Maintenance Fluid Therapy

Isotonic Versus Hypotonic Solutions

Bernie Hansen, DVM, MS[a,*], Alessio Vigani, DVM, PhD[b]

KEYWORDS

- Intravenous fluids • Hyponatremia • Volume overload • Tonicity
- Maintenance requirements

KEY POINTS

- Critical illness predisposes animals to both water and sodium retention.
- No single commercial fluid is ideal for the replacement of normal ongoing losses of water and electrolytes.
- Excessive administration of hypotonic (low sodium) fluids may cause hyponatremia in animals with syndromes of excessive antidiuretic hormone secretion.
- Excessive administration of isotonic (high-sodium) fluids may cause volume overload in immobile animals with systemic inflammation, trauma, and other disorders predisposing to edema formation.
- Anesthetic fluid administration rates exceeding 3 mL/kg/h in animals are excessive and do not support cardiovascular function.

INTRODUCTION

Dogs and cats maintain osmotic and electrolyte homeostasis by ingestion of water and nutrients, behavior that is driven by thirst, hunger, and food preferences relative to need. When an animal becomes a patient under orders for nil per os (NPO) or refuses to eat and drink, the veterinarian assumes responsibility for monitoring and providing for homeostatic needs that may be altered substantially by illness. For the short time periods that typify most hospital stays, the most critical requirements to provide for maintenance of homeostasis are for water and (to a lesser extent) the major electrolytes, and the goal of maintenance fluid therapy is to replace their physiologic losses in urine, feces, and evaporation.

Although a fasted animal soon (within hours) requires a source of calories, protein, and other nutrients to limit tissue catabolism and support metabolic needs, the classic

The authors have nothing to disclose.
[a] Department of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, 1060 William Moore Drive, Raleigh, NC 27607, USA; [b] North Carolina State Veterinary Hospital, North Carolina State University, 1052 William Moore Drive, Raleigh, NC 27607, USA
* Corresponding author.
E-mail address: bdhansen@ncsu.edu

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interpretation of "maintenance fluid therapy" ignores nutrition and assumes that such support is a separate effort that requires a prescription tailored to the individual animal's nutritional needs. Similarly, fluid therapy applied to the correction of specific abnormalities such as dehydration, hypovolemia, acid–base disorders, abnormal serum concentration of electrolytes, and ongoing losses is considered under the separate goals of resuscitation, correction of existing imbalances, and replacement of contemporaneous pathologic losses. Thus, for purposes of this review, we focus primarily on the question, "How much fluid, and of what composition, should be administered to replace physiologic losses in hospitalized dogs and cats held NPO?", as well as the special circumstance of maintenance fluid therapy under general anesthesia. Because decisions regarding the use of isotonic versus hypotonic fluids include both the volume of water to administer and the concentration of electrolytes in that water, is will be useful to begin with a review of the maintenance requirements for normal dogs and cats.

MAINTENANCE NEEDS IN HEALTH

Daily water and electrolyte needs are determined by obligatory losses from the body. Sensible (measurable) losses of both occur via urine and feces; insensible evaporative loss of water via the skin and respiratory tract is largely electrolyte free in dogs and cats. Water and electrolyte requirements vary with species, age, activity, and ambient temperature, and most information about the maintenance requirement for dogs and cats is based on nutritional research using healthy animals confined to small runs or cages. The following discussion pertains to the maintenance requirements of adult animals; the requirements for growth and lactation are not addressed here because those are uncommon considerations for sick, hospitalized animals requiring fluid therapy.

Water

To a large extent, the amount of water and electrolytes required to maintain homeostasis is a function of metabolic size, diet composition, environmental temperature and humidity, and activity level. In health, water is derived from the ingestion of free water, water combined in food, and generation of water from oxidation of foodstuffs. For the oxidation of every 100 g of substrate, protein generates 41 mL of water, fat generates 107 mL of water, and carbohydrates generate 60 mL of water.[1] Because a substantial amount of water is derived from metabolism, estimates of water requirements in hospitalized animals should account for whether the animal is eating or not. In practice, it is unusual for an animal to eat and not drink, and parenteral maintenance fluid therapy is usually discontinued once an animal begins eating a considerable fraction of its daily caloric requirement (or is tube-fed a liquid diet that supplies sufficient water).

Most estimates of daily water requirements in dogs and cats are derived from measurements obtained in laboratory animals housed under conditions that are similar to those of hospitalized sick animals. However, practically all reports have been based on studies of healthy animals, whose activity in a cage or small run may far exceed (especially for dogs) the activity of a sick animal, and therefore may indicate higher water requirements than a sick patient truly needs. For example, using videography one of us (BH) found that the 24-hour distance traveled by healthy Beagle dogs in a 3′ × 6′ (0.9 × 1.8 m) run can approach 6.2 miles (10 km; unpublished observations).

Lewis and colleagues[2] recommended that the daily requirement for water for healthy dogs with minimal activity in a comfortable ambient temperature is proportional to their energy requirement at the rate of 1 kcal = 1 mL with a daily water requirement of 132 mL $\times$ BW$^{0.75}$, where BW is the body weight in kilograms. However, several authors have reported widely different values for this estimate. In a review of the literature of water requirements of dogs, the National Research Council (NRC) found that the reported range of mean values of water requirements for active dogs in laboratory environments (cages or runs, ambient temperature 25°–28°C) was 94 to 183 $\times$ BW$^{0.75}$, and if one instead uses the basal metabolic rate of sedentary dogs, the range of reported water requirement for individual dogs is 48 to 114 mL $\times$ BW$^{0.75}$.[1]

Similar work has been done in cats, and for this species the ratio of water:caloric needs is closer to 0.6 (ignoring metabolic water) or 0.7 (including metabolic water).[1] Reviewing previously published work on laboratory cats, the NRC reported a range of daily energy requirement of 31 to 100 kcal/kg, translating into a range in daily water requirement during fasting of 22 to 70 mL/kg.

Because most evidence suggests that these estimates of water needs for healthy, active laboratory animals are higher than the requirements for sedentary or sick dogs and cats, the authors' intensive care unit uses an estimate of daily water requirement of 97 $\times$ BW$^{0.655}$ and an higher estimate for active animals of 140 $\times$ BW$^{0.73}$ (relatively uncommon). Both of these formulas provide an excess of water that is sufficient to produce at least a mild diuresis. In this application, a sick or quiet fasted 10-kg dog would receive 456 mL of water per day (19 mL/h) and an active dog of the same weight would receive 768 mL per day (32 mL/h).

Electrolytes

Electrolyte requirements to maintain homeostasis in dogs and cats have been reviewed by the NRC and the reviewed primary sources form the basis of their recommendations, which are summarized in **Table 1**.[3] The NRC recommendations are based on the estimated requirements for healthy, active laboratory animals and the relationship to maintenance needs in sick animals is unknown. In addition, the estimates are extrapolated from studies of oral intake, and the complex interactions between macronutrients and micronutrients may render inaccurate any estimates of need when individual electrolytes are administered parenterally. Nevertheless, **Table 1** demonstrates the striking differences between estimated minimal daily requirements for electrolytes and the composition of lactated Ringer solution (LRS) or a commercial maintenance solution. Both products contain an overabundance of sodium and chloride (a 16- to 26-fold excess of sodium in the case of LRS) and are relatively deficient in potassium, calcium, and magnesium.

HEALTH VERSUS ILLNESS

In addition to the reduction in water requirement associated with inactivity, several features of illness may reduce the need for both water and electrolytes. After addressing existing deficits and contemporaneous ongoing pathologic losses in those patients, a modified maintenance fluid therapy plan may be required. Examples of common conditions altering water and salt balance in hospitalized patients are decreased renal water and sodium clearance as part of the stress response to critical illness, excessive secretion of antidiuretic hormone (ADH) in response to certain medications or positive pressure ventilation, and oliguria owing to acute kidney injury. Animals that eat dry food may need additional water to excrete ingested solutes, and animals mechanically ventilated with gas mixtures fully saturated with water may require less. Water losses may be increased when the body temperature is abnormally high, when respiration is increased, or when a dog pants owing to anxiety or in an

Table 1
Maintenance needs for dogs and cats

	Estimates of Daily Needs[3]		Daily Maintenance Requirement		Final Solution Concentration and Rate		Comparision with Commercial Fluids (mEq/L)	
Component	**Dog, $mg \times kg^{0.75}$**	**Cat, $mg \times kg^{0.67}$**	**20 kg Dog**	**4 kg Cat**	**20 kg Dog**	**4 kg Cat**	**LRS**	**Normosol-M**
Sodium	9.85	16	5 mEq	2 mEq	7 mEq/L	8 mEq/L	130	40
Potassium	140	97	34 mEq	7 mEq	49 mEq/L	29 mEq/L	4	13
Calcium	52	32	25 mEq	5 mEq	36 mEq/L	21 mEq/L	3	0
Magnesium	6	4.9	5 mEq	2 mEq	7 mEq/L	8 mEq/L	0	3
Chloride (as NaCl)	40	23.7	11 mEq	2 mEq	16 mEq/L	8 mEq/L	110	40
Water	$97 \times BW^{0.66}$		691 mL	241 mL	29 mL/h	10 mL/h	—	—

Daily requirements for major electrolytes in dogs and cats as reported by the National Research Council. The final concentration of these electrolytes in water administered at a modest maintenance rate, and comparison with the composition of lactated Ringer's solution and Normosol-M (Hospira, Lake Forest, IL).

effort to resolve fever. Edematous animals may require fluid restriction. Strictly speaking, increased water and electrolyte losses owing to burns, wound drainage, or pathologic renal and gastrointestinal losses should be considered under the goal of replacement of contemporaneous pathologic losses, but in practice many clinicians incorporate that replacement into "maintenance" fluid therapy and adjust their maintenance fluid rate and composition accordingly.

Enhanced ADH release associated with impaired circulation, the stress response to illness or injury, or in syndromes of inappropriate ADH release will dissociate ADH from normal osmoregulation (for a review, see Rafat and colleagues[4]). This condition predisposes patients to hyponatremia if given water in excess, and this phenomenon is likely the reason for the striking tendency of humans, especially children, to become hyponatremic when given an excess of hypotonic fluids for the goal of maintenance fluid therapy.

ISOTONIC VERSUS HYPOTONIC SOLUTIONS

There is active debate regarding the merits of isotonic versus hypotonic solutions for maintenance fluid therapy in both human and veterinary medicine. Because sodium and its accompanying anions (chloride and organic anions) account for most of the tonicity of crystalloid fluids, the debate over the relative risks and advantages of isotonic and hypotonic solutions is essentially a debate over the daily administration rates of water and sodium. From the viewpoint of providing for the minimum daily requirements for homeostasis, an "ideal" maintenance solution that provides each in proportion to need has a sodium concentration that is much lower (5–8 mEq/L across a weight range of 1–66 kg, using the formulas in **Table 1**) than found in plasma or commercial replacement solutions. However, high-sodium replacement fluids account for the majority of veterinary maintenance fluid therapy and, more recently, are recommended for maintenance fluid therapy in humans (especially children) because of the high prevalence of iatrogenic hyponatremia associated with hypotonic fluid administration. If one makes a mistake in choosing a high- or low-sodium fluid for maintenance purposes, there are 2 major potential consequences, respectively: creation of edema in patients that are prone to sodium retention, and creation of hyponatremia in patients prone to water retention. We examine the hyponatremia issue first.

HYPOTONIC FLUIDS: HYPONATREMIA

The use of parenteral hypotonic solutions to meet daily water and electrolyte requirements has been common practice in human medicine for more than one-half of a century, but current evidence has brought attention to an high incidence of iatrogenic hyponatremia, especially in hospitalized pediatric patients. A clinical trial involving 690 hospitalized children demonstrated that the administration of half-strength (0.45%) saline compared with isotonic saline was associated with greater risk of hyponatremia (11% vs 4%).[5] Similarly, recent metaanalyses have calculated that the relative risk of clinically relevant hyponatremia associated with hypotonic fluid administration compared with isotonic fluid therapy for children is 2.4 to 17.2, with 1 study estimating the number needed to harm high-risk children with hypotonic fluids as equal to 4.[6–8] However, most of the studies included in these metaanalyses did not have consistent criteria for ongoing adjustment of fluid therapy based on the patient's water requirements. Very few studies reported in the past decade included evaluation of hydration status as an outcome measure, and almost all of those that did used surrogates for weight change, such as physical signs and hematocrit. Most studies of the effect of isotonic versus hypotonic fluid have used fluid administration rates based on the 1956 Holliday–Segar formula, prescribing 100 mL/kg/d for the first 10 kg of BW, then 1 L plus 50 mL/kg/d for each kg between 10 and 20 kg, then 1.5 L plus 20 mL/kg/d for each 1 kg greater than 20 kg.[9] Thus, compared with the NRC findings for basal metabolic rate–based requirements for sedentary dogs, a 10-kg dog would receive 270 to 640 mL/d but a 10-kg child treated with the Holliday-Segar formula would receive 1 L, which is roughly 1.5–3.7 times that volume. It does not seem surprising that administration of these quantities of hypotonic fluid to children at high risk for excessive ADH release results in free water retention and hyponatremia. In summary, although these findings demonstrate the increased risk of hyponatremia from administration of hypotonic solutions, they also highlight the critical importance of regular assessment of any prescribed fluid therapy to ascertain its adequacy for the physiologic requirements of the patient.

ISOTONIC FLUIDS: VOLUME OVERLOAD AND EDEMA

For many years, standard physician practice for fluid therapy in the critically ill patient dictated the administration of isotonic fluids to a target value of central venous pressure. Although the rationale for this has been discredited, it remains as a common practice. For example, the 2012 Surviving Sepsis guidelines[10] suggest targeting and maintaining a central venous pressure of 8 to 12 mm Hg for resuscitation by administration of isotonic fluids, a goal that requires ongoing administration of isotonic fluids as one shifts to the maintenance phase of treatment, and virtually guarantees edema formation in septic patients. That edema production has been considered to be an acceptable adverse effect of fluid protocols directed toward high central venous pressure values is testimony to the fact that morbidity and mortality from iatrogenic edema is less than that associated with the persistent shock caused by failure to administer enough fluids and other interventions in a timely manner.[11,12]

Isotonic solutions (eg, 0.9% NaCl, LRS) are largely restricted to the extracellular fluid compartment after administration, and sodium, chloride, and water retention are the ingredients for clinical volume overload. When these replacement solutions are administered at a maintenance rate for water, the amount of sodium and chloride provided greatly exceeds basal requirements. This salt load requires an exponentially higher renal clearance to maintain the salt–water balance and homeostasis. Volume overload in critically ill patients is common and, in a large proportion of these patients, it is a direct consequence of the combination of excessive fluid administration and intrinsic impairment of renal sodium and water excretion owing to physiologic (stress response to illness) and pathologic (acute kidney injury) causes.[13] Immobility and increased capillary permeability with inflammation further predispose to edema. Current evidence indicates that volume overload is an iatrogenic complication that has a strong negative impact on human patient outcome, independent of the underlying disease process, and warrants attentive prevention, monitoring, and rapid correction.[13–16] Volume overload leads to worsened outcomes by inducing a positive fluid balance with increased lung water, impaired pulmonary gas exchange, decreased renal function, reduced intestinal motility, reduced tissue oxygenation, and increased surgical infection rates. This evidence should warrant important considerations against the indiscriminate selection of isotonic solutions as maintenance therapy in critically ill patients.

The mammalian response to severe illness is to conserve both sodium and water, and excessive medical administration of water (hypotonic fluid) or water and sodium (isotonic solutions) yields complications. Overzealous fluid administration results in free water accumulation and secondary hyponatremia when using hypotonic solutions, whereas salt overload and hypervolemia without occurrence of hyponatremia complicate excessive isotonic fluid administration. Both conditions represent a supraphysiologic increase of total body water, the first associated with altered osmoregulation and the second associated with salt and water retention in equal proportions, expanding the extracellular compartment. It is the responsibility of the clinician therefore to be attentive to early signs of fluid overload with or without associated alterations in water and solute balance and to intervene promptly with adjustments in fluid therapy.

CLINICAL APPROACH TO MAINTENANCE FLUID THERAPY

No single solution can consistently provide for maintenance water and electrolyte requirements in all patients. Individual clinical circumstance always must be considered before prescribing therapy, and the adequacy of any fluid therapy must be regularly reassessed (**Box 1**). The remarkable capacity of normal osmoregulation and renal excretory function provide a considerable margin of safety in most animals treated with intravenous fluids regardless of fluid type and administration rate, and clinicians have considerable latitude when making fluid therapy decisions in all but the most severely compromised patients.

As discussed, even when administered at a conservative maintenance rate for water, the sodium and chloride content of one-half–strength saline (0.45% NaCl, 77 mEq/L) or commercial maintenance solutions (eg, Normosol-M, 40 mEq Na/L [Hospira, Lake Forest, IL]) provide an excess of these electrolytes for small animals. Also, the administration of hypotonic solutions allows a near-physiologic water distribution between the extracellular and intracellular compartments. High-sodium replacement solutions provide proportionally an even greater excess of sodium (130–154 mEq/L), with little or no sodium-free water for distribution into the intracellular compartment. Nevertheless, most animals with normal renal function are able to excrete any excesses of water or sodium and maintain both osmolality and extracellular fluid volume.

It is critical to identify any changes in the usual maintenance water needs of the patient so that the prescribed daily fluid intake can be altered to maintain fluid balance. Ongoing assessment includes net volume balance (ie, difference between input and

Box 1
Clinical approach to maintenance fluid therapy

- Maintenance fluids are administered to replace normal ongoing losses in animals held nil per os (NPO). Deficit repair and replacing pathologic ongoing losses should be considered separately.
- The volume required for maintenance of inactive sick animals may be low compared with healthy animal needs, equal to or less than $97 \times BW^{0.655}$ per day.
- If water is not administered in excess, the sodium and potassium concentrations of an ideal maintenance fluid are much lower and higher, respectively, than present in commercial fluids.
- Relatively healthy animals can tolerate a wide range of water and electrolyte administration rates.
- Excessive administration of low-sodium fluids to animals prone to water retention may produce hyponatremia.
- Excessive administration of sodium and water—especially as an isotonic (high sodium) fluid—to immobile animals prone to salt and water retention will cause edema.
- Edematous animals should often be treated with fluid restriction.

output). In a clinical setting, repeated assessment of patient weight may provide the most reliable method for detection of net gain or loss of fluid because sensible and insensible losses are difficult to monitor and are unpredictably affected by physiologic responses, patient clinical condition, and drug administration.[17]

Specific single parameters for estimating volume status such as urine output may be deceiving. For example, a common misperception guiding fluid therapy is that urine production exceeding 0.5 to 1 mL/kg/h corresponds with "good" renal output. However, the adequacy of urine flow must be considered in relation to the patient's intravascular volume and solute content, and not just in terms of urine fluid and solute excretion. It follows that administration of a large volume of fluid in a normovolemic patient will normally lead to diuresis. In contrast, a similar large volume of fluid administered to a hypovolemic animal will generate a limited increase in urine production until the volume depletion is corrected. Conversely, an animal with decreased renal function and impaired water clearance is not able to compensate for increases in water intake, and a urine output of 1 mL/kg/h or greater may be entirely inadequate to prevent free water retention in excess of the animal's actual needs.

A common clinical misconception is related to the use of serum sodium concentration as a proxy for volume status. The serum sodium concentration is a function of the ratio of the total body content of sodium and potassium to total body water. Based on this relationship, the serum sodium concentration provides only an estimation of water balance in relation to solute content. In other words, the serum sodium concentration on a serum biochemistry panel is a measure of water balance (osmoregulation), not total body sodium content. Volume-overloaded patients may be normonatremic, hyponatremic, or hypernatremic concurrent with an excess in total body water.

A rational approach in prescribing maintenance fluid therapy in hospitalized small animal patients should include the following considerations:

- Hypovolemia is a strong physiologic trigger for ADH release that dissociates ADH from normal osmoregulation. Therapy for hypovolemic animals is first directed at repletion of the estimated volume deficit with an isotonic solution. Adequate volume repletion removes any ongoing physiologic hypovolemia-induced stimulus to ADH secretion, improving the patient's ability to eliminate excess free water properly. Hypovolemic patients are in a state of ADH excess and, if given hypotonic fluids, they are at high risk of hyponatremia secondary to avid renal reabsorption of free water.
- Critically ill and anesthetized patients often have other nonosmotic stimuli for release of ADH with the associated risk of excessive free water retention and volume overload. In euvolemic patients with adequate tissue perfusion parameters, a conservative (volume-restricted) approach to maintenance fluid should be used; this approach may be extrapolated to completely withholding fluids from edematous patients. During anesthesia, cautious and goal-directed fluid therapy with isotonic solution should be used, rather than the indiscriminate selection of conventional "anesthesia fluid rates."
- The rate and choice of fluids for maintenance therapy are continuously adjusted based on ongoing and frequent clinical assessment of the patient's fluid and electrolyte status, and alterations in the normal physiologic and pathophysiologic mechanisms. In patients with impaired renal function, the risk of volume overload and associated deterioration in patient outcome must be considered strongly when prescribing intravenous fluid therapy. As has been reviewed by others, there is ample clinical and experimental evidence that impaired renal function increases the risk of volume overload, and volume overload in turn is associated

with a lesser likelihood of recovery of renal function and with damage to other organs.[13,18] Frequent fluid and electrolyte assessment and restriction of administered volume are necessary to optimize patient outcome.

- The total volume of fluids administered in forms of resuscitation, replacement, and maintenance therapy is usually easy to track for the evaluation of the patient's overall fluid balance. However, the additional volumes administered in the form of catheter irrigation and drug infusions may provide a large additional daily volume of fluid that is not taken into account. A recent study in adult human intensive care patients demonstrated that fluids administered in the form of intravenous drug boluses and intravenous flushes amounted to about 50% of the volume of fluids administered for maintenance.[19] This represents a large proportion of daily water and sodium requirements and, if ignored, would certainly lead to excessive intravenous maintenance fluid administration. This study underscores the importance of keeping account of all fluids administered in any form when evaluating ongoing fluid balance and maintenance needs. This consideration may be even more relevant in the critical care of small animals, where the adjustment of intravenous irrigation volume with respect to patient's BW is not common practice.
- Patients receiving enteral feeding also receive a substantial amount of water from the liquid diet that should be accounted for in the calculation of maintenance needs. Enteral liquid diets for veterinary use have an average water content of 80% and caloric content of approximately 1 Kcal/mL, or about 0.80 mL of water per Kcal of metabolic energy provided (not counting metabolic water). For example, a hospitalized 10-kg dog fed a commonly available enteral diet, such as CliniCare (Zoetis, Kalamazoo, MI), at 100% resting energy requirement using the formula $70 \times (BW)^{0.75}$, would receive 393 Kcal/d in a total volume of 393 mL, of which 314 mL represents water. Based on the basal water requirement formula of $97 \times (BW)^{0.655}$ used by the authors, this patient would only require an additional 124 mL/d (approximately 5 mL/h) to be administered parenterally in the form of maintenance fluid to meet basal water requirements completely. The sodium content of such liquid diet formulations also is adequate to meet basal requirements for dogs and cats, and a hypotonic solution still would represent an appropriate choice for parenteral use in this setting.

If a hospitalized patient develops hyponatremia, 3 main questions should be answered before planning adjustments to maintenance fluid therapy:

1. Has the volume status of the patient changed? Absolute or relative hypovolemia-induced ADH release prevents free water excretion to preserve blood volume. Volume replacement with an isotonic (high-sodium) solution is required in this circumstance.
2. Is the patient developing incipient acute kidney injury? Acute kidney injury is commonly associated with decreased free water renal clearance, increased water retention, and a greater risk of volume overload. Repeated and intensive assessment of renal function, including quantification and considered interpretation of urine output and serial measurements of serum creatinine concentration are recommended. Avoidance of volume overload is of absolute importance in these patients to prevent further worsening of renal function.[13]
3. Is there any other risk factor for syndromes of excessive release of ADH? Common examples include general anesthesia, recent (<24 hours) surgery, other causes of inflammation, severe pain, use of opioid analgesics, and intracranial disease. Fluid restriction represents the therapy of choice in these patients and continued

reassessment of volume status is indicated for the identification of ongoing changes in patient homeostasis.

MAINTENANCE FLUID IN ANESTHESIA

Intravenous fluids often are used to support cardiovascular function in anesthetized or postoperative patients. The beneficial effects on patient hemodynamics from intravenous fluids in this setting are primarily owing to optimization of the rheological properties of blood rather than any volume expansion effect. Improvement of the flow characteristics of blood in the capillary bed maximizes tissue perfusion and oxygen delivery, and isotonic solutions are superior to hypotonic fluids for prevention and correction of hypovolemia owing to fluid losses or increased vascular capacitance (**Box 2**).

The clinical superiority of isotonic fluid in this setting was illustrated by a study of postoperative pediatric patients.[20] In this trial, children given hypotonic solution (0.45% NaCl) had an higher incidence of hyponatremia (30%) than those who received 0.9% saline (10%) regardless of the volume of fluid given. Initial postoperative ADH serum concentrations were 2 to 4 times greater than normal and returned to expected concentrations by 24 hours after surgery. These results indicate that an initial approach of providing isotonic fluid at maintenance fluid volume is preferred to avoid hypovolemia and secondary hyponatremia in the intraoperative and immediate postoperative periods, especially while there is a rapid shift to a state of ADH excess, and the patient's fluid needs are still undetermined. Similarly, a clinical study in healthy dogs undergoing general anesthesia demonstrated a rapid increase in plasma ADH concentration and a proportional decrease in packed cell volume and total solids in response to anesthesia, despite the maintenance of normotension. Intraoperative administration of fluids had no effect on ADH concentration, demonstrating the presence of volume-independent stimulation of ADH secretion induced by general anesthesia, with an associated higher risk of fluid retention.[21]

Perioperative and intraoperative maintenance fluid therapy in small animals continues to be a controversial topic owing to many unsupported opinions regarding the ideal rate of administration and lack of sufficient evidence to define best practice. Despite their wide use, conventional rates of intraoperative fluid administration in small animals (eg, 10 mL/kg/h) cannot be justified either medically or physiologically. The rationale behind such high fluid rates has been based on the concern for increased insensible water losses during anesthesia and surgery and on anesthesia-induced increases in intravascular capacity owing to vasodilatation. However, no evidence has been generated to support the use supraphysiologic fluid rates. In fact, there is research evidence in dogs for the opposite (ie, that there is no improvement obtained in any measured physiologic parameter by supraphysiologic intraoperative fluid

Box 2
Maintenance fluid for anesthesia: important points

- Maintenance fluid therapy for animals under anesthesia should use isotonic solutions to prevent hyponatremia.
- In the absence of hemorrhage, volume needs for maintenance of animals under anesthesia for surgery is low, probably not exceeding 2 to 3 mL/kg/h.
- Administration of higher rates will not increase urine output, blood pressure, tissue perfusion, or oxygen delivery in normovolemic animals.

administration). Muir and colleagues[22] demonstrated that the infusion of 10 to 30 mL/kg/h LRS to isoflurane-anesthetized dogs did not change urine production, blood pressure, or oxygen delivery to tissues. A study by Boscan and colleagues[23] also showed that dogs anesthetized for elective procedures receiving an infusion of 10 mL/kg/h LRS maintained low urinary output (0.46 mL/kg/h), showed progressive hemodilution and low esophageal temperature. By the end of the anesthetic procedure, all dogs retained a large volume of fluids (as indicated by increased BW), had increased total body water volume, and had increased extracellular fluid volume measured by electrical bioimpedance. The authors concluded that evaluation of urine output alone in anesthetized dogs does not represent an adequate indicator of fluid balance.

The paradigm of high “maintenance” fluid rates for prevention of anesthesia-induced hypoperfusion is not evidence based and should be reassessed. Silverstein and colleagues[24] used dark-field videomicroscopy to assess the effects of fluid administration on microcirculation in healthy anesthetized dogs undergoing elective surgeries and treated with LRS at rates of 0, 10, or 20 mL/kg/h. Treatment had no effect on any microcirculatory flow index parameter at any time point. Cardiopulmonary variables (including blood pressure, heart rate, capillary refill time, and hemoglobin saturation) were not different between treatment groups, and no differences were considered clinically relevant. In each group, approximately one-third of the dogs required intraoperative administration of additional LRS (as a rapid infusion) for the treatment of hypotension, indicating the lack of any protective effect of continuous infusions of intraoperative maintenance fluids against the onset of hypotension.

Intraoperative fluid therapy may even be harmful, as suggested by the results of a recent prospective observational study of anesthetic risk that identified fluid administration as an independent risk factor for increased mortality in cats.[25] Although this type of study cannot prove causality, this finding does suggest that additional care be used when considering intravenous fluid administration during general anesthesia in cats.

Notably, insensible water loss during anesthesia is low, rarely exceeding 0.5 mL/kg/h, and surgical trauma commonly causes fluid extravasation of less than 1 mL/kg, suggesting intraoperative fluid administration of 2 to 3 mL/kg/h may be adequate.[26] The administration of a crystalloid to counteract the effects of anesthetic-induced vasodilatation is also often ineffective and inconsistent. The “as-needed” use of intraoperative fluids administered in form of fluid challenges to test fluid responsiveness, use of balanced anesthetic techniques to decrease the amount of inhaled anesthetics, and use of vasopressors to modulate vascular capacitance are more effective and rational ways for treating anesthesia-related hypotension, compared with the liberal and unrestricted administration of intravenous fluids.

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