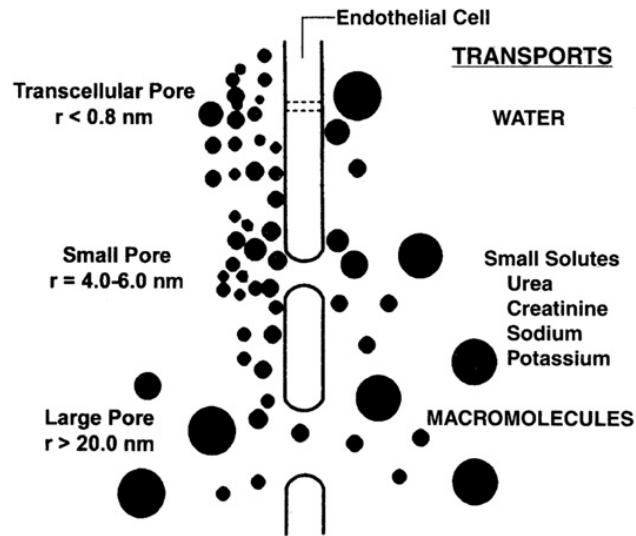
Fig. 2. The 3-pore model. (*From* Daugirdas JT, Blake PG, Ing TS, editors. Handbook of dialysis. 3rd edition. Philadelphia: Lippincott Williams & Wilkins; 2001. p. 284; with permission.)

primarily by osmotic gradient, in contrast to the small pores that are affected by mainly nonosmotic factors.

Diffusion is the most important mechanism responsible for solute transport in peritoneal dialysis. The dialysate, which contains high concentrations of glucose, encourages diffusion of these substances from dialysate into the bloodstream. Molecules in the blood that are not present in high concentrations in the dialysate such as uremic toxins and potassium diffuse from the peritoneal blood into the dialysate (**Fig. 3**) Acid-base disturbances are corrected by having higher concentrations of bicarbonate and lactate in the dialysate than in the plasma, which allows for diffusion of these substances from the dialysate into the body. The rate of diffusion of individual solutes is dependent on many factors, such as the concentration gradient, the molecular weight of solute, and the peritoneal surface area.

Ultrafiltration describes the movement of water across a semipermeable membrane, and can be driven by hydrostatic or osmotic forces. In peritoneal dialysis, a highly osmolar dialysate (the glucose rich solution) causes water to leave the body and enter the dialysate by osmosis. As the water crosses the peritoneal membrane, it carries small molecules into the dialysate (eg, urea, creatinine). This process is also known as convection. Ultrafiltration is an important clinical aspect of peritoneal dialysis that allows manipulation of fluid balance in the patient.

In humans, there is significant variation in the rate of solute transport among different peritoneal dialysis patients. High transporters diffuse substances well but have a low rate of ultrafiltration. Conversely, low transporters have high rates of
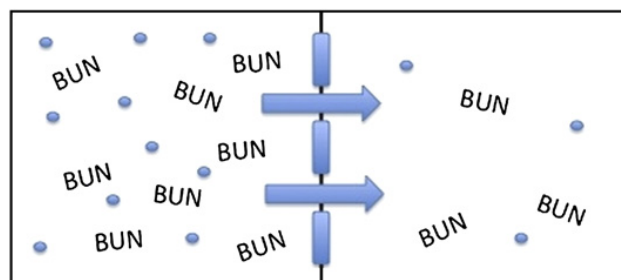

Fig. 3. The process of diffusion across the semipermeable peritoneal membrane.

ultrafiltration but take a longer time for substances to diffuse across the peritoneum. This transport is routinely determined using a peritoneal equilibration test. No studies on peritoneal transport have been performed in veterinary patients. It is not known whether cats or dogs have significant individual variation in their transport status, which may be a contributing factor to the effectiveness of peritoneal dialysis in individual veterinary patients.

INDICATIONS FOR PERITONEAL DIALYSIS

The first and foremost indication for peritoneal dialysis in dogs and cats is anuric acute kidney injury refractory to fluid therapy. Dialysis may also be indicated in nonanuric patients with severe acute uremia, in which the blood urea nitrogen (BUN) exceeds 100 mg/dL, or in which the creatinine exceeds 10 mg/dL.[5] Peritoneal dialysis can also be used to stabilize patients with a uroabdomen or urinary tract obstructions prior to surgery or anesthesia.

Peritoneal dialysis can also be used for a variety of intoxications and metabolic abnormalities. It can be used to remove dialyzable toxins such as ethylene glycol, ethanol, barbiturates, propoxyphene, and hydantoin, and correct electrolyte disturbances such as hyperkalemia.[6,7] However, peritoneal dialysis is limited in its ability to remove toxins from the blood and is about one-eighth to one-fourth as efficient as hemodialysis.[8] In situations where hemodialysis, hemofiltration, or charcoal hemoperfusion is unavailable, vascular access is difficult to obtain or the refractory hypotension makes hemodialysis a high-risk procedure, peritoneal dialysis may be indicated. When performing peritoneal dialysis for intoxications that have life-threatening side effects (hyperkalemia, ethylene glycol), very frequent exchanges should be made to promote a faster rate of clearance.[9] Electrolyte abnormalities such as hyperkalemia and hypercalcemia can also be effectively managed with peritoneal dialysis.

Life-threatening derangements in body temperature can also be corrected with peritoneal dialysis. The concentration of electrolytes in the dialysate solution should be similar to that in plasma to prevent extreme or rapid electrolyte fluctuations.[9] In cases of life-threatening hypothermia, dialysate at a temperature of 42°C to 43°C is instilled into the abdomen with a goal rewarming rate of 1°C to 2°C per hour.[7] In cases of life-threatening hyperthermia, dialysate should be administered at room temperature.[9]

Peritoneal dialysis has also been extensively used in human neonates with disorders of the urea cycle.[7] It is used as an emergency tool for correction of hyperammonemia along with additional medical management to stabilize this condition until liver transplant. It has recently been demonstrated that detoxification is more efficient with hemodialysis or continuous hemofiltration.[10] No studies have been done in veterinary patients to evaluate the utility of peritoneal dialysis to treat life-threatening hyperammonemia secondary to hepatic encephalopathy or urea cycle deficiencies.

Congestive heart failure refractory to medical management is another indication in human medicine for peritoneal dialysis. A recent study looked at patients with severe congestive heart failure, and found decreased mortality with use of hemofiltration followed by automated peritoneal dialysis as compared with patients with similar severities of heart disease.[11] This concept can also be applied to animals with severe volume overload. Exchanges should be performed hourly if the fluid overload is severe, and a markedly hyperosmotic (4.5%) dialysate should be used to encourage ultrafiltration.

CONTRAINDICATIONS FOR PERITONEAL DIALYSIS

Peritoneal dialysis is contraindicated in patients with peritoneal adhesions, fibrosis, or malignancies.[12] The presence of adhesions or fibrosis effectively decreases the surface

area and the efficiency of peritoneal dialysis. Peritoneal dialysis is also contraindicated in patients with pleuroperitoneal leaks because of their predisposition to develop pleural effusion during dialysis.[12] Relative contraindications exist for patients with recent abdominal surgery, and inguinal or abdominal hernias because of the risk for herniation caused by increased intraperitoneal pressures. Patients in a severe hypercatabolic state such as burn victims or extremely malnourished states have a relative contraindication due to their propensity for protein loss through the peritoneum during dialysis.[6] Animals with recent abdominal surgery, especially gastrointestinal surgery, are at risk for dehiscence and infection during peritoneal dialysis because of the increased intraperitoneal pressure and potential fluid leakage through the incision site.[13]

CATHETERS AND CATHETER PLACEMENT

The ideal peritoneal dialysis catheter allows adequate inflow and outflow of dialysate, prevents subcutaneous leakage, and minimizes infection, in both the peritoneal cavity and the subcutaneous tissue.[14] Many of the common complications associated with peritoneal dialysis in veterinary medicine are catheter related, so it is important to consider different catheter types and placement techniques when choosing this modality.

Acute peritoneal dialysis catheters are designed to be placed percutaneously cage-side with a stylet in animals with sedation. These catheters are typically straight with holes at the distal end on the catheter tip. Acute catheters generally do not have cuffs to protect against bacterial infection and catheter migration, which is likely to lead to a high rate of peritonitis with prolonged use.[3] There is also an increased risk of bowel perforation during placement of these catheters.[14]

Chronic peritoneal dialysis catheters have specific designs in both the intraperitoneal and extraperitoneal portions of the catheters to reduce side effects and minimize clogging. Chronic peritoneal dialysis catheters are generally made from silicone rubber or polyurethane. The intraperitoneal portion of the catheters has numerous side holes at the distal tip to allow free flow of dialysate. The distal end of the peritoneal dialysis catheter may be straight or coiled. The coiled tip may help minimize outflow obstruction. The portion of the catheter that leaves the abdomen often has 1 or 2 Dacron cuffs. The most distal cuff is typically embedded in the abdominal rectus muscle. In humans the superficial cuff is placed subcutaneously 2 cm from the catheter exit site on the abdominal wall. The Dacron cuffs cause a local inflammatory response that causes fibrous and granulation tissue to form. This tissue fixes the catheter in position and prevents bacterial migration from the skin into the peritoneal cavity.[14] Some studies have shown that the single-cuff catheter is associated with a shorter time to peritonitis, a shorter catheter survival time, and a higher rate of exit site infections, although other studies have found no difference between numbers of cuffs.[15–17] The extraperitoneal portion of the catheter can be straight or can have a permanent bend between the 2 cuffs. The permanent bend or "Swan-neck" catheters are produced to have a subcutaneous tunnel that is directed downward to decrease the risk of catheter-related infections in humans.

Several different catheter types have been used to perform acute peritoneal dialysis in veterinary medicine. Simple tube catheters with trocars can be placed in conscious animals using local anesthetics in emergency situations.[6] A percutaneous cystotomy tube catheter (Stamey percutaneous suprapubic catheter set; Cook, Spencer, IN, USA) has also been reported as being used in veterinary medicine (**Fig. 4**).[12]

When placing a peritoneal dialysis catheter that is expected to function for longer than 3 days, a more permanent peritoneal dialysis catheter is recommended. A surgical omentectomy is also recommended, due to the high risk of omental entrapment.[6] No
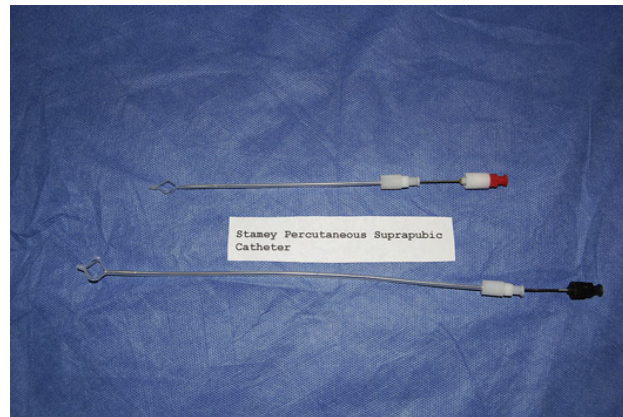
Fig. 4. Stamey percutaneous suprapubic catheter (Cook, Spencer, IN, USA).

studies have been done in veterinary medicine to evaluate the utility of any particular peritoneal dialysis catheter. In human medicine, the Tenckoff catheter is the most widely used chronic peritoneal dialysis catheter. This silicone catheter has a straight extraperitoneal portion and either a straight or curled intraperitoneal portion with multiple holes in the distal end. The Tenckhoff catheter can have 1 or 2 cuffs (**Fig. 5**).

The Fluted T catheter (Ash Advantage peritoneal dialysis catheter; Medigroup, Aurora, IL, USA) was introduced in the 1990s, and research studies in dogs reported good results when compared with the Tenckhoff (coiled tube) catheters.[18] This catheter is made of silicone with 2 Dacron cuffs; it is a T-shaped catheter made of long grooves or flutes (**Fig. 6**). These flutes are designed to offer minimal resistance to the efflux and influx of fluids while preventing omental adhesion.[19] The T-portion of the catheter is designed to be placed against the parietal peritoneum in a cranial-caudal direction. The fluted aspect of this catheter is 30 cm in length, but can be cut to accommodate smaller patients. This catheter has not been used widely in human medicine. Although its use has been reported in veterinary medicine, there are no studies evaluating its utility.

Other catheters that have been used in veterinary medicine include the 15F Blake surgical drain (Johnson and Johnson, Arlington, TX, USA), the Swan Neck straight or curled Missouri catheter (Kendall Healthcare, Mansfield, MA, USA), the 10-cm-length PD catheter, coaxial design (Global Veterinary Products, New Buffalo, MI, USA), Quinton Pediatric Peritoneal Dialysis catheter (Kendall Healthcare, Mansfield, MA, USA), and the Dawson-Mueller drainage catheter (Cook, Spencer, IN, USA) (**Figs. 7–10**).[20–23] These catheters are all placed surgically.
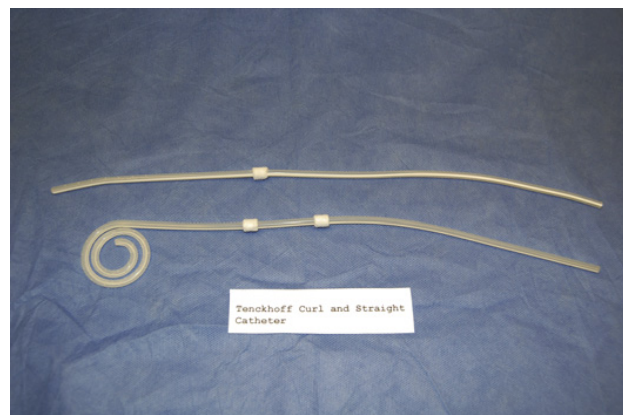

Fig. 5. Tenckhoff curl and straight catheter (Medcomp, Harleyville, PA, USA).
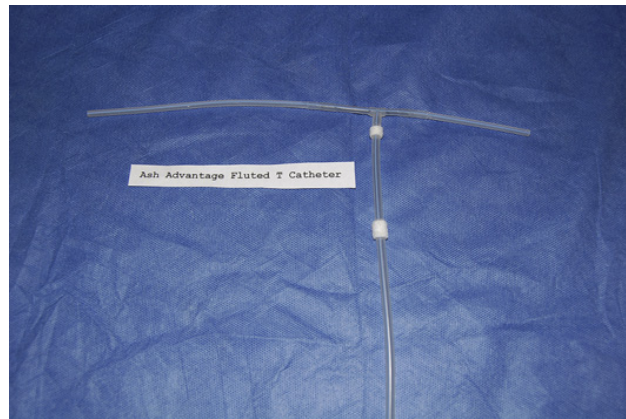
Fig. 6. Ash Advantage fluted T catheter (Medicgroup, Naperville, IL, USA).

The method of placement of peritoneal dialysis catheters is dependent on the catheter itself, the stability of the patient, and the expected length of peritoneal dialysis. In emergent situations where peritoneal dialysis is expected to be less than 72 hours, percutaneous placement of a short-term catheter is warranted. To place a percutaneous peritoneal dialysis catheter the animal is placed in dorsal recumbency, and the abdomen is shaved and sterilely prepared. It is critical that every opportunity is taken to preserve aseptic technique to prevent catheter-related infections. A stab incision is made 3 to 5 cm lateral to the umbilicus, in the direction of the pelvis.[24] The trocar is tunneled subcutaneously for several centimeters before insertion into the abdomen. The catheter is then threaded over the trocar until fully in the abdomen.[6] A purse-string suture can be placed to secure the catheter in place at its insertion site for temporary peritoneal dialysis catheters. Suture material has been reported to increase the risk of tunnel infections in human patients; therefore, peritoneal dialysis catheters with Dacron cuffs are indicated for long-term use.[6] A report in the human literature describes fluoroscopic guidance in placement of percutaneous peritoneal dialysis catheters; this technique has not been reported in veterinary medicine.[25]

When the peritoneal dialysis catheter is to be left in place for a longer period of time, a more permanent catheter should be placed. Long-term peritoneal dialysis catheters can be placed either laparoscopically (with a peritoneoscope) or surgically. Both laparoscopic and surgical catheter placement allow visualization of catheter placement, and the ability to take biopsies and to perform a partial omentectomy. The
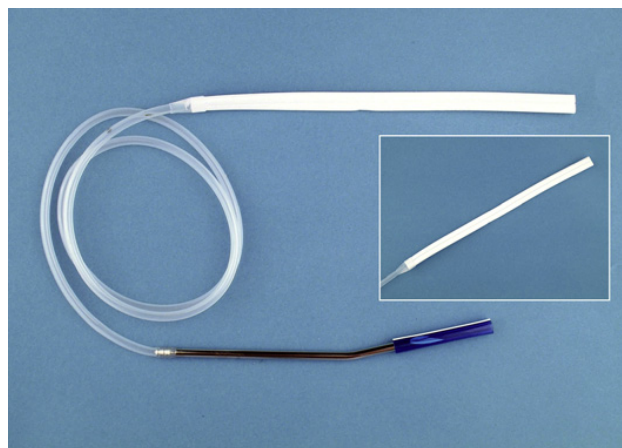

Fig. 7. Blake surgical drain (Johnson and Johnson, Arlington, TX, USA).

Fig. 8. Swan Neck straight and curled Missouri catheter (Kendall Healthcare, Mansfield, MA, USA).

disadvantages of these techniques include longer placement time, greater cost, and larger incision. Many of the catheters that were designed for percutaneous placement for humans are best placed surgically in dogs and cats. A recent study in healthy dogs describes a new method for implanting disk-type peritoneal dialysis catheters through small incisions, with good outcome; however, these catheters are no longer commercially available.[26] Once surgically placed, peritoneal dialysis catheters ideally should not be used for at least 10 to 14 days. This delay allows wound healing and scar formation around the cuffs, minimizing leakage of dialysate around the catheter site. This recommendation is easier to follow in human patients, in whom the peritoneal dialysis is generally used for more chronic kidney disease, rather than the acute kidney injury that is usually treated in veterinary patients. In veterinary patients that require immediate usage, the catheter should be leak tested to ensure a tight seal has been achieved. For the first 24 to 48 hours after placement large volumes of dialysate should not be used, in order to minimize intraperitoneal pressure.[5]

SYSTEM SETUP

Once the peritoneal dialysis catheter is placed, it should be attached to a closed collection system and carefully bandaged into position with dry sterile dressings. The use of topical antibiotic ointment is not recommended because it can macerate the exit-site tissue and inhibit fibroblast proliferation.[12] The peritoneal dialysis catheter

Fig. 9. Coaxial design (Global Veterinary Products, New Buffalo, MI, USA).

Fig. 10. Quinton Pediatric Peritoneal Dialysis catheter (Kendall Healthcare, Mansfield, MA, USA).

is connected to the dialysate bag by a length of plastic tubing called a transfer set. Older references discuss a straight transfer (straight spike), in which the same bag that contains dialysate becomes the effluent bag after the dialysate is instilled into the abdomen.[5] However, this method of performing peritoneal dialysis was associated with higher incidence of bacterial peritonitis and is not currently recommended.[27] The Y transfer set consists of a Y-shaped piece of tubing connected to both a fresh dialysate bag and a drainage container (**Fig. 11**). During the exchange, the dialysate is allowed to flow into the effluent bag. Before instilling fresh dialysate into the peritoneum, a small volume of fresh dialysate solution is drained from the dialysate bag directly into the effluent bag, bypassing the patient. This step is thought to flush bacteria that were introduced into the system at the time of connection. After the flush is done, the instillation of dialysate into the peritoneum can be performed. Newer double-bag systems have been introduced in which the Y-set is already connected to the fresh dialysate bag. This placement allows for one less connection (and opportunity for contamination) to be made at each cycle. A recent Cochrane review comparing the 3 different transfer types and the risk of peritonitis found a clear advantage over the straight spike system with both the Y-set and double-bag transfer systems. There was no significant advantage shown for the double-bag system over the Y-set system, although studies available for review were more limited.[28]

A strict sterile technique should be followed at all times when handling the peritoneal dialysis catheter and collection system. All connections should be wrapped in povidone-iodine connection shields or chlorhexidine-soaked dressings covered with sterile gauze.[12] All injection ports should be scrubbed with either chlorhexidine or povidone-iodine for 2 minutes before injections, and medication vials should be swabbed for 2 minutes before use. To reduce the risk of contamination, multiple-dose vials should not be used for dialysate additives. Hands should be washed thoroughly and sterile gloves should be worn while handling dialysate lines or bags. Catheter movement at the exit site should be minimized; the catheter site should be washed with chlorhexidine or iodine scrub and dried with sterile gauze once daily, and wrapped in dry sterile bandages. The catheter site and dry bandages should be changed more frequently should strike-through occur. The dialysis prescription should be adjusted to minimize the occurrence of exit-site leaks. The dialysate effluent should be examined for cloudiness at every exchange. Should any concern arise, the effluent should be submitted for culture. The effluent should be looked at once daily for any indication of peritonitis. These guidelines cannot be emphasized enough regarding prevention of infection during peritoneal dialysis.[19]
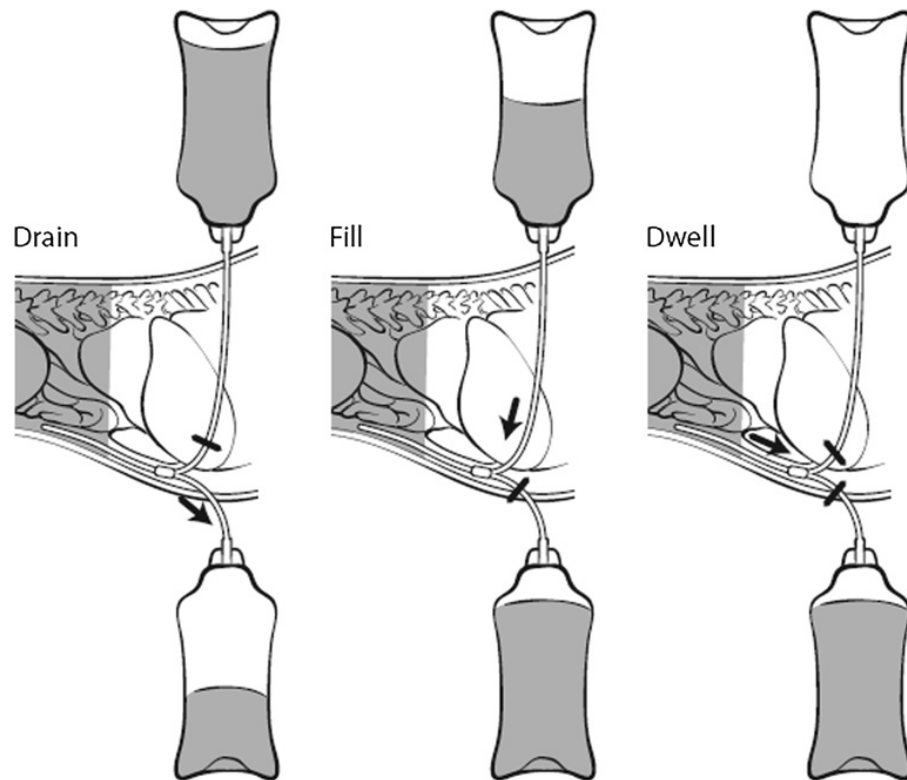
Fig. 11. An illustration of the Y-shaped drain set.

DIALYSATE

The specific composition of dialysate is an important factor to consider when performing peritoneal dialysis. Different dialysate solutions differ based on their buffer, electrolytes, and/or the osmotic agents used (**Table 1**). The ideal dialysate should promote solute clearance with little absorption of osmotic agents, provide deficient electrolytes and nutrients, correct acid-base problems, inhibit the growth of microorganisms, and be inert to the peritoneum.[29] Biocompatibility of dialysate solutions is an intensely studied field. It has been shown that the low pH, lactate buffer, high glucose content, high osmolality, and the presence of glucose degradation products (GDPs) generated during production and sterilization of dialysate can be harmful to the peritoneum.[30] Peritoneal biopsies in patients who have received long-term peritoneal dialysis showed ultrastructural changes that may be secondary to low biocompatibility of peritoneal dialysis solutions.[31] The significance of these findings is unknown, but trends are toward more biocompatible dialysate solutions.

Options for buffers in dialysate historically have included lactate, bicarbonate, and acetate. One of the initial buffers used in peritoneal dialysis solutions was acetate. Bicarbonate is generated when acetate and coenzyme A (CoA) are activated by acetate thiokinase to form acetyl CoA. The use of acetate as a buffer in dialysate solutions has fallen out of favor. Due to its low pH, acetate can produce pain during dialysate inflow. Studies have also shown that it produces vasodilation and alteration of the peritoneum, leading to loss of ultrafiltration and development of sclerosing peritonitis.[32,33] Lactate is the most common buffer used as dialysate today. The buffering effects of lactate are produced through their metabolism in the liver via the Krebs cycle or via gluconeogenesis, with the end product being bicarbonate. However, lactate has been shown in studies to be toxic to mesothelial cells when combined with a low pH, as in typical dialysate solutions.[34] Bicarbonate was not

Table 1
Composition of a commercially available peritoneal dialysate solution

	Manufacturer	pH	Osmotic Agent	Na (mM)	Ca (mM)	Mg (mM)	Lactate (mM)	Bicarb (mM)	Pouches
Dianeal PD1	Baxter	5.5	Glucose	132	1.75	0.75	35	0	1
Dianeal PD2	Baxter	5.2	Glucose	132	1.75	0.25	40	0	1
Dianeal PD4	Baxter	5.5	Glucose	132	1.25	0.25	40	0	1
Stay-Safe 2/4/3	FMC	5.5	Glucose	134	1.75	0.5	35	0	1
Stay-Safe 17/19/18	FMC	5.5	Glucose	143	1.25	0.5	35	0	1
Gambrosol Trio 10	Gambro	6.3	Glucose	132	1.75	0.25	40	0	3
Gambrosol Trio 40	Gambro	6.3	Glucose	132	1.35	0.25	40	0	3
Nutrineal	Baxter	6.5	Amino acids	132	1.25	0.25	40	0	1
Extraneal	Baxter	5.5	Icodextrin	132	1.75	0.25	40	0	1
Physioneal	Baxter	7.4	Glucose	132	1.75	0.25	10	25	2
Balance	FMC	7.4	Glucose	134	1.25	0.5	34	2	2
					1.75				
bicaVera	FMC	7.4	Glucose	134	1.75	0.5	0	34	2
bicaNova	FMC	7.4	Glucose	134	1.25	0.5	0	39	2

From Heimburger O, Blake PG. Apparatus for peritoneal dialysis. In: Daugirdas JT, Blake PG, Ing TS, editors. Handbook of dialysis. 4th edition. Philadelphia: Lippincott, Williams & Wilkins; 2007. p. 340; with permission.

initially used as a buffer for dialysate solutions because during the sterilization process calcium and magnesium would precipitate into salts. Bicarbonate solution has a higher pH than the lactate- or acetate-buffered solutions, and glucose would caramelize at the higher pH, so this solution was initially abandoned. However, because bicarbonate is a more biocompatible solution, this buffer has been studied more readily in recent years. To avoid the problems of precipitation and caramelization, bicarbonate-based solutions are formulated in 2-chambered bags. The chambers are mixed immediately before instillation of the dialysate into the peritoneum. There has been significant research describing improved biocompatibility of bicarbonate-based dialysate solutions, but no evidence has arisen that bicarbonate-based solutions improve long-term outcome.[35–37]

Commercially available dialysate solutions contain sodium, magnesium, calcium, and chloride in varying concentrations. Potassium is generally not included in dialysate solutions, but can be added if patients become hypokalemic during treatment.

Osmotic agents can be grouped into low molecular weight agents and high molecular weight agents. Low molecular weight agents that have been tried include glucose, glycerol, sorbitol, amino acids, xylitol, and fructose.[3] The standard dialysate solution contains glucose as the osmotic agent. Glucose-based dialysate comes in 3 different concentrations: 1.5%, 2.5%, and 4.25%. Dialysis performed for the removal of uremic toxins is generally done using a 1.5% solution. Use of a hypertonic glucose solution is reserved for overhydrated patients in whom the highly osmolar dialysate causes water to leave the body and enter the dialysate by osmosis. Peritoneal dialysis can be performed using commercial dextrose-based dialysate products, or dialysate may be formulated by adding dextrose to lactated Ringer solution.[12] Adding 30 mL of 50% glucose to 1 L of lactated Ringer solution will result in a 1.5% solution.

Glucose has been shown to be safe, effective, inexpensive, and readily available. However, glucose can also be readily absorbed, leading to metabolic derangements such as hyperglycemia, hyperlipidemia, hyperinsulinemia, and obesity.[38,39] Several other problems regarding the long-term safety of glucose-based products have been demonstrated. Glucose can directly and indirectly cause damage to the peritoneum. High concentrations of glucose are toxic to the mesothelium.[30] Glucose is also involved in peritoneal neoangiogenesis. These new blood vessels result in the disappearance of the osmotic gradient and a failure of ultrafiltration.[30] The acidity necessary to prevent caramelization in glucose-containing fluids can be also be harmful to the peritoneum.

GDPs are produced during heat sterilization and production of glucose-containing solutions. GDPs are toxic to fibroblasts and enhance the production of vascular endothelial growth factor by peritoneal cells.[30] These GDPs may also lead to formation of advanced glycosylation end products (AGEs).[35] AGEs are proinflammatory, and have been correlated with impaired peritoneal permeability and ultrafiltration failure.[35]

Concerns over the use of glucose-based dialysate products have led to the investigation of other osmotic agents for peritoneal dialysis in humans. Amino acid–containing peritoneal dialysis solutions have been used to improve nutrition status of peritoneal dialysis patients. Recent studies have shown improvement in nutrition status of patients when given a 1.1% solution of amino acid–containing dialysate, and work is ongoing in human medicine to establish the efficacy of supplementation.[36] A 1.1% amino acid–based solution functions osmotically similar to a 1.5% dextrose solution. Amino acid–based solutions can only be used once daily because they may cause elevations in BUN and worsen acidosis.[27]

High molecular weight osmotic agents include polymers of glucose (polyglucose), such as icodextrin. Icodextrin is a starch-derived water-soluble glucose polymer with a molecular weight of 16,800. Commercially it is available in a 7.5% solution in a lactate

buffer (Extraneal; Baxter Healthcare Corp, McGraw Park, IL, USA). Icodextrin is an iso-osmolar solution (285 mOsm/kg) that produces ultrafiltration via its oncotic effect. Glucose polymers induce ultrafiltration across large pores via colloid oncotic effects, as compared with hyperosmotic dextrose solutions, which induce ultrafiltration across both small and ultrasmall pores. Absorption of icodextrin occurs via peritoneal lymphatics, so it maintains its oncotic effect much longer than dextrose-based solutions. Adverse events reported with icodextrin use include sterile peritonitis in humans.[3] Icodextrin also causes some laboratory instruments to overestimate blood glucose level, due to the presence of maltose in the bloodstream.[30] Icodextrin is used for long dwell times in humans undergoing chronic ambulatory peritoneal dialysis and continuous cyclic peritoneal dialysis, in patients with ultrafiltration failure, and in patients with diabetes mellitus.[3] The use of icodextrin in veterinary medicine has not been investigated.

Several other substances are often added to peritoneal dialysis solutions as needed. Insulin may be added to dialysate solutions in diabetics to help control hyperglycemia. Antibiotics may be added to the dialysate solution to treat peritonitis, although routine use of antibiotics is discouraged. Heparin is frequently added to the dialysate solution to prevent formation of fibrin in the peritoneal dialysis catheter. Addition of heparin to the peritoneum does not lead to systemic anticoagulation.[40]

EXCHANGE PROCEDURE

When initiating peritoneal dialysis for acute kidney injury, the goal is not to immediately normalize the azotemia. The initial objectives should be to normalize the patient's hemodynamic state, and acid-base and electrolyte imbalances, as well as reducing the azotemia to a BUN of less than 60 to 100 mg/dL and a creatinine of 4.0 to 6.0 mg/dL over 24 to 48 hours.[5] For this time, one-quarter to one-half of the calculated dialysate volume (30–40 mL/kg) should be instilled during each cycle. This amount allows the clinician to assess the patient for abdominal distension, respiratory impairment, and dialysate leakage. If the patient tolerates these volumes over the first 24 hours, the amount of dialysate can be increased to 30 to 40 mL/kg per cycle.[24] For patients with normal hydration status, a dialysate containing 1.5% dextrose can be used initially. For patients with volume overload or with high serum osmolality, either a 2.5% or 4.5% dialysate solution can be used for the initial cycles. When using hyperosmotic dialysate solutions, it is imperative to monitor the patient closely to prevent hemodynamic instability from rapid fluid shifts.

The dialysate should be warmed to 38°C to 39°C to improve permeability of the peritoneum and for patient comfort prior to instillation into the peritoneal cavity.[5] Warming should ideally be performed by heating pads or special ovens for the dialysate bags and lines. Microwaving the dialysate bags has been performed but is strongly not recommended by manufacturers because of uneven heating and potential "hot spots" that may be produced during the heating process.[27] In addition, overheating can lead to chemical alterations in the dialysate solution. Warming the dialysate by immersing the bag in warm water is also not recommended because of the risk of contamination.[27]

Most animals with acute kidney injury will have hyperkalemia, and most dialysate solutions do not have potassium added. In the initial cycles of peritoneal dialysis this is ideal; however, hypokalemia can occur with time. To prevent this, 2 to 4 mEq/L of potassium can be added to the dialysate solution after several cycles have occurred. Heparin at 100 to 500 U/L can also be added to the dialysate during the initial sessions to prevent fibrin occlusion of the catheter.[5]

To begin a peritoneal dialysis session, the fresh dialysate bag is placed above the patient while the effluent bag is placed below the patient. A small amount

of dialysate is flushed from the dialysate bag directly into the effluent bag. With the first instillation, 10 mL/kg of dialysate solution is then instilled by gravity into the peritoneum over 10 minutes and is allowed to dwell for 30 to 40 minutes. The peritoneal cavity is allowed to drain by gravity into the sterile effluent bag over 20 to 30 minutes. The system is closed off to the patient and the procedure is then repeated with flushing of the line. One recent study reported achieving success using a closed intermittent negative pressure system instead of a gravity-dependent drainage period.[22] During each drainage period the effluent volume should be recorded, and the bag should be checked for color and turbidity of the fluid. If there is any blood, turbidity, or change in character of the fluid, it should be cultured immediately. After each cycle is completed a new cycle is started, making this a continuous and effective process.

Meticulous records should be kept to record details of exchange volumes and fluid balance of peritoneal dialysis patients. If the fluid balance becomes positive, or if return of dialysate effluent is less than 90%, the dialysate solution should be switched to 4.5% dextrose-containing solutions, to encourage ultrafiltration and subsequent volume removal. If the fluid balance becomes negative, hyperosmotic dialysate solution should be switched to a 1.5% solution, and steps should be taken to avoid hypovolemia.[5] Renal values, electrolytes, blood pressure, and central venous pressures should be monitored every few hours during the initial peritoneal dialysis period.

After the initial 24 to 48 hours of exchanges, the patient can be switched to a more chronic peritoneal dialysis protocol. Cycle lengths of 3 to 6 hours may be instituted, and may be increased to 3 to 4 exchanges daily as kidney function is restored. The frequency of exchanges and length of dwell time should be adjusted based on the patient's degree of azotemia, normalization of acid-base status, electrolyte disturbances, volume status, and control of uremic symptoms.[5] The amount of solute transferred across the peritoneal membrane is related to the concentration gradient for each solute and the size of the molecule. If increased removal of a larger-sized molecule such as creatinine is warranted, longer dwell times are instituted.[12] Gradual reduction of the number of exchanges and lengthening of the dwell time leading to intermittent peritoneal dialysis over 3 to 4 days with frequent reassessment is recommended before discontinuation of dialysis.[12] For example, once the patient's BUN is less than 100 mg/dL and the creatinine is less than 5.0 mg/dL, the exchanges should go from hourly to every 2 hours with a 1.5-hour dwell time. Dwell times and exchanges than can be extended on a daily basis as needed. If in the acute situation an animal receiving well-managed, aggressive peritoneal dialysis has not improved after several days, intermittent hemodialysis, renal transplantation, or euthanasia should be considered.

Continuous ambulatory peritoneal dialysis (CAPD) is the delivery technique most appropriate for animals with end-stage chronic kidney disease that require peritoneal dialysis. Long dwell times of 4 to 6 hours are instituted, permitting the animal to be ambulatory for most of the day.[5] This technique is the one most commonly used in humans with end-stage kidney disease, although it has never gained clinical acceptance in veterinary medicine for chronic kidney disease.

MONITORING

Blood volume and electrolyte changes can occur rapidly in the first few days of peritoneal dialysis. Catheter outflow obstructions can cause retention of dialysate in the abdomen and a less efficient dialysis session. For these reasons careful monitoring

of patients undergoing peritoneal dialysis is critically important. Body weight and hydrations status should be monitored frequently. Body weight should be assessed in the same clinical condition (ie, without dialysate in the abdomen) during each assessment period. Central venous pressures should be checked every 4 to 6 hours and systemic arterial blood pressures should be checked every 6 to 8 hours. Urine output should be recorded every 4 hours. The patient's heart rate and respiratory rate should be recorded every 2 hours, noting whether dialysate in the abdomen causes any respiratory difficulty. Renal values, electrolytes, and acid-base status should be checked every 4 to 6 hours initially, and then at least twice daily. Magnesium should be checked at least once every 3 days if it is not evaluated in more routine bloodwork.[6] Detailed flow sheets are used at the authors' institution to assess trends in volume and electrolyte status (**Figs. 12** and **13**).

EVALUATING ADEQUACY OF PERITONEAL DIALYSIS: UREA KINETICS

The goal of urea kinetics is to provide a measure of dialysis quality and quantity. Urea kinetic modeling allows quantification of solute clearance that is delivered to the patient. Although originally conceived for the monitoring of hemodialysis, urea kinetic modeling is used as a measure of dialysis adequacy for peritoneal dialysis as well. The amount of dialysis delivered can be expressed as Kt/V, a unit-less value that measures fractional urea clearance.[41] In peritoneal dialysis, Kt/V is obtained by analyzing a 24-hour collection of the dialysate effluent, urine, and average blood urea level. When calculating urea kinetics for a patient, both the peritoneal clearance and residual renal clearance must be taken into account. Peritoneal Kt is calculated by measuring the urea content of the 24-hour dialysate effluent, and dividing the result by average plasma urea content for the same period. Residual renal Kt is calculated by measuring the urea content of the 24-hour urine collection, and dividing the result by the average urea content for the same 24-hour period. The peritoneal Kt and residual renal Kt can then be combined to obtain the total Kt. The volume of distribution of urea is represented by the letter V, and is calculated based on the patient's body size and published tables.[41] To determine Kt/V, the total Kt is then divided by V. In peritoneal dialysis, the number obtained is then multiplied by 7; by convention Kt/V is expressed in weekly periods.

The ideal Kt/V for human peritoneal dialysis patients is not entirely known and is a subject of much discussion. Recent prospective controlled studies have shown that higher clearance targets once previously recommended did not improve outcome, therefore targets have been decreased.[42–44] With human peritoneal dialysis patients, it is now recommended that the Kt/V should target 1.7 per week.[45] Those who are familiar with hemodialysis adequacy may find peritoneal dialysis Kt/V to sound small (compared with a goal hemodialysis Kt/V of 1.2 in each of 3 weekly sessions). However, because peritoneal dialysis is a continuous modality, it is much more efficient than hemodialysis and the different Kt/V values cannot be compared.[41] Evaluation of the Kt/V in veterinary peritoneal dialysis has not been reported in the literature, which may be due to the difficulty in collecting effluent and urine over 24 hours, or assessing a 24-hour average of the plasma urea.

Creatinine clearance is another method of assessing dialysis adequacy in peritoneal dialysis. The peritoneal creatinine clearance is calculated in a similar manner to the peritoneal Kt, as discussed above. The residual renal creatinine clearance is measured by taking an average of the urinary urea clearance and the urinary creatinine clearance; this is done by convention, as the residual renal creatinine clearance has been shown to markedly overestimate the true glomerular filtration rate.[41] This value is then corrected for total

Date	dialysate	# Please note Am or PM. Also note date on each sheet inflow time	dwell time	outflow time	dialysate volume in	dialysate volume out	current exchange net balance of dialysate only (volume out - volume in = balance)	running total of balance of dialysate only	IV fluids in	Urine out	Total fluids in	Total fluid out	Current exchangeFluid difference (total fluid in - total fluids out = fluid diff)	Running total of Fluid difference	exchange	Comments
		1						0			0	0	0	0	1	
		2						0			0	0	0	0	2	
		3						0			0	0	0	0	3	
		4						0			0	0	0	0	4	
		5						0			0	0	0	0	5	
		6						0			0	0	0	0	6	
		7						0			0	0	0	0	7	
		8						0			0	0	0	0	8	
		9						0			0	0	0	0	9	
		10						0			0	0	0	0	10	
		11						0			0	0	0	0	11	
		12						0			0	0	0	0	12	
		13						0			0	0	0	0	13	
		14						0			0	0	0	0	14	
		15						0			0	0	0	0	15	
		16						0			0	0	0	0	16	
		17						0			0	0	0	0	17	
		18						0			0	0	0	0	18	
		19						0			0	0	0	0	19	
		20						0			0	0	0	0	20	
		21						0			0	0	0	0	21	
		22						0			0	0	0	0	22	
		23						0			0	0	0	0	23	
		24						0			0	0	0	0	24	
		25						0			0	0	0	0	25	
		26						0			0	0	0	0	26	
		27						0			0	0	0	0	27	
		28						0			0	0	0	0	28	

Fig. 12. Peritoneal dialysis flow sheet.

Date Parameters	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Wt (KG) same scale Q 8 hrs							
Creat/BUN q 12 hrs							
Na/K/CL q 12 hrs							
PCV/TS/BG Q 12 hrs							
Fluid character							
Fluid Cytology Q 24 hrs							
CVP q 8 hrs							
BP q 12 hrs							
Blood Gas q 24 hrs							
Kidney Profile EOD							
CBC EOD							
Urine output q 4 hrs							

Fig. 13. Flow chart used to monitor dialysis patient's laboratory values.

body surface area as calculated by the duBois formula.[41] The use of creatinine clearance in assessing adequacy of peritoneal dialysis in veterinary patients has not been reported in veterinary literature, likely because of the same reasons as listed here for Kt/V.

Urea reduction ratio (URR) is another measure of dialysis adequacy that is more commonly used in hemodialysis. URR is a simple calculation of the percent reduction in urea after a dialysis treatment. The formula for URR is as follows:

$$URR = (\text{Pre-dialysis BUN} - \text{Post-dialysis BUN})/\text{Pre-dialysis BUN} \times 100$$

URRs are not commonly used in CAPD in humans. Because these patients are at a steady state, meaning their urea clearance rates are similar to their urea generation rates, the URR will always approach zero. In veterinary patients with acute kidney injury and a significantly higher urea clearance rate than the urea generation rate, this measure may be useful to assess adequacy in peritoneal dialysis. Two recent studies have measured urea reduction ratios in the assessment of peritoneal dialysis adequacy.[21,23] More studies are warranted to evaluate the utility of URR for assessment of peritoneal dialysis adequacy in veterinary patients.

COMPLICATIONS

Complications of peritoneal dialysis are a frequent, but manageable, occurrence. The most common complications of peritoneal dialysis include catheter occlusion problems such as dialysate retention and subcutaneous leakage of dialysate, electrolyte disturbances, hypoalbuminemia, and bacterial peritonitis.

Dialysate retention, as defined by recovery of less than 90% of dialysate, occurred in 20% to 77% of animals reported in several retrospective studies.[20,21,23,46] Common causes of dialysate retention are catheter occlusion due to omental entrapment or fibrin accumulation in the peritoneal dialysis catheter. Performing a partial omentectomy would likely reduce the frequency of this complication. In one study, 100% (8/8) of cats with percutaneously placed peritoneal dialysis catheters developed

retention of dialysate, whereas only 54.5% of cats with surgically placed peritoneal dialysis catheters developed retention of dialysate.[21] Two cats with percutaneously placed peritoneal dialysis catheters eventually required surgical placement of peritoneal dialysis catheters because of catheter outflow obstruction problems. One of these cats had a surgically placed catheter, but partial omentectomy was not performed and the cat continued to have complications involving retained dialysate. Later, a partial omentectomy was performed and fewer complications were reported postoperatively.[21] One recent retrospective study noted a low rate of dialysate retention, which was attributed to a closed intermittent negative pressure system.[22] The use of negative pressure systems for dialysate drain periods requires further investigation. Catheter design may also play a role in prevention of catheter occlusion, but not enough data are available to make any conclusions for veterinary medicine. Heparin (250–1000 U/L) can be added to the dialysate solution to try and prevent catheter obstruction from fibrin accumulation, especially in the first few days of dialysis or when the effluent is noted to be cloudy. If fibrin deposition is suspected in the catheter, treatment with a high-pressure flush of saline, urokinase (15,000 U), streptokinase, or tissue plasminogen activator has been recommended.[14]

Sequestration of dialysate subcutaneously was noted in 20% to 50% of animals in different studies.[20,21,23,46] In one study the incidence of sequestration of dialysate was similar between cats with surgical (58.3%) and percutaneously (62.5%) placed catheters. The immediate use of dialysis catheters after placement may contribute to the high rate of dialysate leakage. In humans undergoing peritoneal dialysis, it is recommended to wait for 2 to 4 weeks before the use of newly placed peritoneal dialysis catheters.[14]

The prevalence of hypoalbuminemia in animals undergoing peritoneal dialysis has been reported to be 41% to 90%.[20,21,23,46] Low dietary protein intake, gastrointestinal or renal protein loss, dialysate loss, uremic catabolism, and concurrent disease may all contribute to the hypoalbuminemia seen in animals undergoing peritoneal dialysis.[12] Protein loss may increase dramatically when peritonitis is present.[1] Usually animals that are eating well can maintain their protein levels. However, many patients undergoing peritoneal dialysis are anorexic, or nauseated secondary to their severe uremia or other concurrent disease. Enteral or parenteral nutritional supplementation is critical in these patients to help maintain protein levels. A 1.1% amino acid dialysate solution may also be used for additional nutritional supplementation. Electrolyte abnormalities are commonly reported in peritoneal dialysis. Hyponatremia, hypochloremia, hypomagnesemia, hypokalemia, hyperkalemia, and hyperglycemia have all been reported in veterinary studies to varying extents.[20–22,46]

Peritonitis is diagnosed when 2 of the following 3 criteria are recognized: (1) cloudy dialysate effluent, (2) greater than 100 inflammatory cells/μL of effluent or positive culture results, and (3) clinical signs of peritonitis.[6] Peritonitis has previously been reported as a common side effect in veterinary medicine. The most common source of peritonitis is contamination of the bag spike or tubing by the handler, but intestinal, hematogenous, and exit-site sources of infection do occur.[1] Several more recent retrospective studies have reported a significantly lower rate (4%, 0%, and 0%) of peritonitis.[20–22] The lower rate of peritonitis may be due to the use of the Y-Set transfer system as opposed to the straight-spike transfer system, or increased vigilance and adherence to aseptic technique. In one study *Escherichia coli* was the major contaminant, but other studies have reported a variety of bacteria, including *Klebsiella*, *Pseudomonas*, *Enterococcus*, *Mycoplasma*, *Acinetobacter*, and *Providencia*.[21,23,46]

Pleural effusion and dyspnea are uncommon side effects of peritoneal dialysis in humans and animals. Pleural effusion can be caused by overhydration or

pleuroperitoneal leakages. Careful and frequent monitoring of the patient's hydration status, central venous pressures, urine output, and weight can decrease the incidence of overhydration. If overhydration is suspected, the dialysate should be changed to a more hyperosmotic solution to promote ultrafiltration. The concentration of blood glucose can be tested in the pleural fluid, as elevated glucose levels would indicate a pleuroperitoneal leak. Pleuroperitoneal leaks are a contraindication for peritoneal dialysis, so the procedure should be immediately discontinued if a pleuroperitoneal leak is diagnosed. Respiratory distress due to increased intra-abdominal pressure can occur, and careful attention to the patient's respiratory rate in relation to dialysate inflows should be noted. Dialysate volumes should be decreased if increased intra-abdominal pressure is contributing to ventilatory dysfunction.

Dialysis disequilibrium is a rare complication of peritoneal dialysis, characterized by dementia, seizures, coma, and/or death.[1] It is thought to occur secondary to rapid drops in blood osmolality that often occur during the first cycles of dialysis. Rapid solute removal causes influx of water into the brain and neurologic dysfunction.[12] Animals that have severe azotemia, hypernatremia, hyperglycemia, or acidosis may be at increased risk.[1] Dialysis disequilibrium was suspected in 2 dogs.[20,46] Clinical signs exhibited included head tremors or head-bobbing in each respective animal. One of the dogs developed clinical signs after the third cycle, and temporary discontinuation of peritoneal dialysis helped resolve clinical signs.[46] The other dog developed clinical signs after 2 days of peritoneal dialysis and had a documented drop in measured osmolality of 42 mOsm from the start of dialysis to the onset of clinical signs.[20] If there is suspicion for disequilibrium, the dialysate prescription should be adjusted to include fewer exchanges or longer dwell times to remove urea and small solutes at a slower rate. Osmolality should be monitored closely, especially during the first few days of dialysis, to make sure that changes are not occurring too rapidly.

In human medicine, peritoneal membrane changes and loss of ultrafiltration are significant complications associated with peritoneal dialysis. Such conditions have not been reported in veterinary patients. It is possible that in the short duration of peritoneal dialysis in veterinary patients, peritoneal membrane changes do not have time to occur, or that it is not noted in veterinary patients because monitoring dialysis adequacy is not routinely done. If dialysis adequacy is more routinely examined, it is possible that these complications will begin to be noted.

PERITONEAL DIALYSIS IN VETERINARY MEDICINE

There have been several case reports[47–51] and retrospective studies on peritoneal dialysis in dogs and cats. The earliest large retrospective study performed by Crisp and colleagues[46] looked at peritoneal dialysis in 25 dogs and 2 cats. Animals enrolled in this study had either chronic kidney disease or acute kidney injury. Of 21 animals with acute kidney injury, 11 had ethylene glycol toxicity, 4 had gentamicin toxicity, 3 had leptospirosis, 1 dog had a ureteral laceration, 1 dog had thiacetarsemide toxicosis, 1 dog had E coli pyelonephritis, and 1 dog had acute kidney injury of unknown cause. Of the dogs diagnosed with chronic kidney disease, 3 had chronic interstitial nephritis, 1 had chronic interstitial nephritis and pyelonephritis, and 1 had glomerular amyloidosis. Peritoneal dialysis was effective in decreasing the magnitude of azotemia, but the overall survival rate was very low. No data were evaluated to predict outcome of peritoneal dialysis in this study.

Beckel and colleagues[20] looked at peritoneal dialysis in a small group of dogs that had acute kidney injury secondary to leptospirosis. This study reported a high survival

rate of 80%, which is similar to that reported in studies of dogs with leptospirosis treated with conservative management (82%) and with hemodialysis (86%).[52] The outcome is also similar to an older retrospective study from Europe in which dogs with acute kidney injury secondary to leptospirosis and treated with peritoneal dialysis had a survival rate of 73%.[53]

Two recent studies have looked at peritoneal dialysis exclusively in feline populations. A study by Dorval and Boysen[22] looked at 6 cats with acute kidney injury. The cause of acute kidney injury was determined in 4 cats, which included pyelonephritis in 1, suspected pyelonephritis in 1, Easter lily toxicity in 1, and traumatic acute kidney injury following bilateral pyelectomies in 1. Five cats (83%) were discharged from the hospital, and all 4 of the cats with 1-year follow-up had no residual renal disease noted. A study by Cooper and Labato[21] (pending publication) looked at 22 cats with acute kidney injury that received peritoneal dialysis. Causes of renal disease included acute-on-chronic kidney disease in 7 cats, ureterolithiasis in 5, spay complications in 4 (bilateral ureteral ligation in 3 cats and hypotension under anesthesia in 1), and 4 with Easter lily toxicity. Ten cats (45.5%) were discharged from the hospital. There was no significant difference noted among indications for peritoneal dialysis in predicting survival, but it should be noted that 0% of cats with toxicities were discharged and 100% of cats with spay complications were discharged. Overall it seemed that animals with surgically treatable disease that needed peritoneal dialysis for stabilization and support had better prognoses than cats with nontreatable disease.

Another recent study by Nam and colleagues[23] looked at 20 dogs treated with peritoneal dialysis for acute kidney injury and chronic kidney disease. The survival rate was higher for the dogs with acute kidney injury (67%) than for chronic kidney disease (37.5%).

More veterinary studies are needed to evaluate which catheters, indications for dialysis, and prescriptions are most ideal for veterinary patients to achieve the fewest complications and the best outcomes.

SUMMARY

Although hemodialysis and continuous renal replacement therapy are emerging as safe and effective therapies for acute kidney injury, they are not readily available in many places. Peritoneal dialysis is labor intensive, but is technically simpler than hemodialysis and may be performed in any clinic with adequate technical assistance and supervision. Peritoneal dialysis is an effective treatment option for veterinary patients with acute kidney injury refractory to fluid therapy. It can be used an adjunctive therapy to medical management, or can be used as a temporary means to stabilize a patient prior to a surgical procedure. Peritoneal dialysis can also be used to manage a variety of other conditions in humans, and these may be applicable in veterinary medicine as well. Peritoneal dialysis has a high rate of complications, but most are manageable with intense nursing care and careful attention to aseptic technique. Understanding the physiology of dialysis and fluid transport through the peritoneal membrane allows the clinician to make informed decisions regarding dialysate dose and treatment regimen. Peritoneal dialysis is an important modality in the treatment of acute kidney injury and toxicities in veterinary patients.

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