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Current techniques in peritoneal dialysis

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Abstract

Objective – To provide a current overview of the technique of peritoneal dialysis in dogs and cats.
Clinical Implication – Peritoneal dialysis is the process by which water and solutes move between blood in the peritoneal capillaries and fluid (dialysate) instilled into the peritoneal cavity, across the semipermeable membrane of the peritoneum. The primary indication for peritoneal dialysis (PD) in animals is for treatment of renal failure to correct water, solute, and acid-base abnormalities and to remove uremic toxins.
Summary – Peritoneal dialysis is a modality of renal replacement therapy commonly used in human medicine for the treatment of chronic kidney disease and end-stage kidney failure. Peritoneal dialysis utilizes the peritoneum as a membrane across which fluids and uremic solutes are exchanged. 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.

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Keywords: acute kidney injury, peritoneum, renal replacement therapy

Introduction

Peritoneal dialysis (PD) is the process by which water and solutes move between blood in the peritoneal capillaries and fluid (dialysate) instilled into the peritoneal cavity, across the semipermeable membrane of the peritoneum. The primary indication for PD in animals is for treatment of kidney failure to correct water, solute, and acid-base abnormalities and to remove uremic toxins.

Biology of the Peritoneal Membrane

In people, the surface area of the peritoneum is approximately the same as the body surface area (1–2 m^2), and the visceral peritoneum accounts for approximately 80% of the total.[1] Peritoneal surface area is proportionately larger in comparison to body surface area in infants and children,[2] suggesting that this difference would also be true for dogs and cats.

The peritoneal mesothelium consists of a simple squamous epithelial-like monolayer supported by a basement membrane. The mesothelial cells have many apical microvilli that increase the functional surface area of the membrane. In people, the basement membrane contains type IV collagen, proteoglycans, and glycoproteins. The interstitium is a layer of connective tissue below the basement membrane that contains collagen, fibronectin, and elastin. The peritoneal microvasculature is composed of true capillaries and postcapillary venules that are supported by a negatively charged glycocalyx.[3,4] These vessels are located at varying distances from the mesothelial surface and can be found throughout the connective tissue layer. Lymphatics also are found in this layer, most commonly in the subdiaphragmatic peritoneum. These lymphatics drain primarily via stomata in the diaphragmatic peritoneum.[1,5] The role of lymphatics in fluid and solute exchange from the peritoneum is poorly understood because of the difficulty in directly measuring lymph flow.

Abbreviations

AKI	acute kidney injury
AGE	advanced glycosylation end products
BUN	blood urea nitrogen
GDP	glucose degradation products
MCP-1	monocyte chemoattractant protein-1
MTAC	mass transfer area coefficient
MV	molecular weight
PD	peritoneal dialysis
TGF-B1	transforming growth factor-beta1
VEGF	vascular endothelial growth factor

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The mesothelium is not thought to represent a significant barrier to water transport[3]; rather, the barriers are the walls of the capillaries and the extracellular matrix located in the submesothelial cell connective tissue.[6–8] Peritoneal capillaries are composed primarily of nonfenestrated endothelial cells supported by a basement membrane. Endothelial cells contain aquaporins, which are 20 kDa cellular membrane proteins that are responsible for water transport. Intercellular clefts between endothelial cells also play a role in solute transport.[9]

Fluid and Solute Transport

The mechanisms by which fluids and solutes are transported across the peritoneal membrane include diffusion, convection, and ultrafiltration. Diffusion can be defined as the movement of particles from a space with a higher concentration to one with a lower concentration.[2] When this movement occurs across a semipermeable membrane, the rate of diffusion is governed by the concentration of solute on either side of the membrane, the size of the molecule, the permeability of the membrane, and the surface area available for diffusion. The mass transfer area coefficient (MTAC) is the theoretical clearance rate that would occur if the concentration gradient for a solute is infinitely high. The osmotic gradient, MTAC, and rate of diffusion are highest immediately after dialysate is infused into the peritoneal cavity, when the concentration gradient is highest.[10,11] In PD, diffusion is responsible for the transfer of urea, creatinine, and other small solutes. Urea has a relatively low molecular weight (MW) of 60 and diffuses more rapidly than creatinine, which has a MW of 113. Larger molecules such as albumin (MW 69,000) are dependent on diffusion through larger pores, and the rate is comparably slower.

Ultrafiltration is the removal of fluid (water) during PD. The rate of ultrafiltration is dependent on the osmotic or oncotic gradient between peritoneal capillary plasma and dialysate, as well as the effective peritoneal surface area and capillary blood flow.[10,11] Ultrafiltration is accomplished by instilling fluid into the peritoneal cavity that is of higher osmolality than that of plasma.

Convection (solvent drag) is the movement of solutes accompanying the flow of water from peritoneal capillaries into the peritoneal cavity. For most solutes, movement by convection does not occur in direct proportion to their concentration in blood. This effect is termed sieving and occurs because there is a greater barrier to solute than water movement across the peritoneum. Sieving coefficients vary depending upon the charge and MW of the solute.[1,10–12] As a result of sieving, the rate of decrease in solute concentration gradient gradually slows with longer dwell times. In people, physical properties of the peritoneal membrane vary, resulting in different coefficients.

Transport of water and solutes across the peritoneal membrane is best explained by the 3 pore theory.[3,6,8,10–13] Large pores, 100–200 Å in diameter, correspond to clefts in the endothelium and allow the transport of macromolecules such as albumin. They are present in very small numbers, accounting for less than 0.01% of the total pore surface area. Small pores, 20–25 Å in diameter, also correspond to clefts in the endothelium. They are present in large numbers, representing more than 90% of the pore surface area, and allow the passage of low MW substances such as urea, creatinine, and glucose. Ultrasmall pores, 4–6 Å in diameter, are aquaporin I channels found within peritoneal capillary and mesothelial cells, and transport only water.[3,14–19] The ultrasmall pores account for approximately 50% of ultrafiltration and account for the rapid decrease in the sodium dialysate to plasma ratio in the first hour of PD.[17,19,20] Aquaporin expression in mesothelial cells can be induced by exposure of the cells to hyperosmotic solutions.[16]

People treated with chronic PD undergo testing to determine the rate of ultrafiltration and solute clearance. One such test measures the rate at which creatinine appears in the dialysate compared with its concentration in plasma. The reason for performing such tests is that people who are treated with chronic PD have or develop changes in the peritoneal membrane that affect the rate at which solutes are transported. In low solute transporters, the osmotic gradient between plasma and dialysate remains high for a longer period, and therefore, there is a high rate of ultrafiltration of water into dialysate. In high transporters, there is more efficient removal of urea, creatinine, and other uremic substances, but ultrafiltration is less efficient. In average transporters, the rates of solute and water movement are intermediate between the above 2 types.[2,9,21] There is no such corresponding information available for clinical use in dogs and cats. Although such information would be useful in formulating an accurate dialysis prescription, its benefit in the treatment of acute disease is likely less important than for chronic disease.

Indications for PD

The primary indication for PD in animals is for the treatment of acute kidney injury (AKI). This includes oliguric or anuric kidney injury, acute polyuric kidney injury with severe uremia that is unresponsive to fluid therapy, and postrenal uremia resulting from ureteral obstruction.[4,22] Although PD is less efficient than hemodialysis in correcting uremia and water and solute abnormalities, it still has a number of therapeutic advantages.[3] The decreased efficacy may be beneficial in

treating cats and small dogs, in which rapid water and electrolyte shifts can result in serious pathophysiologic abnormalities. PD can be performed relatively easily in the practice setting because the equipment and supplies are easily obtained, and the technique, although labor intensive, is not difficult.

Additional indications for PD include treatment of toxicities in which the offending toxin can be removed by diffusion across the peritoneal membrane. Such toxins include ethylene glycol, ethanol, and barbiturates.[4,22] Severe metabolic disturbances, such as hypercalcemia, hyperkalemia, hepatic encephalopathy, and resistant metabolic acidosis, also can be corrected with PD.[22] PD with hypertonic dialysate can be used to remove excess body water in animals with life-threatening fluid overload, such as that which occurs with heart failure. There are other disorders in which peritoneal lavage, using solutions and techniques very similar to those for PD, may be beneficial. These include hypothermia, hyperthermia resulting from heat stroke, and pancreatitis.[23]

Published reports of PD in dogs and cats have found varying outcomes.[24–31] Although most described improvement in renal function during dialysis, overall survival remained poor. More recent publications reported improved survival, perhaps indicating an improvement in technique or overall management of critically ill animals. In one study of 27 dogs and cats, 24% improved and were discharged from the hospital.[26] However, 11 of 21 of the animals with AKI suffered from ethylene glycol intoxication, which is known to result in a mortality rate approaching 100%.[31,32] In another study, 45% (10/22) of cats treated with PD were discharged from the hospital[33] One study of PD for the treatment of leptospirosis in 5 dogs reported a survival rate of 80%.[25] Complications identified in these dogs were hypokalemia (60%), hypoalbuminemia (40%), hypomagnesemia (20%), pelvic limb edema (40%), central nervous system signs (40%), dialysate retention (20%), and leakage from the catheter site (20%). A report of 6 cats treated with PD for AKI of varying etiologies reported survival in 5 of the 6 cats, all of which eventually had normal kidney parameters. All cats had complications, including subcutaneous edema (83%), hyperglycemia (67%), dialysate retention (50%), and hypoalbuminemia (50%).[34]

The success rate of PD must be compared to the overall survival rate of animals with AKI treated with other means, because animals undergoing dialysis traditionally have been those with the most severe kidney failure. The survival rate of dogs with leptospirosis treated with fluids and antimicrobials has been reported to be 59–85%.[35–37] In a study of 99 dogs with AKI, 43% were discharged from the hospital. Of these, 24% were left with residual renal dysfunction, and only 19% had return to normal renal function.[32] In another report of 80 dogs with AKI, only 20% survived to discharge; 44% of the dogs had ethylene glycol intoxication.[31] It may be that the survival of animals with AKI treated with PD is more dependent on the underlying cause of disease than the technique.

PD could theoretically be used for the long-term management of animals with chronic kidney failure. However, technical problems with catheter flow and complications such as infection make chronic PD difficult. Few such cases have been reported.[38–41]

Contraindications to PD

There are few situations in which PD is absolutely contraindicated. In people, these include peritoneal adhesions that prevent fluid distribution throughout the abdominal cavity and pleuroperitoneal leaks that would result in pleural effusion and respiratory compromise. Although adhesions are common in people, especially those that have had abdominal surgery,[42] they are not often seen in dogs and cats. Infusion of dialysate in animals with diaphragmatic or pericardiodiaphragmatic hernias could result in respiratory or cardiac dysfunction. In contrast, pleural dialysis has been described in 2 dogs with AKI.[43] Relative contraindications for PD include recent thoracic or abdominal surgery, inguinal or abdominal hernias, and severe hypercatabolic states, such as those seen with cutaneous burns or skin denudation. Animals with recent abdominal surgery, especially gastrointestinal surgery, are at risk for dehiscence and infection during PD because of the increased abdominal pressure and potential fluid leakage through the incision site. Similarly, progressive herniation may occur as the result of increased intraabdominal pressure. Concomitant catabolic diseases contribute to the hypoalbuminemia that can occur during PD.

Protocol for PD

Catheter types and placement

The key to successful PD is the catheter and its placement. An ideal catheter allows efficient inflow and outflow. It is biocompatible and resists infection of both the peritoneum and the subcutaneous tunnel.[22,44,45] There are many catheter designs available and most are modifications of a fenestrated silicone tube with Dacron[a] cuffs positioned to promote fibrous adhesions at the peritoneal and cutaneous exit sites (Table 1).

Simple tube catheters with stylets can be placed percutaneously in conscious animals using local anesthetics in an emergency situation.[4,22,45–47] A percutaneous cystotomy tube catheter[b] has been used successfully for acute short-term PD (Figure 1). The Tenckhoff catheter, developed in 1968 is a straight soft silastic tube fenestrated at

Table 1: Suppliers of peritoneal dialysis catheters

Cook Medical Inc. PO Box 4195 Bloomington, IN 47402–4195. www.cookmedical.com. Stamey and other suprapublic PD catheters.
Covidien/Kendall/Tyco Healthcare 15 Hampshire St Mansfield, MA 02048 800–962-9888. www.Kendallhq.com/healthcarecatalog.asp. www.covidien.com. A variety of peritoneal dialysis catheters.
Medcomp 1499 Delp Drive Harleyville, PA 19438 215–256-4201. www.medcompnet.com. Straight and curled, one and two cuff peritoneal dialysis catheters.
Medigroup Inc (division of Janin Group Inc) 505 Weston Ridge Drive 800–323-5389. www.medigroupinc.com. Ash Advantage Fluted-T Catheter. Flex-neck PD catheters.
Smiths Medical PM, Inc. N7W22025 Johnson Drive Waukeshsa, WI 53186 888–745-6562. www.surgivet.com. Acute peritoneal dialysis catheter.

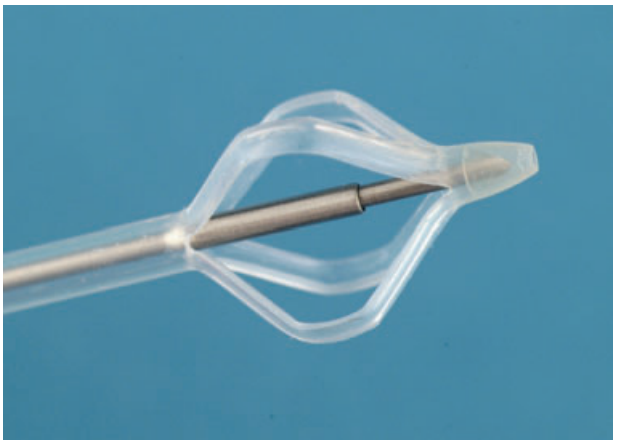

Figure 1: A Stamey prepubic temporary peritoneal dialysis (PD) catheter. Close up view of the catheter tip over trocar. Cook Medical Inc., Bloomington, IN.

the distal end and furnished with 1 or 2 Dacron velour cuffs that can be blindly placed using a trocar.[30,48,49] For short-term use the beneficial effects of the dacron cuffs such as fibroblast ingrowth resulting in a secure and relatively closed tunnel site are not generally fully appreciated. For AKI the duration of treatment is predicted by the animal's condition, it is typically performed for a minimum of 48–72 hours. For percutaneous placement the patient should have the abdomen shaved and aseptically cleaned as for a surgical procedure. An indwelling urinary catheter should be placed to ensure that the bladder is collapsed and away from the trocar. A small skin incision should be made 3–5 cm lateral to the umbilicus. The trocar should be inserted subcutaneously through the skin incision pointing toward the pelvis and inguinal canal and then tunneled for several centimeters before it is inserted through the abdominal muscles into the abdomen. The catheter is advanced over the trocar until it is fully in the abdomen. Ideally the subcutaneous tunnel should create a snug fit. Use a purse string suture pattern to secure the catheter.

There are a variety of straight and curled catheters with straight and flexed necks for placement for long-term use (Figure 2). The 2 catheters that have been most successful in veterinary medicine for long-term use are the Fluted-T catheter and the Missouri catheter (Figures 3 and 4).[22] The pediatric lengths are best used

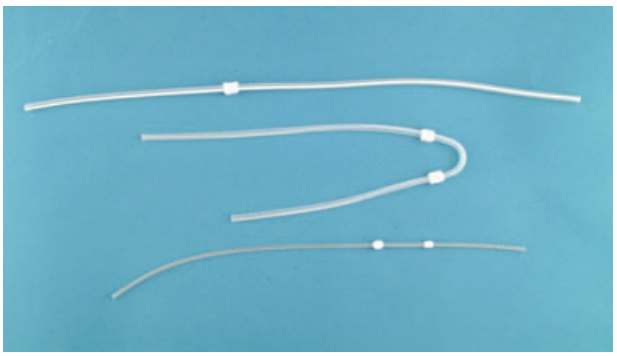

Figure 2: A variety of straight and swan neck peritoneal dialysis (PD) catheters.

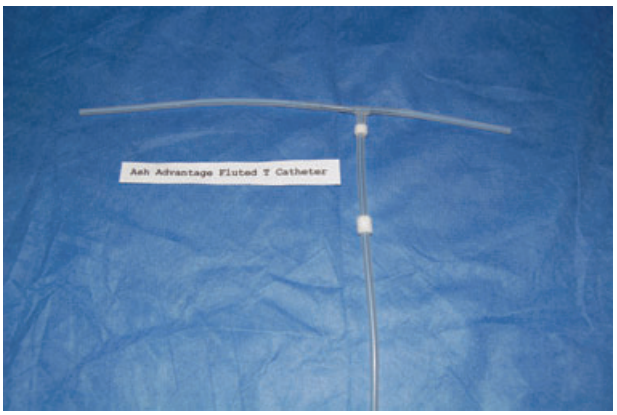

Figure 3: The Ash Advantage Fluted-T peritoneal dialysis (PD) catheter. Medigroup Inc, IN.

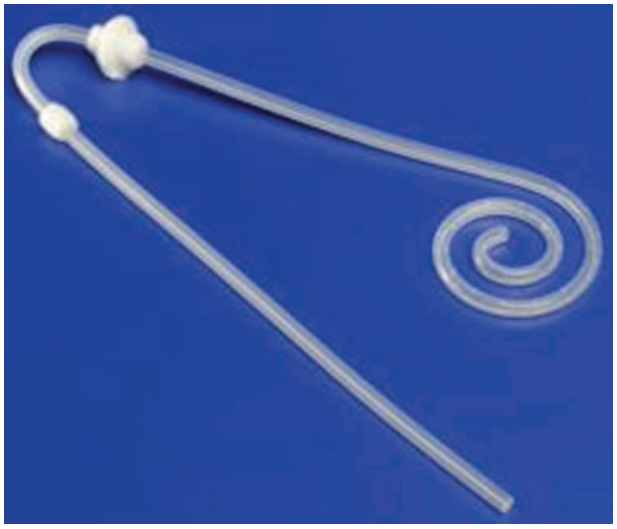

Figure 4: A Missouri Swan Neck Curled peritoneal dialysis (PD) catheter. Covidien/Kendall/Tyco Healthcare, MA.

in cats and ferrets. When it is believed PD will be performed for longer than 24 hours, a surgically placed catheter should be utilized. Because of the high rate of omental entrapment, surgical omentectomies are advocated. Although some catheters such as the Fluted-T and the Missouri Swan Neck curled catheter have been designed to be placed either via laparoscope or blind trocarization in human medicine it is preferable to place these catheters surgically in dogs and cats. The curled tip should be positioned in the inguinal area. The fluted aspect of the Fluted-T catheter is placed against the parietal peritoneum and oriented in a cranial to caudal plane. It is placed in a paramedian location with the long aspect directed toward the inguinal ring. The subcutaneous tunnel should be such that there is a gentle bend in the catheter that does not kink and that exits caudally and off midline by 3–5 cm. When a cuffed catheter is used the cuffs should be soaked in sterile saline before placement to remove air and facilitate fibroblast cuff invasion. The inner cuff is placed in the rectus muscle, and the other cuff is placed in the subcutaneous tunnel. A tight subcutaneous tunnel with fibrous ingrowth into the cuff decreases the incidence of dialysate leak.[44,50] Although not specifically designed for PD, the Blake surgical drain[c] (Johnson and Johnson, Arlington, TX) functions in a manner similar to the fluted-T catheter and has been utilized for PD in veterinary patients (Figure 5).[46,47]

The catheter should be attached to a sterile closed exchange system and carefully bandaged into position with dry sterile dressings. The use of topical antimicrobial ointments is not recommended because of the potential to cause maceration of the exit site tissues and fibroblast inhibition. Minimizing catheter movement during

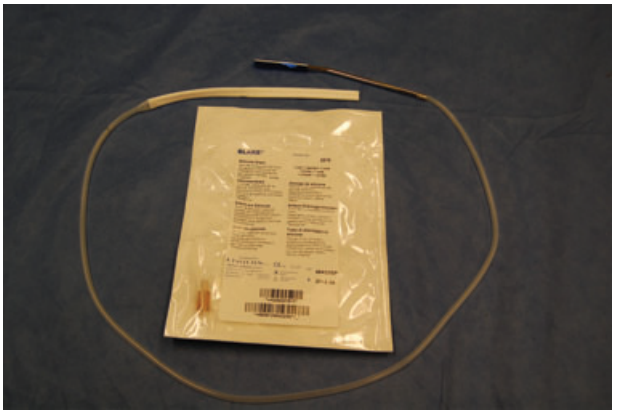

Figure 5: Blake surgical drain. May be used as a temporary peritoneal dialysis catheter. Johnson and Johnson, TX.

the invasion of fibroblasts into the cuffs is crucial for minimizing exit leaks and infections. After placement of the dialysis catheter, the tail of the catheter tubing is connected to a transfer tubing set which previously has been attached to and primed with a prewarmed bag of dialysate. Strict sterile technique should be maintained throughout all manipulations. Connections should be protected with povidone-iodine connection shields or chlorhexidine-soaked sponges.

Delievery technique and the exchange procedure

Aseptic technique during delivery of dialysate is essential to minimize the risk of peritonitis. Hands should be thoroughly washed with soap or cleaned with a hand sanitizer and sterile gloves used while changing the dialysate bag or lines because the most common cause of peritonitis is contamination of the bag spike.[22,38] Routine use of a face mask while doing bag exchanges and catheter maintenance has been shown to be unnecessary as long as proper hand care is maintained.[51] Every line connection should be covered with a povidone-iodine connection shield or chlorhexidine soaked dressings covered with sterile gauze. All injection ports should be scrubbed with chlorhexidine and alcohol before injections and the use of multiple-dose vials (eg, heparin or potassium chloride) for dialysate supplements should be avoided to decrease the risk of introducing microorganisms.

For the first 24–48 hours after catheter placement the exchange volumes should be one quarter the calculated ideal volume to assess the degree of abdominal distention, the effect on respiratory function, and the potential for dialysate leakage.[52–54] After the first 48 hours the dialysate can be infused at a dosage of 20–40 mL/kg during a 10-minute period.[44,55] The dialysate is allowed to remain in the peritoneal cavity for 30–40 minutes

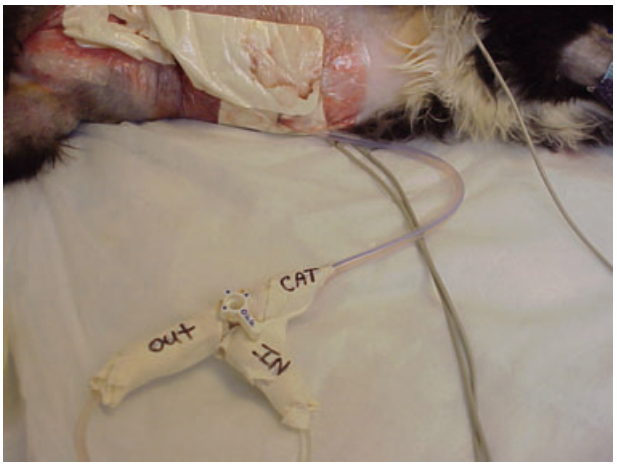

Figure 6: A Y system for flush-before-fill set up. Line labeled cat is the peritoneal dialysis (PD) catheter. Line labeled in comes from the dialysate solution bag. Line labeled out is the drain line. After a dwell period the dialysate is drained from the patient. Before the next instillation of dialysate solution, the line is flush from the IN line to the OUT line and then new dialysate is infused to the patient.

dwell time and then is drained into a collection bag by gravity during a 20–30 minutes period. A 90–100% recovery of dialysate is expected. This process is repeated continually and the dialysate formula and dwell times are adjusted every 12–24 hours according to the animal's needs. This form of continuous exchanges or cycling is referred to as continuous PD.[56]

Although dialysis can be performed with a straight-line transfer set, use of a closed, flush system has been associated with lower infection rates.[57–59] The closed "Y" system allows the lines to be flushed free of possible bacterial contamination before each dialysate infusion without opening the system to outside air (the drain, flush, instill method). A Y-set tubing with a fresh dialysate bag and a drainage container attached to either segment is connected to the catheter tubing or transfer set. First, a small amount of fresh dialysate is flushed into the drainage bag, and then the peritoneal cavity is drained so that any contaminants introduced during the connection procedures are flushed into the drainage bag and not into the peritoneal cavity (Figure 6). After drainage the fresh dialysate is infused. This "drain first-infuse later" principle has markedly decreased the incidence of peritonitis in people on PD as compared with the "infuse first-drain later" principle used in the straight single-spiked system.[60]

The exchange procedure for severe azotemia should follow the described protocol. The dialysate should remain in the abdomen for 30–40 minutes. Dialysis cycles should be repeated every 1–2 hours until the animal is clinically improved, blood urea nitrogen (BUN) and serum creatinine concentrations have decreased and volume overload has been corrected. This initial intensive dialysis typically continues for 24–48 hours. Do not attempt to bring the BUN and creatinine concentrations into the normal range. A reasonable goal is a BUN concentration of 21.4–35.7 mmol/L (60–100 mg/dL) and a serum creatinine concentration of 353.6–540.4 μmol/L (4.0–6.0 mg/dL). The animal can then be switched to a chronic dialysis schedule. A chronic dialysis schedule involves allowing the dialysate solution to remain in the abdomen for 3–6 hours. Three to 4 exchanges per day are performed. The dialysate should remain in the abdomen during these extended exchange periods. The rate of infusion can be rapid in most cases without problems. If the animal shows signs of discomfort during infusion check that the solution temperature is not too hot or too cold and also slow the rate of infusion.

The frequency of the exchanges and the dwell time duration are adjusted for each animal's individual needs. The goal of PD for an animal with kidney failure is to remove enough urea to maintain the BUN concentration at <24.9 mmol/L (≤70 mg/dL).[22] The amount of solute transferred across the peritoneal membrane is determined by the concentration gradient for each solute. If there is a need to increase removal of large molecules such as creatinine the dwell time for each exchange is extended.

Dialysis should be continued until kidney function has normalized or is adequate to maintain the patient without dialysis as determined by urine output, the stabilization of blood values and clinical signs. Gradual reduction of the number of exchanges and having exchange free periods are recommended. This intermittent PD should be done during a 3–4-day period with continual reevaluation of the patient's clinical state. If and when the patient becomes polyuric than the discontinuation of exchanges may be accelerated. If the animal receiving aggressive, well-managed continual PD has not improved according to biochemical parameters or uremic signs after several days, chronic PD, chronic hemodialysis, renal transplantation or euthanasia should be considered.

Dialysate solutions

The biocompatibility of a PD solution can be defined as the ability of a formulation to permit long-term dialysis without any clinically relevant changes in the functional characteristics of the peritoneum. Solution components can affect leukocyte, mesothelial cell, endothelial cell, and fibroblast function, resulting in alterations in cytokine, chemokine, and growth factor networks, up-regulation of proinflammatory and profibrotic pathways, impaired peritoneal host defense, and

the induction of carbonyl and oxidative stress.[61] Such perturbations of normal physiology have been proposed as causative factors contributing to changes in peritoneal structure, such as peritoneal fibrosis, sclerosis, and vasculopathy, and changes in peritoneal function including increased solute permeability and ultrafiltration failure.[61–63] The majority of PD fluids used today have the composition of a lactate-buffered, balanced salt solution devoid of potassium, with glucose as the osmotic agent. Lactate is used as a buffer instead of bicarbonate because bicarbonate and calcium may precipitate during storage. However the advent of newer multichambered PD delivery systems makes it currently possible to replace lactate with bicarbonate and to make a number of other solution modifications which previously were not feasible. Very few of these newer solutions will be utilized during the relatively short durations PD is utilized in veterinary medicine.

Hypertonic dextrose-containing dialysate solutions are effective for minimizing edema in overhydrated patients and for enhancing ultrafiltration in all patients. Hypertonic dextrose appears to favor capillary vasodilation and promotes solute drag. A 1.5% dextrose dialysate is used in dehydrated or normovolemic patients. The 2.5% and 4.25% dialysates should be used in mildly to severely overhydrated patients. Intermittent use of a 4.25% dialysate solution may increase the efficiency of dialysis in all patients.[22] Heparin (250–1,000 U/L) should be added to the dialysate for the first few days after catheter placement to help prevent occlusion of the catheter by fibrin deposition. This heparin is minimally absorbed by the patient's circulation and is unlikely to prolong clotting times.[22,23,52,53,64] The dialysate should be warmed to 38°C to improve permeability of the peritoneum. The dialysate line should be placed in a fluid warmer to help maintain this temperature.

In an emergency situation where there is no commercially prepared dialysate solution available a suitable dialysate solution can be made by adding dextrose to lactated Ringer's solution. Osmolality should closely approximate that of the patient and the dextrose concentration should be at least 1.5%. Adding 30 mL of 50% glucose to 1 liter of lactated Ringer's solution will result in a 1.5% dextrose solution.

The glucose concentration of dialysate solution is high, clearly in the diabetic range. Over time, these concentrations of glucose are toxic to the mesothelium. Glucose activates the polyol pathway and the secretion of transforming growth factor-beta1 (TGF-B1), monocyte chemoattractant protein-1 (MCP-1) and fibronectin. There are studies suggesting that prolonged exposure to glucose is involved in the development of peritoneal fibrosis.[65,66] The clinical importance of this finding is that it leads to impairment of ultrafiltration. A second mechanism by which glucose can damage the peritoneal tissue is by inducing nonenzymatic glycosylation of tissue proteins which leads to the formation of advanced glycosylation end products (AGEs).

Glucose degradation products (GDPs) are formed during the heat stabilization process of dialysate solutions. GDPs consist of aldehydes such as formaldehyde and dicarbonyl products such as glyoxal and methylglyoxal. GDPs may affect the peritoneal membrane by 3 mechanisms. These compounds are toxic to fibroblasts. Methylgloxal enhances the production of vascular endothelial growth factor (VEGF). And the final mechanism is that GDPs trigger the formation of AGEs at a much faster rate than glucose.[66] However, for short-term use in veterinary medicine, no adverse effects have been recognized.

Bicarbonate based solutions are being developed to increase solution biocompatibility and thus protect the peritoneal membrane. Their formulation also reduces infusion pain associated with the low acidity of most conventional commercial preparations. A 1.1% amino acid solution is now available in many countries to supplement protein intake and treat or prevent malnutrition. One exchange of the 1.1% amino acid solution per day has been shown to improve nitrogen balance and biochemical markers for nutrition in malnourished chronic ambulatory peritoneal dialysis (CAPD) patients.[67–69]

Complications

Complications with PD are common but manageable if recognized early. The most common complications include catheter flow problems, exit site leaks, hypoalbuminemia, peritonitis, pleural effusion, dyspnea caused by increased abdominal pressure, changes in hydration status and electrolyte abnormalities (Table 2).[22,44,70]

Catheter flow obstruction by fibrin or omentum leading to dialysis retention is common.[55,71] In one study, 30% of dogs undergoing PD developed such obstructions.[26]

Table 2: Potential complications of peritoneal dialysis

Acute pleural effusion
Catheter related
• Catheter obstruction
• Exit site and tunnel infection
• Dialysate leakage
Electrolyte disorders
Hypoalbuminemia
Peritonitis
• Diagnosis based on presence of at least 2 of 3 criteria
○ Cloudy dialysate effluent
○ Detection of >100 inflammatory cells/μL, or organisms in gram stain or cultures
○ Clinical signs of peritonitis

In a review of cats treated with PD, 77% had dialysis retention with 3 of 22 or 13.6% having a clogged catheter. Fifty-eight percent of cats with surgically placed catheters experienced dialysate retention while 100% of those cats with percutaneously placed catheters had retention problems. Careful catheter placement and management are important preventative steps. Heparinized saline flushes of the catheter for the first few days may decrease the occurrence of fibrin formation around the catheter fenestrations.[23] If a clot in the catheter is suspected, a high pressure saline flush or the addition of 15,000 U of urokinase to the catheter for 3 hours may dislodge clots.[60] Decreasing volumes of dialysate during outflow or abdominal pain on dialysate inflow are evidence of omental entrapment. If omental entrapment occurs temporary catheters need to be repositioned or replaced to correct this problem. For this reason it is strongly recommended that catheters be surgically placed and an omentectomy performed if use of the PD catheter is anticipated for longer than 48 hours.

A common easily corrected cause of dialysate solution retention occurs when there is kinking of the catheter or catheter outflow lines. Care should be taken when daily bandaging of the catheter is performed. Subcutaneous kinking of the catheter can be avoided by using a swan neck catheter and allowing the natural bend of the catheter to lie in the subcutaneous tissue.

The most frequent complication at the author's institution is dialysate leakage into the subcutaneous tissue. Sixty-two percent of cats with percutaneously placed catheters experienced subcutaneous leakage and 50% of cats with surgically placed catheters had subcutaneous leakage secondary to too large of a volume of dialysate infusion before tunnel site or laparotomy incision has developed an adequate seal.[33] This complication is managed by having the surgeon closely appose the abdominal incision (simple interrupted suture pattern only), starting the initial exchange volumes at one quarter of the calculated infusion amount, and if leakage does occur, intermittently wrapping the limbs to promote mobilization of the edema. If at all possible it is beneficial to wait a minimum of 12 hours after surgical placement to begin the exchanges, unfortunately because the indication for PD is typically associated with an acute process this opportunity to wait is typically not an option. In addition, if subcutaneous leakage occurs the dialysate solution should be changed to the lowest possible osmolality formulation available.

Acute pleural effusion is an uncommon complication and usually occurs early in the course of treatment. A common PD complication is overhydration of the patient. If the patient is gaining weight, the central venous pressure is increasing, or the effluent recovered is not at least 90% of the dialysate infused, the prescription should be changed to ultrafiltration with more concentrated dextrose (2.5 or 4.25%) solutions.

Protein losses can be clinically important with PD especially when performed for greater than 2–3 days.[72] Losses may increase dramatically (50–100%) when peritonitis is present. Hypoalbuminemia was the most common complication in a review of PD cases in dogs and cats, and 41% of the animals were affected.[26] In another study 16% of cats developed hypoalbuminemia.[33] Hypoalbuminemia may be the result of low dietary protein intake, gastrointestinal or renal protein loss, loss in the dialysate itself, uremic catabolism, and concurrent diseases. Usually the animal can maintain normal serum albumin concentrations if nutritional intake is adequate. Adequate enteral nutrition may be difficult to maintain given the anorexia and vomiting common in uremic patients. Nutritional support includes feeding tubes, parenteral nutrition, and the technique of PD utilizing 1.1% amino acid solutions.[46,63,67,69,73] Gastrostomy and jejunosotomy tubes are contraindicated during PD because of increased risk of infection and abdominal wall exit site dialysate leaks.

The prevalence of peritonitis in veterinary patients on PD had previously been reported as being higher than that reported for people 22% versus 15%.[26,74] In addition exit site infection is a troublesome problem in people.[75] In recent studies at the author's institution peritonitis was not identified in any of the PD cases in dogs reviewed during a 4-year period and was reported in only one of 22 cats (2.5%) over a 5-year period.[25,33] 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. It is important to recognize pericatheter leaks to minimize exit site sources of infection.[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. The incidence of peritonitis has dramatically decreased with the use of the closed Y-system and drain first protocol. Because *Staphylococcus* spp is the most common organism cultured cephalosporins administered systemically and intraperitoneally are empirically recommended. The author commonly will administer one dose of cefazolin in 1 dialysate exchange daily and also administer the antimicrobial intravenously as well.

Dialysis disequilibrium is a rare complication of PD characterized by dementia, seizures, or death. Dysequilibrium may occur during early exchanges especially in patients with extreme azotemia, acidosis, hypernatremia or hyperglycemia. Rapid removal of urea and other small solutes causes influx of water into brain cells and neurological dysfunction.[22] A more efficient removal

Table 3: Monitoring parameters for patients receiving peritoneal dialysis

1. Check systemic arterial blood pressure every 6–8 hours
2. Evaluate packed cell volume (PCV), total protein, serum urea nitrogen (BUN), creatinine, electrolytes, albumin, and venous blood gas analysis once to twice daily depending on severity of azotemia
3. Monitor body temperature every 6–8 hours
4. Perform adequate peritoneal catheter exit site care, and evaluate for exit site infection daily. Apply antibiotic ointment at exit site, cover with sterile dry gauze pad and then wrap with bandaging material.
5. Record heart rate and respiratory rate every 2 hours. Note if there is respiratory difficulty with dialysate infusion.
6. Record or weigh the amount of dialysate infused and recovered with each exchange
7. Weigh the patient twice daily before dialysate infusion

of urea from plasma as compared with the brain favors movement of water to the intracellular space leading to cerebral edema and an increase in intracranial pressure. Idiogenic osmoles are also thought to play a role as well as paradoxical intracellular acidosis.[76] If evidence of disequilibrium occurs, the dialysate prescription should be adjusted to remove urea and small solutes at a slower rate (ie, fewer exchanges or longer dwell times).

Monitoring

Monitoring of the PD patient should include carefully recording the volume of the dialysate infused and recovered during each exchange period as well as the volume of urine produced and any additional fluids administered. If the patient is volume overloaded and a high osmolality fluid is utilized the fluid recovered from the abdomen may be greater than that delivered for the first few exchanges. As dialysis proceeds, outflow should approximate or exceed inflow if the patient is adequately hydrated. If less fluid is recovered with subsequent exchanges the patient should be evaluated for dialysate leakage into subcutaneous fluids or for dialysate retention. At that point the catheter should be checked for evidence of obstruction to outflow.

In the acute setting, body weight and hydration status should be monitored frequently, with body weight recorded consistently on the same scale and either with or without dialysate in the abdomen. Determination of PCV and total plasma protein should be performed at least twice daily. Serum electrolyte concentrations and other blood chemistries such as BUN, creatinine, albumin and acid-base should be assessed initially every 8–12 hours and then daily (Table 3).

A number of metabolic aberrations may occur in patients on PD, including alterations in serum sodium, potassium, magnesium, and glucose concentrations as well as changes in acid-base status. Frequent monitoring and adjustment in dialysate and supplemental parenteral fluid composition may be necessary.[22,77,78]

Conclusions

PD, while an older technology in veterinary medicine, can still play an important tole in the management of animals with kidney failure. Because of the relatively low cost and straightforward technique, it lends itself to use in situations in which more advanced types of renal replacemnt therapy are not available. Understanding the principles and techniques for PD are important to ensure its appropriate use.

Footnotes

[a] INVISTA, Wichita, KS.
[b] Stamey percutaneous suprapubic catheter set, Cook Medical, Bloomington, IN.

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