Fluid Therapy for Pediatric Patients

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KEYWORDS

- Pediatric • Neonate • Fluid therapy • Crystalloids • Colloids • Blood transfusion
- Neonatal isoerythrolysis • Intraosseous

KEY POINTS

- Pediatric patients have a higher fluid requirement compared with adults because of increased extracellular fluid, decreased renal ability to conserve water, a larger surface area/body weight ratio, and larger fluid losses through skin.
- In pediatric patients less than 6 weeks of age, hydration and volume status are difficult to assess.
- Fluids should be warmed to near body temperature (37°C/98.6°F) before administration to the pediatric patient, and should be kept warm even in fluid lines.
- Multiple routes of administration of fluid therapy are used in the neonate or pediatric patient including oral, subcutaneous, intraperitoneal, intraosseous, and intravenous. Clinicians should be aware of the limitations or potential complications of each route of delivery.

INTRODUCTION

Although dogs and cats are often referred to as puppies and kittens until a year of age, the term pediatric generally refers to the first 6 months of life.[1] This terminology is further divided into the following: neonate aged 0 to 2 weeks, infants aged 2 to 6 weeks, and juvenile aged 6 to 12 weeks.[1–3] The term pediatric is used throughout this article, which focuses on the first 12 weeks. Medical treatment of pediatric patients presents challenges because of their small size and unique physiology, but understanding these challenges allows the veterinarian to provide life-saving supportive care to these young patients.

Ill pediatric patients can quickly become critically ill patients; any of several disease states, or even problems with basic animal husbandry or lack of maternal care, can result in a debilitated pup or kitten that requires critical care.[4] It is estimated that

12% to 15% of pups born at full-term succumb by the time of weaning, with half of all deaths said to occur in the first 3 days of life.[5] Common causes of neonatal (ie, <2 weeks) illness are related to poor mothering, inadequate nutrition (eg, poor suckling, inadequate milk production), congenital defects, hypoxemia associated with dystocia, poor sanitation, neonatal isoerythrolysis (kittens only), or the poorly understood "fading" puppy or kitten syndrome.[4–6] These conditions are often manifested in the first week of life, but if the mother herself becomes ill days or weeks after whelping these issues may be delayed. During the infant period from 2 to 6 weeks of age, life-threatening diseases, such as juvenile hypoglycemia, parasitism (internal and external), trauma, or dehydration from diarrhea, are often seen.[2,4] Weakness, tremors, seizures, stupor, or coma can indicate severe hypoglycemia.[2,7] When hypoglycemia is suspected or confirmed, rapid treatment with intravenous (IV) or intraosseous (IO) glucose solution is imperative, along with monitoring and follow-up care. Infestation with fleas or parasitism with hookworms can result in severe anemia in these very small animals, seen clinically as listlessness, tachycardia, and pale mucous membranes. Dehydration often follows quickly from diarrhea of any cause, such as overfeeding, improper nutrition, parasites, or other infections (**Box 1**). During the juvenile period of 6 to 12 weeks, maternal antibody is waning, resulting in increased susceptibility to infectious diseases.[4] Even pups vaccinated during this juvenile period may not be protected when there is just enough maternal antibody to interfere with vaccine response or when only a single dose of vaccine has been recently administered. Among the most common juvenile infections of puppies and kittens are canine parvovirus and feline panleukopenia; these lead to diarrhea, vomiting, and anorexia, all of which predispose to severe dehydration and hypovolemia.

Dehydration and hypovolemia are two distinct conditions that are seen either separately or together in a single patient. Dehydration refers to a water deficit in the interstitial and intracellular fluid compartments, whereas hypovolemia is a state of decreased intravascular volume that can occur with or without dehydration. Severe

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Box 1
Infectious causes of diarrhea that can result in profound dehydration in the juvenile patient

1. Parasitism
   a. Coccidiosis
   b. Giardiasis
   c. Hookworms
   d. Roundworms

2. Viral infections
   a. Parvovirus
   b. Coronavirus
   c. Rotavirus

3. Bacterial infections
   a. *Salmonella*
   b. *Clostridia*
   c. *Campylobacter*
   d. *Escherichia coli*

4. Nutrition
   a. Overfeeding
   b. Inappropriate milk replacer (eg, cow's milk)
   c. Improper handling of the milk replacer diet
   d. Lactose intolerance

dehydration leads to hypovolemia as fluid is pulled from the intravascular space into the interstitial and intracellular tissues. Because of their higher body water needs, this can happen quickly in young pups and kittens such that critically ill pediatric patients are at risk for rapid progression from dehydration to hypovolemic shock. They require appropriate fluid therapy to ensure survival.

Unfortunately, the small size and physiologic differences between pediatric patients and mature animals can make clinical assessment of fluid status more difficult in these young patients.[8] For example, dehydration is typically graded as 5% to 7% in animals with "tacky" mucous membranes, but tiny mouths and frequent nursing can interfere with assessment of oral mucous membranes. Skin tenting occurs at approximately 7% dehydration, but excess loose skin can affect this determination, and pups less than 6 weeks maintain skin turgor even when dehydrated.[8] Sunken globes are described at approximately 9% dehydration, and dull corneas at approximately 10% to 11%, but pups and kittens do not open their eyes until they are 1 to 2 weeks old. Clues to hypovolemia usually include mucous membrane color and capillary refill time, pulse quality, and jugular venous defensibility. Each of these is far more difficult to gauge in very young animals. The other clue frequently used to assess volume status is heart rate, but heart rate in pediatric patients does not respond to volume change in a manner equivalent to mature animals. As difficult as it may be to gauge dehydration and hypovolemia, it is likewise difficult to judge overhydration. Signs of volume overload can include serous nasal discharge, chemosis (eg, particularly in the conjunctival region), tachypnea, altered breathing pattern, restlessness, cough, tachycardia, ascites, pulmonary crackles on auscultation, and polyuria. Careful monitoring of body weight, often several times per day, is absolutely crucial in neonates and helpful in all pediatric patients.

PEDIATRIC PHYSIOLOGY

Fluid requirements in pediatric patients are dramatically higher compared with adults.[1,2,5] As with humans and other species, neonatal dogs and cats have more extracellular fluid on a volume per kilogram body weight basis than older animals, and a higher water content (80% compared with 60% of body weight in adult animals).[9,10] Young pups and kittens use more water as a result of their higher metabolic rate. In addition, they have larger inherent fluid loss caused by a higher body surface area, a larger surface area/body weight ratio, and more permeable skin.[1,2] In addition, fluid is lost because the immature kidney cannot concentrate urine.[1,11]

The unique cardiovascular physiology of pediatric patients contributes to their inability to respond adequately to hypovolemia.[12] Cardiac output is determined by heart rate multiplied by stroke volume. Adult animals compensate for hypovolemia through activation of the sympathetic nervous system to increase heart rate, activation of the renin-angiotensin system and release of antidiuretic hormone to retain fluid, and vasoconstriction, all in an attempt to maintain cardiac output. Pediatric patients lack the compensatory mechanisms to increase heart rate in an attempt to maintain cardiac output.[12,13] In the neonate, cardiac output cannot be increased by increasing cardiac contractility, because only 30% of fetal cardiac muscle is made up of contractile elements.[12] Puppies also seem to have fewer sympathetic nerve fibers supplying the myocardium than adults.[12,13] As a result, tachycardia in response to hypovolemia may not occur as it would in an older patient with hypovolemia.

Kidneys are not fully mature at birth, and renal physiology differs in pediatric patients compared with adults.[9,14,15] Even at 2 months of age, puppies have an increased glomerular filtration rate, higher daily urine volume, and greater fractional exertion of

phosphorus than adult dogs.[16] There are conflicting data on the ability of young pups to concentrate urine. Traditionally, urine-specific gravity greater than 1.030 was not believed to occur before 8 weeks of age, but a study of healthy pups found that although neonates were unable to concentrate urine, pups 4 weeks and older generated urine comparable with that of adult dogs and could concentrate to specific gravity greater than or equal to 1.030.[17] Young puppies also have limited autoregulation of renal blood flow in response to changes in arterial blood pressure or hypovolemia, and they may not be able to respond to rapid changes in sodium or water load.[9,11,15,18]

Importantly, pediatric patients are prone to hypoglycemia compared with adult animals and are perhaps more susceptible to the adverse effects of hypoglycemia than are adults.[10,12,19,20] Because of their limited glycogen stores, deficiency of gluconeogenic substrates, poor response to glucagon, and inefficient hepatic gluconeogenesis, pediatric patients are unable to maintain glucose homeostasis if deprived of food for even relatively short periods.[19,21] This tendency toward hypoglycemia is exaggerated by smaller size and younger age. Although the brain of all animals depends primarily on glucose as an energy source, lactic acid and ketones can be used as substitutes. The lack of fat and the time required to produce ketones prevents ketone bodies from being a substitute energy substrate in juveniles.[19] As a result, pediatric patients should have frequent blood glucose monitoring. Bolus administration of glucose is often indicated during the acute presentation of weak pups and kittens (see fluid dosing). Routine ongoing dextrose supplementation in IV or IO fluid therapy should be considered for all pediatric patients that are not receiving complete and adequate enteral nutrition.

FLUID THERAPY

Crystalloid replacement solutions that resemble extracellular fluid in composition (eg, lactated Ringer solution, Normosol-R, Plasmalyte-A) can safely be administered to pediatric patients.[2] Some sources suggest avoiding lactate-containing fluids in animals less than 6 weeks of age because they do not effectively metabolize lactate into bicarbonate.[8] Other sources suggest that because lactate is used as an energy source by the neonatal brain, lactated Ringer solution may actually be preferred to other crystalloids.[10,22] Supplementation with dextrose (2.5%–5% dextrose as a constant rate infusion [CRI]) and potassium (20–30 mEq potassium chloride per liter, or as guided by serum potassium concentration) are often necessary in critically ill pediatric patients.

Colloids, large-molecular-weight fluid solutions, have a tendency to stay within the intravascular space longer than do crystalloids and are thus useful in the treatment of hypovolemia. Examples include the natural colloids; plasma or whole blood; and synthetic colloids, such as hydroxyethyl starch and dextrans. Colloids are often used during volume resuscitation when crystalloids alone fail, or in patients with severe hypoalbuminemia. Young animals may have lower serum albumin and globulin concentrations compared with adults, and hypoalbuminemia is often exaggerated by disease, and especially by blood loss. Recent evidence has suggested that the use of synthetic colloids may potentially increase the risk of acute kidney injury in humans and dogs,[23] but this has not been investigated specifically in pups or kittens. Because of the relatively large volume of plasma required to improve colloid osmotic pressure (ie, it requires approximately 22.5 mL/kg plasma to increase albumin by 0.5 g/dL in a dog), plasma is not generally used specifically for its colloidal properties in mature animals.[24] However, the use of plasma as a source of colloidal support and fluid volume might be a viable consideration in small pediatric patients because they tolerate high relative fluid volumes and require small absolute fluid volumes. The use of plasma

entails some risk of transfusion reaction or transmission of infectious disease, but naturally occurring antibodies in the administered plasma may offer limited benefit to neonatal patients deprived of colostrum.[25,26] Canine albumin, or less ideally human albumin, are other options for colloidal support. For anemic pediatric patients, transfusion of whole blood supplies oxygen-carrying support in addition to aiding with vascular volume (**Box 2** for more information on bolus dosing for volume resuscitation).

Any of several blood products may be necessary in the pediatric patient for a variety of reasons. They are useful when colostrum ingestion has not occurred.[25,26] The administration of plasma or serum from the mother or another healthy, well-vaccinated adult animal can provide antibodies. The recommended dose for this purpose is 16 mL for puppies and 15 mL for kittens, divided into two or three portions, subcutaneous (SC) every 6 to 8 hours.[3,25–27] Feline neonatal isoerythryolysis is another condition that often requires blood transfusion. Queens with type B blood have strong naturally occurring antibodies against type A blood. When these queens are bred to type A males, colostrum ingested by any resulting type A kittens may cause life-threatening hemolysis.[28] Clinical signs include tail tip necrosis, icterus, pale mucous membranes, listlessness, "fading," or sudden death. Ideally, kittens should be removed from the queen for the first 24 hours after birth to prevent colostrum ingestion but if neonatal isoerythrolysis has already occurred, transfusion of washed red blood cells may be required. Initially, cells from the type B queen can be given at a dose of approximately 5 mL per kitten (IV, over several hours) because the circulating antibodies attack type A blood.[28] If further transfusions are required more than 3 days postpartum, the type A kitten may have formed antibodies to type B blood. At this point, washed cells from a type A donor should be used in place of the mother's cells.[28]

Pups and kittens have a lower red blood cell mass than adults even in health. Anemia from any cause, such as external or internal parasites or parvovirus, may warrant transfusion of red blood cells. Kittens should always be blood typed, and ideally cross-matched before transfusion. For pups, the same is ideal but initial transfusions are often safe even from mismatched donors simply because dogs do not have preformed antibodies to other blood types.[29]

ROUTES OF ADMINISTRATION

Whatever route of fluid administration is chosen it is advisable to warm the fluid to approximately body temperature before administration. Neonates and infants especially are unable to control their body temperature and are susceptible to chilling. Remember that fluids that run through a length of administration tubing may cool

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Box 2
Emergency fluid dosages for neonates

- Bolus fluid for hypovolemia: 3 to 4 mL/100 g (pups); 2 to 3 mL/100 g (kittens)
- Bolus glucose for hypoglycemia: 1 mL to 3 mL of 12.5% dextrose (eg, 1:3 dilution of 50% dextrose with sterile water)
- Bolus colloid for hypovolemia that is nonresponsive to multiple crystalloid boluses: 2 mL/kg to 5 mL/kg, followed by 1 mL/kg/h as needed
- Whole blood for anemia: 10 mL/kg to 20 mL/kg

rapidly, so temperature control of fluid in the tubing matters as much as warming of fluid in the bag or syringe.

Oral replacement is generally recommended in the stable, pediatric patient with normothermia that does not have vomiting or nausea.[2,5,8,30] However, because oral replacement is the slowest means of replacing fluids, it should not be used in a dehydrated, hypovolemic, hypothermic, or hypoglycemic patient. A stomach tube (eg, 5F or 8F premeasured red rubber catheter) is used for oral fluid administration. The tube should be measured from the tip of the nose to the last rib, and the tube marked accordingly. Although the gag reflex is not present until 10 days of age, passage down the left side of the mouth allows for easy feeding of milk replacer, dextrose solution, or water. A small amount of water should be administered via the stomach tube first, making sure that it does not come out through the nares. Once the stomach tube is confirmed to be in the appropriate location, an appropriate amount of commercial milk replacer can be used. The exact amount depends on the labeled instructions and should be adjusted every several days for weight gain. Normal stomach volume is approximately 40 mL/kg to 50 mL/kg, and overfeeding must be avoided.[2,5,8,30] The fluid should be warmed to near body temperature, and administered over a few minutes. In general, 10 mL can be fed to a puppy every 2 to 4 hours, whereas for kittens, 5 mL can be fed every 2 to 4 hours. The amount of feeding is increased by 1 mL per day in puppies and kittens.[2] After delivery of fluid, kink the tube before withdrawal to prevent aspiration pneumonia. Owners can be taught how to easily tube feed if the neonate has a weak suckle reflex or if nursing from the mother is discontinued or contraindicated (eg, rejection, eclampsia).

The use of SC fluids should be limited to stable patients with euvolemia with only mild dehydration. Advantages of the SC route are ease of administration and a low likelihood of overhydration, but disadvantages include slow fluid absorption, limitations in the types of fluid administered (ie, this route should be reserved for crystalloid fluids), and the potential for abscess formation. In general, fluids for SC administration should not contain dextrose, although 0.45% saline with 2.5% dextrose has been given by this route.[2] Ideally, only warm isotonic crystalloids, such as Norm-R, LRS, or 0.9% NaCl, should be given by the SC route.

Absorption of intraperitoneal (IP) fluids is slow, and therefore should not be used in hypovolemic or very dehydrated patients. Although it is sometimes used in very young neonates simply because of administration difficulties related to size, it is never preferred over the IV or IO route. Unlike the SC route, not only crystalloid fluids but also blood products (eg, whole blood, plasma, or red blood cells) can be given by the IP route.[2] However, hypertonic dextrose solutions should still be avoided because they can draw fluid from the interstitium and intravascular space into the abdominal cavity.[2] Absorption of blood cells by the IP route is very slow (up to 72 hours for most cells to be absorbed) and is therefore not acceptable for animals with hemorrhagic shock.[2,31] Although IP administration of a replacement crystalloid allows for large volume administration, it can cause patient discomfort, increased intraabdominal pressure that might interfere with respiration, and can result in peritonitis. Aseptic technique is of utmost importance with IP fluid administration, and fluids should be warmed to near body temperature before administration. Repeated IP fluid administration is not recommended because of risks of septic peritonitis.

IV administration is the preferred route of fluid therapy in the critically ill pediatric patient; however, depending on the size of the patient, it may be difficult to accomplish. Peripheral venous access with a 22- to 27-gauge catheter can be attempted. Provided there is no contraindication to doing so (eg, coagulopathy), a small cephalic catheter can often be placed in the jugular vein. The neck may be immobilized by a soft padded

wrap when a jugular catheter is placed or, if the animal is large enough to use a limb for placement of a peripheral catheter, a tongue depressor and wrap can help prevent catheter dislodgement. Aseptic technique and catheter care is imperative. Although placement of IV catheters is challenging, they offer instantaneous access to the vascular compartment for administration of all fluid types. Heparin irrigation of IV catheters is not necessary,[32] and can easily lead to coagulopathy in very small patients. Normal saline should be used in place of heparinized saline during catheter placement and maintenance.

Although IV access is ideal, it is sometimes simply impossible in the smallest patients, and placement of an IO catheter for fluid administration is life-saving in these patients. Access to the bone marrow sinusoids and medullary channels via IO catheter placement allows for rapid administration of fluid therapy suitable for the treatment of hypovolemic shock.[8,33–35] In addition, such catheters allow for administration of all fluid types including blood products, and for administration of drugs typically meant for IV use.[33,34,36] The IO catheter must be placed and maintained in an aseptic fashion, even more so than for an IV catheter because not only sepsis but osteomyelitis can result from infection at the site. Appropriate sites for IO catheterization include the greater tubercle of the humerus, trochanteric fossa of the femur, tibial tuberosity, or wing of the ilium (Fig. 1).[33–35] An 18- to 22-gauge spinal needle or hypodermic needle is used for catheterization. Although placement of an IO catheter is fairly simple in even the smallest of patients, it is difficult to wrap and protect the catheter. Ideally, such a catheter is replaced with an IV catheter as soon as the animal has been stabilized. Rarely, IO catheterization can result in bone fracture, osteomyelitis, and pain.[8]

FLUID DOSAGE

As with mature animals, pediatric fluid dosage varies by goal, fluid type, and route of administration. In general, pediatric patients have higher fluid requirements than do mature animals but they are also more easily volume overloaded because of their small size and difficulties in monitoring volume and hydration status in very small patients. A syringe pump is ideal for administration of very small volumes of fluid by IV or IO CRI in neonatal patients, whereas larger pediatric patients may be treated using routine fluid pumps. If no syringe or fluid pump is available, intermittent bolus therapy

Fig. 1. Intraosseous catheter placed in the femur of a Rottweiler mix pup for rapid fluid administration when intravenous catheterization was not possible. (*Courtesy of* Louise O'Dwyer, MBA, BSc(Hons), VTS (Anaesthesia/Analgesia & ECC), DipAVN (Medical & Surgical), RVN, Clinical Support Manager, Vets Now UK).

is often a better option than relying on a drip set alone for CRI. Even microdrip sets are prone to error, and accidental fluid overdose is possible in very small patients. Alternatively, a newer, economic option is a spring-powered syringe pump with flow-control tubing, which allows more careful fluid bolusing when an electronic syringe pump is not available.[37]

The fluid volume required to replace the fluid deficit is calculated as for adults, but for reasons previously described, estimation of hydration is more difficult in the youngest patients. For pediatric patients with hypovolemia, an initial slow (eg, 10 minutes) bolus fluid administration by either the IV or IO route at a dosage of 3 to 4 mL per 100 g of body weight in neonatal pups or 2 to 3 mL per 100 g of body weight in neonatal kittens is a reasonable starting bolus dosage. Administration of additional bolus doses depends on serial examination, with the aim or normalizing volume and hydration. Overaggressive crystalloid fluid administration can lead to pulmonary edema and death.[38]

Maintenance fluid requirements for pediatric patients are higher than for mature animals. A rate of 80 mL/kg to 120 mL/kg (8–12 mL/100 g) is reasonable for the youngest pups, whereas a slightly lower rate of 60 mL/kg to 80 mL/kg (6–8 mL/100 g) is reasonable for kittens. Maintenance fluid rates decrease to those of adult animals by about 4 to 6 months of age. Some references suggest maintenance fluid rates of 200 mL/kg/d,[1,2,5] although this is likely overly aggressive once the animal is well hydrated if there are no ongoing fluid losses. For patients with euvolemia with mild dehydration, the total daily maintenance fluid requirement can be administered by the SC route. Of course, for pediatric patients with normothermia without gastrointestinal signs, maintenance fluids are ideally given in the form of milk replacer via the oral route to provide food and fluid needs.[2,5,30]

Fluid losses caused by vomiting or diarrhea should be considered when calculating a parenteral fluid plan and the estimated volume of loss added to maintenance therapy. Especially when vomiting or diarrhea is present, electrolyte replacement may be required for pediatric patients. After the initial fluid bolus is given, 20 mEq/L potassium supplementation is reasonable, or an amount guided by the measured serum potassium concentration.[8]

Many pediatric patients are hypoglycemic and weak when presented for care. A glucose bolus can be administered even before blood glucose concentration is measured, but additional bolus doses should only be given when necessary based on measured blood glucose concentration. A 50% dextrose solution can be diluted 1:3 in sterile water to make a 12.5% dextrose solution, and 1 mL to 3 mL of this solution can be administered IV or IO. Crystalloid fluids given by IV or IO CRI are supplemented with dextrose to make a 2.5% to 5% solution. If a dextrose concentration greater than 5% is desired, such fluids should be administered only via a central (eg, jugular) catheter. Oversupplementation of dextrose can result in osmotic diuresis and resultant worsening of dehydration.[12]

Although pups and kittens have lower colloid osmotic pressure than do adults, colloid dosages are similar in pediatric and adult animals. Hetastarch is typically administered at 20 mL/kg/h,[2] with a goal of maintaining colloid osmotic pressure in the range of 16 mm Hg to 25 mm Hg.[2] For animals with anemia, red blood cells and plasma proteins are beneficial. Whole blood is collected at 9:1 in citrate anticoagulant and given through a Millipore blood filter at a dosage of 20 mL/kg over 2 to 3 hours.[2]

DISCONTINUATION OF FLUID THERAPY

Fluid therapy is discontinued if the pediatric patient is able to maintain hydration by eating and drinking. Usually, fluids are weaned slowly over 2 to 4 days to ensure the

patient maintains adequate voluntary intake and remains hydrated.[8] In many cases, the pup or kitten may not yet be willing to take in enough food and water, but IV or IO fluid therapy is replaced with forced oral fluid administration as long as the gastrointestinal tract is functional and there is no vomiting or nausea. As fluids are decreased, or when the route of fluid administration is changed, patients should be monitored carefully and frequently to ensure that rapid dehydration does not reoccur.

SUMMARY

Fluid therapy for the neonate and pediatric patient can restore hydration and vascular fluid volume, and correct life-threatening electrolyte disturbances. Clinicians must be aware of the higher fluid requirement in pediatric patients compared with adults. Depending on the stability of the patient, the appropriate route of fluid administration (eg, oral, SC, IP, IO, IV) should be implemented for life-saving care. Clinicians should be aware of the limitations or potential complications of each route of delivery and appropriately monitor patients for improvement or overhydration.

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