A new way to monitor & individualize your fluid therapy plan

Recent findings point to new ways to monitor fluid therapy perioperatively and to gear fluid therapy protocols to each individual animal.

By William W. Muir, DVM, MS, PhD, DACVA, DACVECC

In this final article of the series, I discuss advances in monitoring fluid therapy, and I describe a more individualized and goal-directed approach to tailoring intravenous fluid therapy based on an animal’s needs before, during, and after surgery.

MONITORING: OLD AND NEW METHODS

Traditional methods for monitoring perioperative intravenous fluid administration are not reliable.1 Other than increases in postoperative body weight, there have been few accurate indicators of excessive fluid administration.2 Traditional static methods for monitoring fluid therapy, such as central venous pressure (CVP), ventricular end diastolic pressure, and pulmonary capillary wedge pressure, have been shown to be unreliable and generally late indicators of changes in blood volume, fluid responsiveness, and fluid overload (see “Perioperative fluid therapy dilemmas” on page 70).1,3,4

A new method

Dynamic variables (indices evaluating the response to cyclical changes in venous return, or preload) are more predictive of fluid responsiveness. Among these, arterial pulse pressure variation induced by assisted (manual) or mechanical ventilation has been demonstrated to be a specific and sensitive guide to fluid therapy.6,7 Respiratory variations in the amplitude of the noninvasively recorded pulse oximeter-derived plethysmographic (change in volume) pulse pressure waveform have been shown to predict fluid responsiveness.6,8

The plethysmographic variability index (PVI) measures the dynamic changes...
in perfusion index (PI) over respiratory cycles and is calculated as follows:

\[ \text{PVI} = \left( \frac{\text{PI}_{\text{max}} - \text{PI}_{\text{min}}}{\text{PI}_{\text{max}}} \right) \times 100 \]

The PVI is accurate and far less expensive than esophageal Doppler measurement of variations in stroke volume.\(^4\) The greater the PVI, the more likely the patient will respond to fluid administration.

The use of PVI-based goal-directed fluid management in surgical patients reduces the volume of intraoperative fluid infused and decreases intraoperative and postoperative lactate concentrations.\(^8\) PVI was less accurate in predicting fluid responsiveness during spontaneous breathing than during mechanical ventilation, but PVI was still better than CVP, at least in people.\(^9\)

### An automatic PVI measurement

The Masimo pulse oximeter (Masimo Corp.) uses an algorithm to continuously quantify changes in pulse volume (i.e., PVI) \((\text{Figure 1})\). PVI is better than CVP for determining the animal’s response to fluid therapy.\(^5\)

Clinical evaluation of PVI in dogs and cats suggests that PVI values above 20 indicate hypovolemia and a need for fluid replacement therapy. Data collected from 113 dogs and 12 cats given fluid boluses (ranging from 3 to 15 ml/kg over 10 to 15 minutes) to treat intraoperative hypotension showed improvement in the animals’ palpable arterial pulse and peripheral perfusion and a decrease in PVI \((\text{Table 1})\). Of these animals, 23 dogs and three cats did not respond to fluid administration and required administration of a catecholamine \((e.g., \text{dopamine, norepinephrine})\). Clearly, this monitoring modality requires further evaluation in both dogs and cats.

Keep in mind that not all animals respond \((\text{show a decreased PVI})\) to fluid administration \((\text{volume expansion})\). Sick, depressed, and debilitated animals; animals with reduced cardiac function due to acquired disease; or animals that are overly depressed by anesthetic drugs may not be capable of increasing cardiac output when venous return \((\text{preload})\) increases.\(^4,5,9-11\)

### INDIVIDUALIZING FLUID THERAPY

#### The dangers of hypovolemia and hypotension

Intraoperative hypovolemia \((\text{loss of} > 10\% \text{of the blood volume})\) results in tissue hypoperfusion, which leads to metabolic acidosis and increased morbidity and mortality.\(^12,13\)

**Absolute hypovolemia** refers to the actual loss of volume from the extracellular space, such as from blood loss. Furthermore, the stress of major surgery and anesthesia can alter fluid distribution to the body’s fluid compartments and promote salt \((\text{sodium, chloride})\) and water retention, which may take five to 10 days to return to normal.

**Relative hypovolemia** \((\text{blood volume is normal but insufficient because of widespread vasodilation})\) is caused by diseases \((\text{e.g., sepsis, trauma})\) or drugs \((\text{e.g., anesthetics})\) that produce vasodilation and results in dilatation of the intravascular space and a decrease in the effective circulating blood volume.

Both absolute and relative hypovolemia cause hypotension. Absolute hypovolemia requires fluid replacement, while relative hypovolemia requires careful consideration of its cause \((\text{anesthesia, trauma, sepsis})\) and the side effects of intravenous fluid administration. Note that fluids do not correct vasodilatation.

### Five factors to consider

The question is, how should current knowledge be used to provide the most medically rational perioperative...
fluid therapy possible? The following are five considerations to help optimize intravenous fluid delivery. (Also see sidebar “Guide to optimal perioperative fluid therapy” on page 80.)

1. Preoperative fluid loss and fluid loading

Basal fluid water requirements depend on metabolic rate and rarely exceed 1 to 2 ml/kg/hr at room temperature (70 F) in dogs and cats.14 Any attempt to restore estimates of fluid deficit due to dehydration with a crystalloid immediately preoperatively (within one to four hours of the surgery) or intraoperatively almost always leads to tissue edema. Simple dehydration (i.e. loss of water alone) results in proportional reductions of both interstitial fluid and plasma volume. The dehydrated interstitium absorbs the crystalloid solutions that are infused and decreases their effectiveness to produce plasma volume expansion.

Furthermore, there is no evidence to support preoperative fluid loading with a crystalloid to prevent hypotension during anesthesia (Table 2).15 Studies in both hydrated and dehydrated human surgical candidates suggest that it is an ineffective and unfounded practice whether or not patients have been fasted.11,14-18 Fluid loading immediately before anesthesia and surgery in an attempt to replace fluid losses due to mild dehydration should be abandoned.

Arterial blood pressure and tissue perfusion (mucous membrane color, capillary refill time) should be normalized and stabilized in animals that are moderately to severely dehydrated, if time permits, before the animals are anesthetized. And only 75% to 80% of the dehydration deficit should be replaced during the 24 hours before anesthesia, to avoid fluid overload. The fluid deficit due to dehydration can gradually be replaced over 24 to 48 hours after surgery.19

2. Fasting loss

Mature dogs and cats can be fasted for six to eight hours; however, for older and younger animals, two to three hours of fasting before surgery is more appropriate.20,21 Except for medical or behavioral reasons, access to water should be allowed until the preanesthetic medication is administered. An additional 1 to 2 ml/kg of crystalloid can be added to the base fluid administration rate for each hour the animal does not have access to water before surgery and can be administered during the first hour of surgery to replace water losses if water has been withheld.14

3. Insensible loss

Insensible fluid loss in people and animals is generally less than 1 to 2 ml/kg/hr during anesthesia.9,14 Evaporative losses from surgically traumatized tissues are more difficult to assess but have been experimentally determined to range from 2 to 30 ml/hr in nonexteriorized and exteriorized viscera, respectively.22 Surgically manipulated tissues do not accumulate marked amounts of fluid unless they are severely inflamed or traumatized.

These insensible fluid losses,
taken together with basal and fasting losses, suggest that initial rates for intravenous fluid replacement to otherwise normal healthy dogs and cats rarely need to exceed 5 ml/kg/hr (basal + fasting + insensible). In those circumstances in which greater rates of fluid administration are required (> 10 to 30 ml/kg/hr), the fluid should be administered during the first hour and decreased to the basal rate while accounting for blood loss thereafter.23

4. Surgical and traumatic loss
 Fluid loss from the vascular compartment is either absolute (e.g. hemorrhage) or relative (e.g. vasodilatation). Although conceptually thought to be a myth, third space losses can also be either absolute or relative.24 Loss of intravascular fluid to a third space can be either anatomical or nonanatomical.25 Anatomical third space loss represents the accumulation of fluid within the interstitium, whereas non-anatomical third space losses include fluid accumulation in traumatized tissue, the bowel, and the peritoneal cavity. Non-anatomical third space losses contain protein concentrations similar to that of plasma and are lost from further extracellular exchange. Therefore, they represent an absolute loss of protein-containing fluid.

Blood loss during anesthesia should be estimated or quantified during surgical procedures, considered in relation to the animal’s hemoglobin concentration, and replaced as soon as possible.26 Timely fluid resuscitation reduces later volume requirements. Fluid loss into surgically traumatized tissues can be highly variable and is independent of the animal’s weight. Fluid accumulation at bowel anastomotic surgical sites is minimal and has been experimentally determined to depend on the rate of fluid (crystalloid) administration and ranges from 5 to 10 ml.27

Blood loss can be replaced with adequate amounts of crystalloid, colloid, or blood (see sidebar “Guide to optimal perioperative fluid therapy” on page 80). The amount of crystalloid required to effectively replace blood loss is difficult to determine and usually exceeds

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td><strong>Treatment of hypotension</strong></td>
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<table>
<thead>
<tr>
<th>Hypovolemia—Absolute (e.g. due to blood loss)</th>
<th><strong>Fluid</strong></th>
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</thead>
<tbody>
<tr>
<td>&gt; Crystalloid: 4 to 5 ml for each 1 ml of blood loss</td>
<td></td>
</tr>
<tr>
<td>&gt; Colloid: 1 to 1.5 ml for each 1 ml of blood loss</td>
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<tr>
<td>&gt; Blood: 1:1</td>
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<tr>
<td>• Hemoglobin &lt; 6 g/dl—RBC transfusion is reasonable</td>
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<tr>
<td>• Hemoglobin &gt; 6 but &lt; 7 g/dl—Reasonable in most postoperative animals</td>
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<tr>
<td>• Hemoglobin &gt; 7 g/dl—Not recommended</td>
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<table>
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<tr>
<th>Hypovolemia—Relative (e.g. due to anesthesia)</th>
<th><strong>Decrease anesthetic depth</strong></th>
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<tbody>
<tr>
<td>&gt; Consider analgesic adjunct, such as fentanyl at 0.3 to 0.7 µg/kg/min (dogs); 0.025 to 0.5 µg/kg/min (cats)</td>
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<tr>
<td>&gt; Colloid: 3 to 15 ml/kg total; 3 ml/kg over 1 to 3 min</td>
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<td>&gt; Vasoconstrictor</td>
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<td>• Dopamine 1 to 10 µg/kg/min for dogs; 3 to 10 µg/kg/min for cats; to effect or a systolic blood pressure &gt; 90 mm Hg if refractory to above (e.g. sepsis)</td>
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<tr>
<td>• Norepinephrine 0.01-1 µg/kg/min (to effect) to a systolic blood pressure &gt; 90 mm Hg</td>
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<tr>
<td>• Vasopressin: 0.0002–0.0004 U/kg/min</td>
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Your fluid therapy plan derived from estimates for the distribution of water between the intravascular and interstitial fluid compartments. The traditional 3:1 replacement ratio derived from estimates for the distribution of water between the intravascular and interstitial fluid compartments.28-30 Experimental data in isoflurane-anesthetized dogs and clinical studies in people suggest that crystalloid fluid replacement ratios ranging from 4 to 5 ml or greater for each milliliter of lost blood (4:1 or 5:1) are more efficacious than a 3:1 ratio, depending on the amount of blood loss and whether concurrent hypotension exists.29-32 Administering large volumes of crystalloid (> 30 ml/kg) during the first hour of anesthesia to replace blood loss is more likely to produce hemodilution, fluid accumulation at the surgical site, and interstitial edema.23,29,30 Hemodilution decreases hemoglobin and protein concentrations and can produce coagulation defects.33-35 It is important to monitor hemoglobin concentrations and coagulation and treat dilutional coagulopathy when it occurs (e.g. with fresh plasma: 5 to 15 ml/kg). Hemodilution (should be > 7 g/dl) and total protein (should be > 4 g/dl) concentrations should be measured before and during surgery to minimize oxygen delivery deficits and interstitial edema. Either a colloid or blood (recommended if the hemoglobin concentration is < 5 to 7 g/dl) is a more rational and effective choice for replacement of blood loss. Reducing or terminating anesthesia, when possible, and co-administering fluids with vasoressors or inotropes are the best methods for managing hypotension caused by anesthetic drugs.

5. Hypotension
Hypotension in dogs and cats is one of the most frequent complications of general anesthesia and is related to the animal’s health status. The development of hypotension during anesthesia in a normal healthy dog or cat is more a testament to the animal’s physical status and the anesthetist’s competency than to blood loss or the vasodilatory and negative inotropic effects of anesthetic drugs. But keep in mind that all anesthetic drugs can induce hypotension, particularly when administered to dehydrated, sick, depressed, or debilitated animals. Absolute hypovolemia (e.g. blood loss) requires fluid replacement therapy with a crystalloid, colloid, or blood, depending on the animal’s hemoglobin concentration (Table 2). The question is how to treat hypotension due to relative hypovolemia during anesthesia. The answer is determined by its principal cause (e.g. vasodilatation, poor cardiac function).

Anesthetic drugs. Relative hypovolemia (vasodilatation) is most likely due to the vasodilating effects of anesthetic drugs on venous vascular tone and suppression of compensatory homeostatic mechanisms.3 Isoflurane, sevoflurane, and propofol inhibit sympathetic compensatory homeostatic mechanisms and directly interfere with smooth muscle contraction (e.g splenic contraction), thereby decreasing venous vascular tone and increasing venous capacitance.42,43 These effects combine to decrease venous return, cardiac filling pressures, cardiac output, and arterial blood pressure and are as important, if not more important, than their arterial vasodilatation effects.3

Conventional rates of fluid administration, whether crystalloid or colloid, may be ineffective for restoring normal arterial blood pressure unless anesthetic

A guide to optimal perioperative fluid therapy

Step 1: Calculate the preoperative fluid deficit volume
Attempts to replace fluid losses due to dehydration < 24 hours before anesthesia with crystalloid solutions (fluid loading) generally result in interstitial edema and urinary losses that impede rehydration.19 To avoid fluid overload, replace only 75% to 80% of the deficit volume during the 24 hours preceding anesthesia. Stabilize arterial blood pressure and tissue perfusion in dehydrated or “shocky” animals before surgery.

Calculate the dehydration deficit (ml)  
\( \% \text{ dehydration} \times \text{BW}_{kg} \times 1,000 \times 0.80 \)

Add this deficit to the 24-hr fluid maintenance requirement (ml):14  
\( (30 \times \text{BW}_{kg}) + 70 \)

Then divide by body weight (kg) and then by 24 (hr).

Step 2: Calculate the preoperative fasting deficit volume  
Fasting deficit volume (ml) =  
\( \text{BW}_{kg} \times \text{hours no water} \times 1.5 \text{ to } 2 \text{ ml/kg/hr}^* \)

* 1 to 2 ml/kg/hr for 2- to 10-kg animal or 1.5 ml/kg/hr for 10- to 100-kg animal

Add this volume to the basal fluid requirements (see next step) and administer during the first hour.
### Step 3: Calculate the ongoing basal fluid requirement.

The basal fluid requirement is:

- 1 to 2 ml/kg/hr for 10- to 100-kg animal
- 2 ml/kg/hr for animals weighing <10 kg

Also consider the animal’s weight, metabolic rate, age, and concurrent diseases (e.g. heart, renal).

**Step 4: Calculate anticipated surgical fluid losses.**

Anticipated tissue trauma\(^\text{27}\) (ml/kg/hr) x weight (kg)

- **Minimal** (e.g. laceration): 2 to 4 ml/kg/hr
- **Moderate** (e.g. mass removal): 4 to 6 ml/kg/hr
- **Severe** (e.g. bowel resection): 6 to 8 ml/kg/hr

**Step 5: Adjust for blood losses (monitor hematocrit or hemoglobin).**

- For every 1 ml of blood loss, administer 4 to 5 ml of crystalloids.
- For every 1 ml of blood loss, administer 1 to 1.5 ml of colloids.

Remember to add up lap pads (100 to 150 ml each) and 4-x-4 pads (10 ml each).

**Monitor PFI.**

### Case Example

A 7% dehydrated 10-kg dog is scheduled for an exploratory laparotomy. The dog has not drunk water for about five hours.

#### 24 Hours Pre-Anesthesia

**Step 1:** Replace 80% of the dehydration deficit during the 24 hours preceding surgery not as a fluid preload immediately before surgery.

\[
0.07 \times 10 \text{ kg} \times 1,000 \times 0.80 \\
= 560 \text{ ml (dehydration deficit)} \\
+ \\
(30 \times 10) + 70 \\
= 370 \text{ ml (ongoing 24-hour fluid maintenance requirements)} \\
= 560 + 370 = 930 \text{ ml}
\]

930 ml/10 kg/24 hr = 3.88 ml/kg/hr (about 4 ml/kg/hr) for the 24 hours before anesthesia

**Step 2:** Calculate the fasting deficit volume.

10 kg x 5 hr x 1.5 ml/kg/hr = 75 ml

**Step 3:** Calculate the basal fluid requirement.

1.5 ml/kg/hr x 10 kg = 15 ml

**Step 4:** Calculate the anticipated surgically induced fluid losses.

- **Moderate** tissue trauma: 5 ml/kg/hr x 10 kg = 50 ml

This dog would be administered about 140 ml (14 ml/kg/hr) of fluid during the first hour of anesthesia:

75 ml + 15 ml + 50 ml 
= 140 ml (14 ml/kg/hr)

**After First Hour**

**Step 5:** Adjust for blood loss of approximately 50 ml.

- If hemoglobin concentration > 7 g/dl and total protein concentration > 3.5 g/dl, administer 200 to 250 ml crystalloid.
- If hemoglobin concentration > 7 g/dl, administer 50 to 75 ml colloid.
- If hemoglobin concentration < 7 g/dl, consider administering 50 ml blood.

The fluid rate is adjusted to the basal requirement plus surgically induced fluid losses after the first hour of anesthesia:

15 ml + 50 ml (colloid) 
= 65 ml (6.5 ml/kg/hr)

**Note:** Fluids should not be administered at a rate exceeding 30 ml/kg/hr (about 0.5 ml/kg/min) to minimize tissue edema, unless there is excessive surgical trauma and additional blood loss. A 10-kg dog could be administered 50 ml of colloid or blood in 10 minutes (0.5 ml/kg/min x 10 kg = 5 ml/min; 50 ml at 5 ml/min = 10 min).

If there is blood loss or hypotension or both (see Table 2): Maintain hemoglobin ≥ 7 g/dl and total protein ≥ 3.5 g/dl.

- If hemoglobin or total protein fall below the stated values, then blood or plasma therapy may be required.
depth is reduced.\(^5\)\(^,\)\(^33\) An experimental study in isoflurane-anesthetized dogs demonstrated that arterial blood pressure improved only when anesthetic depth was decreased.\(^5\) Notably, the fluid administration rate in this study was six times greater (60 ml/kg/hr) than the currently suggested conventional rate (10 ml/kg/hr).\(^5\) This rate of crystalloid administration is likely to produce hemodilution and hypervolemia unless administered for a very short time. Clearly, more practical and effective recommendations are required for the intraoperative treatment of hypotension in anesthetized animals.

Toward this end, we have administered 3 to 5 ml/kg of tetrastarch over one to three minutes to isoflurane-anesthetized dogs and produced an immediate and sustained increase in arterial blood pressure. The magnitude of the beneficial effect was directly related to the depth of anesthesia (i.e. deeper level then less effect). Similar but shorter duration effects were produced when lactated Ringer’s solution was administered. The relatively short duration of fluid administration decreases the potential for fluid overload (e.g. for a 10-kg dog, 30 ml of crystalloid or colloid over one to three minutes). If arterial blood pressure does not increase, then the administration of a catecholamine (e.g. vasoconstrictor, inotrope) should be considered (Table 2).

**Catecholamines.** Catecholamines increase heart rate and cardiac contractility, and some are potent vasoconstrictors (e.g. dopamine, norepinephrine). Notably, catecholamines alter the intravascular volume-expanding effects of fluid therapy.\(^44\),\(^45\) Drugs that activate alpha receptors (e.g. dopamine, norepinephrine, and phenylephrine) and induce vasoconstriction reduce blood volume expansion, while those that activate beta receptors augment blood volume expansion.\(^46\) Since optimization of blood pressure and blood flow is the goal in a hypotensive anesthetized animal, the administration of a mixed alpha-beta agonist (e.g. dopamine) is the more rational therapeutic choice for maintaining arterial blood pressure.\(^46\)

**Final considerations.** Finally, it should be emphasized that anesthetic-induced or -associated hypotension is best treated by decreasing or stopping the administration of anesthetic drugs. A potent analgesic (e.g. fentanyl) can be administered to reduce the requirement for inhalant or injectable anesthesia.\(^37\) A vasoconstrictor (e.g. dopamine, norepinephrine) or positive inotrope (e.g. dopamine, dobutamine) may be required to restore and maintain blood vessel tone or cardiac contractile function, blood flow, and arterial blood pressure, respectively, in animals that do not respond to fluid therapy due to vasodilatation or poor cardiac contractile function.\(^46\)

**CONCLUSION**

Perioperative fluid therapy in animals is not innocuous and should be considered identical to drug therapy—individualized and goal-directed. Differences in the types of fluids (crystalloid or colloids) available determine their effects upon electrolyte and acid-base balance and their ability to restore or maintain arterial blood pressure and tissue perfusion.

Isotonic balanced crystalloids maintain water requirements, blood osmolality, tissue perfusion, and acid–base balance in otherwise normal healthy surgical candidates. Colloid solutions are more effective for treating low arterial blood pressure, poor tissue perfusion, and blood loss. Both crystalloids and colloids are dilutional to substances; they do not contain (e.g. hemoglobin) and should be dosed in order to prevent excessive hemodilution (hemoglobin < 7 g/dl) and avoid fluid overload. Thus, accurate assessment of fluid status (i.e. fluid responsiveness) and careful definition of targets at all stages of the perioperative period are needed to improve clinical outcomes.

Fluid administration is essential for optimizing tissue perfusion. The determination of PVI helps to predict fluid therapy responsiveness and to guide fluid replacement during anesthesia in dogs and cats. VM

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For references, see dvm360.com/FluidTherapy3Refs.

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