Chapter 46

Trauma and Critical Patients

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Introduction

Proper care of trauma or critical patients requires advanced planning, an ordered protocol, and efficient use of time and resources. When a team approach is taken in the emergency room, with each member of the team given preassigned duties, rapid evaluation and treatment are possible. Airway, breathing, circulation, and neurological status should be immediately assessed upon a patient's arrival, and circulation, ventilation, and neurological function should be reassessed frequently during the initial treatment period. Respiratory rate and effort, heart rate and rhythm, blood pressure, pulse quality, capillary refill, central nervous system (CNS) function, and pain should be evaluated to determine the patient's status and prognosis.[1] Severely traumatized or critical patients are subject to a variety of complications that may manifest in the first few days following presentation. These complications may not be directly related to the initial insult, but reflect overall tissue destruction, immune suppression, and metabolic imbalances. These complications may be septic, nonseptic, or both in origin.[2,3]

Critically ill patients should always be considered likely candidates for developing some form of *shock*, a state of generalized inadequate tissue perfusion. Hypotension usually accompanies shock, but during early compensation, shock can occur with normal blood pressure. Shock may result from blood loss, poor car-

diac function, sepsis, or interruption of tissue blood flow. The probability of recovery from shock is related to the magnitude of the oxygen debt that occurs. After an overwhelming injury or infection, the sequelae to oxygen debt may not be reversible. Inadequate resuscitation, another major insult (e.g., anesthesia and surgery), or several small insults during this time often result in death.

When anesthetizing critically ill patients, the primary goal is to optimize tissue perfusion and oxygen delivery to all vital organ systems while inducing unconsciousness, an appropriate degree of analgesia, and muscle relaxation. The ultimate goal of therapy should be optimal physiological function rather than restoration of measured hemodynamic parameters to normal. Values generally considered normal for healthy anesthetized patients are associated with higher rates of mortality in high-risk patients. In prospective studies of human trauma patients, survivability is associated with cardiac indexes 50% higher and blood volumes 110% to 120% higher than normal at the end of surgery.[4] These values are necessary to meet the increased metabolic demand of fever and tissue repair in posttrauma and postoperative patients (Table 46.1).

Traumatized or critically ill patients are often near cardiopulmonary collapse or arrest. Causes of acute circulatory failure in these patients include severe myocardial ischemia, malignant dysrhythmias, hypoxemia associated with severe lung damage or airway obstruction, hemorrhagic shock, acid-base or electrolyte abnormalities, profound vagal tone such as is associated with the oculocardiac reflex, and electrocution. When cardiovascular collapse occurs during attempts to stabilize severely traumatized or critically ill patients, cardiopulmonary resuscitation should be instituted immediately.

Shock

Septic Shock

As a general rule, anesthesia should not be undertaken until a patient's vital organ functions have been assessed and stabilized. If the patient is in shock, the etiology should be determined and corrective measures initiated before anesthesia. Anaphylactic shock and neurogenic shock are characterized by relative hypovolemia and hypotension caused by acute increases in vascular capacitance. Hypovolemic shock and neurogenic shock are typically observed in acutely traumatized patients, whereas septic shock and the systemic inflammatory response syndrome (SIRS) develop after the initial insult. SIRS is a global activation of the

Table 46.1. Cardiovascular resuscitation goals for animals with systemic inflammatory response syndrome.

Variable	Goal
Mixed venous oxygen tension, PvO_2 (mm Hg)	>40
Pulmonary artery pressure (mm Hg)	>25/10
Pulmonary wedge pressure (mm Hg)	218
Systemic vascular resistance (dyne $\times$ s/cm^{-5} $\times$ m^2)	>1450
Pulmonary vascular resistance (dyne $\times$ s/cm^{-5} $\times$ m^2)	45–250
Oxygen extraction (%)	22–30
Cardiac index (L/min $\times$ m^2)	>4.5
Oxygen delivery (mL/min $\times$ m^2)	>600
Oxygen consumption (mL/min $\times$ m^2)	>170

PvO_2, mixed venous oxygen tension.
From Hardie.[5]

Table 46.2. Proposed definitions of systemic inflammatory response syndrome in dogs and cats.

Proposed for dogs, the presence of two or more of the following clinical conditions:
  Body temperature > 40°C or < 38°C
  Heart rate > 120 beats/min in calm, resting dogs
  Hyperventilation of $PaCO_2$ < 30 mm Hg
  White blood cell count > 18,000/mL or < 5000/mL or > 5% immature (band) forms
Proposed for cats, the presence of two or more of the following clinical conditions:
  Body temperature > 40°C or < 38°C
  Heart rate > 140 beats/min in calm, resting cats
  Respiratory rate > 20 breaths/min or $PaCO_2$ < 28 mm Hg
  White blood cell count > 18,000/mL or < 5000/mL or > 5% immature (band) forms

$PaCO_2$, arterial carbon dioxide partial pressure.
From Hardie.[5]

immune system and release of many cytokines, resulting in a generalized increase in vascular permeability, neutrophil infiltration, and capillary microemboli. Early signs of SIRS and septic shock include brick-red mucous membranes, tachycardia, high cardiac output (in euvolemic patients), normal or low blood pressure, and low vascular resistance. Classifications of SIRS for dogs and cats based on the presence of various key clinical signs have been proposed and are listed in Table 46.2.[5] Clinically, in cats, the signs of late-stage sepsis are more commonly recognized than are those of early hyperdynamic sepsis.[6] Cats often differ from dogs in that a cat's signs of late shock include bradycardia, hypotension, and hypoglycemia.

In cats, lung function is often impaired early in SIRS because of rapid fluid accumulation. In dogs, the order of organ dysfunction is commonly gastrointestinal tract, followed by liver, kidney, and then lung. Patients suffering from noncardiogenic pulmonary edema may have this condition exacerbated by rapid crystalloid fluid administration. Persistent microcirculatory perfusion failure may lead to sludging of blood and increased immune cell and platelet aggregation. Along with the release of inflammatory mediators, these conditions result in poorly regulated coagulation and propagation of the inflammatory response. Toxic oxygen free radicals can cause further cellular damage, persistent edema, and increased oxygen diffusion distance between cells and capillaries. If oxygen delivery to tissues is chronically impaired, the systemic inflammatory state can lead to multiple organ dysfunction syndrome (MODS), traditionally defined as *irreversible shock*.

Successful management of animals with septic shock or SIRS depends on anticipation, not reaction.[3] Appropriate antibiotic administration, aggressive cardiovascular support, and monitoring of the susceptible organs must be undertaken early. An algorithm depicting SIRS management is presented in Fig. 46.1.[3] Therapeutic agents and doses used in the treatment of various metabolic derangements associated with SIRS are listed in Table 46.3.

Hemorrhagic Shock

Clinical signs of hemorrhagic shock most commonly encountered in acutely traumatized patients include pallor, cyanosis, disorientation, tachycardia, cold extremities, cardiac dysrhythmias, pump failure, tachypnea, hypotension, oliguria, disseminated intravascular coagulation, and progressive metabolic acidosis.[1] With acute blood loss, normal homeostatic reflexes vigorously defend blood pressure in an attempt to maintain vital organ function. As hemorrhage ensues, plasma renin levels elevate, the antidiuretic hormone level increases, and the sympathetic nervous system activates to produce tachycardia and arteriolar vasoconstriction. These mechanisms can maintain blood pressure until about 40% of normal blood volume is lost (more loss than is clinically acceptable).[1] Thus, an animal can be severely hypovolemic but normotensive. Once blood loss exceeds 40% of blood volume, compensatory organ mechanisms fail over time, and shock becomes irreversible. Prolonged poor tissue perfusion causes tissue ischemia, loss of cell membrane integrity, and cell death.[1] If the trauma involves crushing of tissues or severe burns, shock is accompanied by increased capillary permeability and rapid translocation of fluids. In addition, toxic factors from exogenous
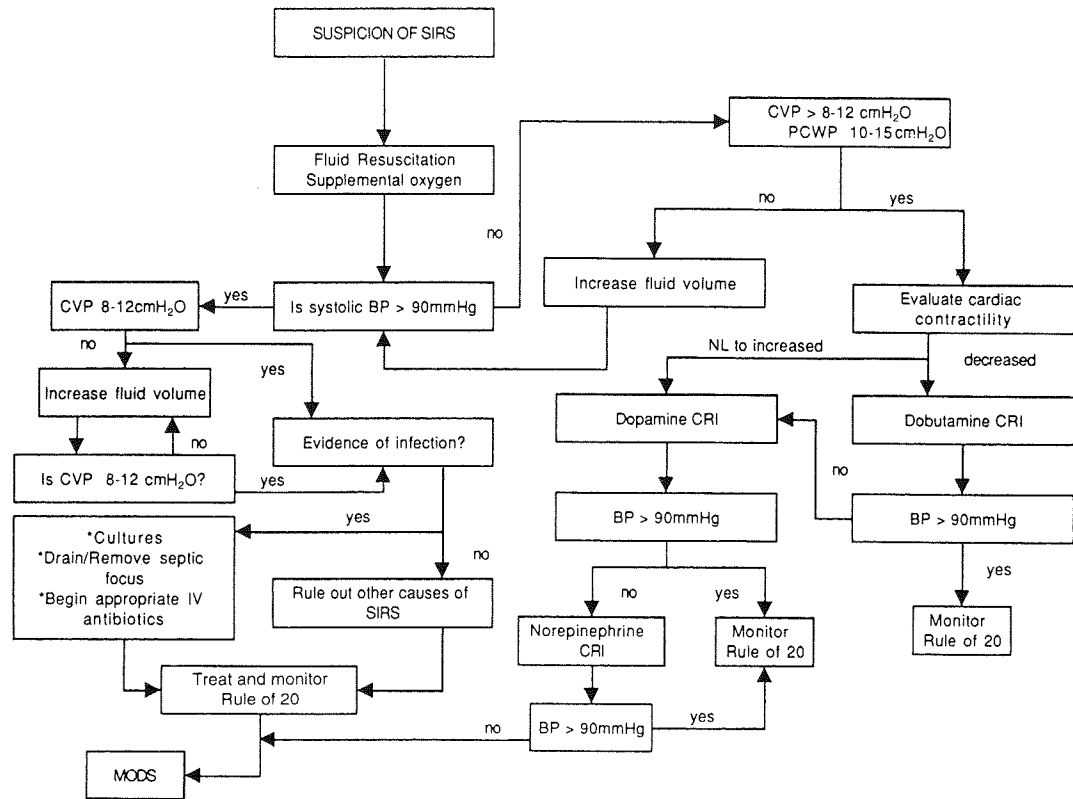
Fig. 46.1. Algorithm depicting SIRS patient management. BP, blood pressure (implies systolic); CRI, continuous-rate infusion; CVP, central venous pressure; IV, intravenous; MODS, multiple organ–dysfunction syndrome; NL, normal; PCWP, pulmonary capillary wedge pressure; and SIRS, systemic inflammatory response syndrome. From Purvis and Kirby.[3]

sources (e.g., microbial toxins) and endogenous sources (e.g., fat emboli, potassium-ion release, lysosomal enzymes, and myocardial depressant factor) are simultaneously released, causing further organ malfunction.[7]

The primary treatment of hemorrhagic shock is aggressive fluid therapy. Large-bore intravenous catheters should be placed in each cephalic vein and/or jugular veins, and warm, crystalloid solutions, blood, and/or hemoglobin-based oxygen-carrying solutions infused. If necessary, fluids can also be administered rapidly into the intraosseous space of the tibia or femur. When rapid infusion of large volumes of crystalloids decreases the concentration of serum total solids to below 3.5 to 4.0 g/dL, simultaneous colloid solution administration is advantageous in maintaining intravascular volume.[8]

Albumin is an excellent plasma expander, but is expensive and can induce immune responses. Hetastarch compares favorably to albumin and has an extremely low toxicity in people and animals.[9] The dose of hetastarch is up to 20 mL/kg/day in dogs. In cats, a smaller volume and slower rate of administration are recommended. All colloids can affect coagulation, but rapid hemodilution with larger volumes of crystalloids can, as well. In dogs administered less than 30 mL/kg hetastarch, clotting time, clot retraction, platelet count, and whole clot lysis are not significantly affected.[10,11] Hetastarch does, however, decrease all three components of the factor VIII–related complex. After a single

hetastarch dose, plasma expansion can last 24 to 48 h.[9] Plasma administration decreases the continual decline of plasma protein level, but it is difficult to increase total protein significantly by plasma administration alone. The use of fresh-frozen plasma is best reserved for patients that are deficient in coagulation factors.

Hypertonic saline may be beneficial in the early treatment of hypovolemic and hemorrhagic shock.[12] Intravenous administration of small volumes (4 to 6 mL/kg) of 7.5% hypertonic saline has beneficial cardiovascular effects in hypovolemic dogs and cats.[13–15] Increases in pressure and cardiac output appear to be mediated primarily by rapid increases in plasma volume.[14] A second potential benefit of hypertonic saline administration is minimization of the risk of cerebral edema in patients with head trauma.[16,17] Hypertonic saline (7.2% sodium chloride [formulations vary]; 4 mL/kg intravenously [IV]) may be administered over 15 min in acute hypovolemic episodes. The addition of a colloid to hypertonic saline appears to prolong its effects. It is important to remember that hypertonic saline shifts fluid from the extravascular space to the intravascular space. Total body water does not significantly increase unless additional crystalloid fluids are given soon after the hypertonic saline. Contraindications for hypertonic saline administration include hypernatremia, cardiogenic shock, renal failure, hyperosmolarity, uncontrolled hemorrhage, and thrombocytopenia (if in dextran). Hypertonic solutions may produce hyperchloremic nonrespiratory acidosis and hypokalemia.

Table 46.3. Therapeutic agents used to treat metabolic derangements associated with systemic inflammatory response syndrome.

Metabolic Derangement	Dose Regimen	Use and/or Frequency
Hypovolemia		
Hypertonic crystalloids		
7.5% NaCl solution (70 mL 23.4% NaCl in 180 mL 0.9% NaCl or 6% dextran 70)	4 mL/kg IV	Once
Colloids		
Plasma	Maximum: 20 mL/kg/24 h IV	As needed
Hetastarch 120	Maximum: 20 mL/kg/first 24 h, and then 10 mL/kg/24 h IV (slow infusion)	As needed
Dextran 70	Maximum: 20 mL/kg/first 24 h, and then 10 mL/kg/24 h IV (slow infusion)	As needed
3% Albumin (12 mL 25% human albumin in 488 mL lactated Ringer's solution)	20 mL/kg IV	Resuscitation
Isotonic crystalloids		
Lactated Ringer's solution	90–270 mL/kg IV	Resuscitation
	10–20 mL/kg/h IV	To meet ongoing needs
Altered clotting function		
Heparin (low dosage)	75–100 U/kg SC	Every 6–8 h
Heparin-activated plasma (incubate 5–10 U/kg heparin with 1 U fresh plasma for 30 min)	10 mL/kg IV	Every 3 h, based on clotting function
Metabolic dysfunction		
KCl	0.125–0.25 mEq/kg/h IV; do not exceed 0.5 mEq/kg/h	As needed
Glucose	50–500 mg/kg/h IV	As needed
$NaHCO_3$	Base excess $\times$ 0.3 $\times$ body weight in kg = mEq needed to correct deficit, IV (slow infusion)	As needed (pH 7.1 or less)
Gastrointestinal tract dysfunction		
Cimetidine	5–10 mg/kg IV, IM, PO	Every 6–8 h
Ranitidine	2 mg/kg IV, IM, PO	Every 8–12 h
Omeprazole	0.7 mg/kg PO	Every 24 h
Misoprostol	3 µg/kg PO	Every 24 h
Sucralfate	250 mg (cats) PO	Every 8–12 h
	500 mg (dogs < 20 kg) PO	Every 8–12 h
	1 g (dogs > 20 kg) PO	Every 8–12 h
Kaolin-pectin	1–2 mL/kg PO	Every 6–8 h
Metoclopramide	0.2–0.5 mg/kg SC	Every 6–8 h
Renal dysfunction		
Mannitol	0.25–1 g/kg IV	Once (slow bolus)
Furosemide	1–2 mg/kg IV	If no effect, repeat in 2 h and increase dose by 1 mg/kg
Dopamine	1–3 µg/kg/min IV	As needed until urine production consistently > 2 mL/kg/h

IM, intramuscularly; IV, intravenously; PO, per os (orally); SC, subcutaneously; U, units.
From Hardie.[5]

Massive blood loss will eventually require transfusion of whole blood or packed red blood cells to replace oxygen-transport capacity. Hemoglobin-based oxygen-carrying solutions (e.g., Oxyglobin [bovine hemoglobin glutamer 200]) can serve to increase oxygen capacity; however, the effects are usually brief, requiring additional blood-product transfusion. Trend monitoring of hematocrit (or hemoglobin concentration), total solids, central venous pressure, and urine output is helpful in guiding resuscitation. The use of whole blood should be reserved for patients that need cells and plasma. If the packed cell volume (PCV) is less

Table 46.4. Vasoconstrictor and mixed inotropic-vasoconstrictor drugs.

| Drug (Trade Name) | Catecholamine Receptor Activation | | | | Drug Dose and Infusion Schemes |
	α_1	α_2	β_1	β_2	
Phenylephrine (Neo-Synephrine)	+++	+	− Little at high dose	−	Bolus: 0.15 mg/kg IV Infusion: 0.5–1.0 µg/kg/min
Methoxamine (Vasoxyl)	++	+	−	−	Bolus: 0.1–0.8 mg/kg IV (cardiac arrest) Bolus: 0.01–0.04 mg/kg IV (vasopressor)
Ephedrine	+	+	+	+	Bolus: 0.1–0.25 mg/kg IM; 0.03–0.07 mg/kg IV
	Direct and indirect (NE release) effects				
Metaraminol (Aramine)	+	+	+	+	Bolus: 30–100 µg/kg IM Infusion: 20–50 µg/kg/min
	Similar to ephedrine effects initially[a]				
Mephenteramine (Wyamine)	+	+	+	+	Bolus: 0.2–0.6 mg/kg IM
	Similar to ephedrine effects				
Norepinephrine (Levophed)	+++	+++	+	Little	Infusion: 0.01–0.03 µg/kg/min up to a maximum 0.1 µg/ kg/min to effect

IM, intramuscularly; IV, intravenously; NE, norepinephrine; +, positive effect; −, no effect.
[a]Metaraminol replaces NE in storage vesicles in the nerve terminal. It has only one-tenth the potency of NE at α receptors and may eventually produce a hypotensive effect.

that 20% and the protein level is normal, transfuse cells. The rule of thumb is that 2.2 mL of blood/kg body weight increases the recipient's PCV by 1%; however, this depends somewhat on the hematocrit of the donor blood.

Oxyglobin is a hemoglobin-based oxygen-carrying solution that increases plasma and total hemoglobin concentration. Its elimination half-life is 30 to 40 h, but its effective action may be much shorter. Some blood tests that use colorimetric changes will be altered after the administration of Oxyglobin, because of the change in plasma color. The recommended dose in dogs is approximately 15 mL/kg IV (the label dose is up to 30 mL/kg) at a rate of 5 mL/kg/h (the label rate is 10 mL/kg/h). Patients should be carefully monitored during and after Oxyglobin administration because of its effects on vascular resistance and right atrial pressure. A more conservative dosing strategy considers trends in monitored total hemoglobin concentration (i.e., maintain 8 to 10 g/dL total hemoglobin). In cats, smaller volumes and slower administration should be used. To avoid volume overload when administering larger doses of Oxyglobin, it is recommended that central venous or right atrial pressure be monitored.

Spinal Shock

This is a common sequela to spinal cord injury or blunt trauma, which can disrupt sympathetic nervous system outflow. The patient's extremities will feel warm (peripheral vasodilation), and even though hypotension is present, heart rate is slow because of sympathetic denervation. These patients are relatively hypovolemic; that is, intravascular capacity greatly exceeds intravascular volume. Organ perfusion may or may not be adequate, and vascular resistance is drastically reduced. These patients are more susceptible to hypothermia because they cannot constrict peripheral vasculature. Fluids should be administered to increase vascular volume. If arterial pressure is low and the pulse cannot be pal-

pated, mixed inotropic-pressor–type drugs should be given to increase blood flow to vital organs. Intravenous ephedrine, mephentermine, or metaraminol are good choices in these patients (Table 46.4).[18] Since resistance and flow are inversely related, the usefulness of pressors alone is limited. Use of vasopressors may compound compromised visceral perfusion and increase cardiac workload.[6] If there is any question as to adequacy of contractility, pressors should not be used before inotropes. Not all inotropic or vasoconstrictor drugs produce equivalent hemodynamic effects. Hemodynamic responses to norepinephrine, epinephrine, and isoproterenol are illustrated in Fig. 46.2. These differences are medi-
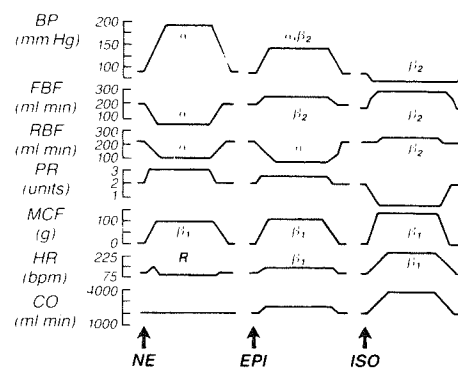
Fig. 46.2. Differences in cardiovascular effects of intravenously administered norepinephrine (NE), epinephrine (EPI), and isoproterenol (ISO). Schematics represent relative effects on blood pressure (BP), femoral blood flow (FBF), renal blood flow (RBF), peripheral vascular resistance (PR), myocardial contractile force (MCF), heart rate (HR), and cardiac output (CO). Primary responses are noted as either α-, β_1-, or β_2-receptor mediated; and R, reflex mediated. Differences in cardiovascular effects of these catecholamines are caused by variation in α and β selectivity for each agonist and dose.

ated by variations in adrenergic receptor activation and dose. Indirect-acting agents such as ephedrine enhance release of endogenous norepinephrine from sympathetic neuronal terminals and also induce direct vasoconstrictive effects.

Cardiogenic Shock

This type of shock occurs when the ability of the heart to maintain cardiac output is insufficient to meet the body's demand. The circulatory compromise is caused entirely by cardiac dysfunction. Once overwhelming cardiac disease progresses and a patient can no longer compensate, signs of failure appear. If therapy does not improve systemic perfusion and the patient's ability to meet metabolic needs, the patient will die. The diagnosis and treatment of cardiogenic shock are beyond the scope of this chapter, but have been reviewed.[19]

Patient Monitoring and Pharmacological Support

Measurement of perfusion is challenging in veterinary patients. Lactate can be used as a surrogate measure for perfusion. In low-flow situations, tissue hypoxia results in increased anaerobic metabolism and subsequent increased lactate production. Studies suggest that trends in lactate concentration are more helpful in predicting outcome than is measuring cardiac output.[20,21] The magnitude of the elevation is positively correlated with the magnitude of the underlying problem and negatively correlated with prognosis. The normal lactate concentration should be determined for each laboratory, but is generally less than 1.5 mM/L.

In traumatized or critically ill patients, either a continuous or intermittent electrocardiogram should be monitored with a rhythm printout obtained immediately prior to anesthesia or if abnormalities are noted. Antiarrhythmic drugs that may be useful during management of traumatized or critically ill patients include lidocaine, procainamide, and esmolol. Lidocaine can be used to treat ventricular arrhythmias (dogs: 1 to 4 mg/kg IV bolus, followed by 40 to 80 μg/kg/min IV infusion).[22] Lidocaine should be used more cautiously in cats (0.25 to 1.0 mg/kg IV over 5 min).[22] Refractory ventricular arrhythmias may require treatment with procainamide (1 to 10 mg/kg IV, followed by 20 to 50 μg/kg/min IV infusion).[22] Since procainamide may cause profound hypotension, it should be administered in smaller doses, which are repeated when necessary. Esmolol (0.5 mg/kg slow IV, followed by 50 to 200 μg/kg/min IV infusion) is a β blocker with a very short half-life (a half-life of elimination of about 10 min) that may be used in the treatment of supraventricular tachycardias and ventricular arrhythmias. Esmolol significantly decreases contractility and should not be routinely used unless hemodynamic monitoring is available.[23,24]

Several drugs commonly recommended for resuscitation and stabilization have been reevaluated since their introduction. Because of the potential complications of sodium bicarbonate, its use in resuscitation and intensive care units is continuously scrutinized. It has been used in advanced cardiac life support for 40 years, but its nonselective use has become controversial over the last 15 to 20 years.[25] In the treatment of arrest, it has gone from being a first-line drug in the first American Heart Association's Standards for Cardiopulmonary Resuscitation and Advanced Cardiac Life Support to current recommendations that its use may be indicated in cases of protracted arrest or long resuscitative efforts with preexisting metabolic acidosis.[25] Reasons include lack of clinical studies of buffer therapy, knowledge that normal pH can be maintained by compression and hyperventilation, and the potential ill effects of bicarbonate therapy.[26]

If sodium bicarbonate is used, it is reasonable that the time interval to its administration be based on the rate of metabolic acidosis development, rather than the duration of resuscitative efforts.[25] In dogs, serum-base deficits increase by 1.1 to 1.5 mEq/L for every minute of circulatory arrest; the arterial lactate concentration increases by 0.3 mmol/L/min (with epinephrine administration) and 0.6 mmol/L/min (without epinephrine administration) of arrest and cardiopulmonary resuscitation.[25]

The role of bicarbonate therapy for metabolic acidosis caused by diminished oxygen delivery to tissues in critically ill or traumatized patients is also controversial.[27] Successful treatment of the underlying excessive intracellular production of hydrogen ions will often resolve the acidosis. It is not clear whether buffering the blood, extracellular fluid, and intracellular fluid actually slows the production of metabolic acid or simply facilitates its removal. Most current recommendations advise avoiding bicarbonate therapy for lactic acidosis unless acidosis is so severe that physiological functions are dangerously impaired. Little existing experimental data support the use of bicarbonate for the treatment of acidosis.[27] Additionally, bicarbonate administration is not without risk. Its potential adverse effects include negative inotropy, paradoxical cerebrospinal fluid acidosis, hypercarbia, alkalosis, vasodilation, hyperosmolarity, electrolyte disturbance (e.g., hypokalemia and hypocalcemia), shifting of the oxyhemoglobin-dissociation curve (i.e., decreased oxygen delivery because of increased affinity of hemoglobin for oxygen), and volume overload caused by sodium.[28] The standard formula used to calculate bicarbonate replacement is milliequivalents of bicarbonate = base deficit × 0.3 × body weight (kg). This formula is used for correcting metabolic acidosis in the extracellular fluid compartment. Total-body base-deficit correction may require a greater dose and intravascular correction a smaller dose. To avoid a vascular alkalosis, the dose should not be administered faster than it can be redistributed from the vascular space to the interstitial space. If administered too quickly, severe hypotension and death may result. A more conservative approach is to calculate the deficit, but administer only one-third of the dose at a time. Allow enough time for equilibration and recheck a blood gas. There are alternative alkalinizing agents such as tromethamine (THAM) and Carbicarb (a mixture of sodium carbonate and sodium bicarbonate), but these alternative agents have not proven to be superior.

Dopamine has been used as a sympathomimetic and dopaminergic drug since the 1960s. The potential for protective effects of low-dose dopamine on renal and splanchnic perfusion has led to the widespread use of this drug in critically ill patients (Table 46.5). Although low-dose dopamine may increase urine production, it neither prevents nor improves acute renal failure. Even

Table 46.5. Positive inotropic drugs.

Drug (Trade Name)	Catecholamine Receptor Activation					Noncatecholamine Mechanism	Drug Dose and Infusion Schemes
	α_1	α_2	β_1	β_2	Dopamine		
Epinephrine (Adrenalin)	+++	+++	++	++	−	No	0.01–0.03 µg/kg/min (vasopressor) 0.1–0.2 mg/kg IV (cardiac arrest)
Isoproterenol (Isuprel)	−	−	+++	+++	−	No	0.01–0.1 µg/kg/min; used primarily to increase heart rate; may cause hypotension
Dobutamine (Dubutrex)	Little	Little	+++	++	−	No[a]	2–10 µg/kg/min
	Direct and minimal indirect effects						
Dopamine (Intropin)	++ (High dose)	+	++ (Low dose)	+ (Low dose)	+++	No[a,b]	2–5 µg/kg/min; "renal dose" 5–10 µg/kg/min; β effects 10–20 µg/kg/min; vasoconstriction
	Direct and indirect actions						
Dopexamine	−	−	Little	+++	++	No[a]	1–10 µg/kg/min
Ephedrine	+	+	+	+	−	No[b]	0.1–0.25 mg/kg/min IM 0.03–0.07 mg/kg IV
	Both direct and indirect effects						
Milrinone	−	−	−	−	−	Yes	50–75 µg/kg IV bolus; oral administration possible
	Phosphodiesterase inhibitor, ↑ cAMP in heart, peripheral vasodilator, ↑ inotropy additive to other types						

cAMP, cyclic adenosine monophosphate; IM, intramuscularly; IV, intravenously; +, positive effect; −, no effect; ↑, increased.
[a]Blocks reuptake of norepinephrine.
[b]Promotes release of norepinephrine from nerve terminal.

though low-dose dopamine does increase diuresis, it may actually increase the risk of acute renal failure in normovolemic and hypovolemic patients.[29] Similarly, there is no evidence that low-dose dopamine has beneficial effects on splanchnic function or decreased progression to MODS in sepsis.[29] Because of its effects on gastrointestinal motility, and respiratory, endocrine, and immunologic function, the use of low-dose dopamine is no longer routinely advised.[29] At higher doses, dopamine has been used as a pressor in septic patients, with the thought that β_1 activity, in addition to α_1-adrenergic–mediated pressor effects, would improve contractility and minimize the effect of increasing afterload on cardiac output. Because of the aforementioned potential adverse effects, its use as a pressor is likewise being further questioned.[29]

Additional controversy exists regarding the presence of dopaminergic receptors in the feline kidney. Putative DA_1-like receptors have been discovered in the cortex of the feline kidney.[30] DA_1 receptor pharmacology in the feline kidney appears to be similar to that of humans. There is a much smaller population of receptors in the feline renal cortex than in the renal cortex of rats, dogs, or people. It has been hypothesized that the smaller population of DA_1 receptors could account for the higher dose requirement to induce diuresis and natriuresis in cats when compared with other species.[30] However, as indicated for dogs, diuresis does not necessarily equate with improved renal function. Dopamine may be useful as an inotropic sympathomimetic agent in cats that have decreased cardiac output secondary to anesthetic drug administration.

Management of Selected Traumatized Patients

Head Trauma

The hallmark of severe closed head injury is loss of consciousness associated with increased intracranial pressure and brain ischemia. Severe lacerations of the head may be associated with severe blood loss and shock. If airway obstruction is evident, a tracheostomy may be necessary to ensure airway patency. Time is of the essence, because intracranial hemorrhage or hypertension can have devastating effects if undiagnosed or untreated for even a short period. In general, severe closed head injury resulting in stupor or coma has a poor prognosis.

Anesthetic agents that increase cerebral blood flow (e.g., halothane, nitrous oxide, and ketamine) are not recommended for use in these patients. Because barbiturates produce rapid induction, decrease cerebral metabolic requirement for oxygen ($CMRO_2$), and decrease cerebral blood flow, they may be reasonable agents for patients with severe head injury.[31] Following acute brain injury, large doses of glucocorticosteroids (1 to 3 mg/kg dexamethasone) may be helpful in controlling cerebral edema, although this use is now quite controversial.[32] Intubation and modest hyperventilation (arterial carbon dioxide partial pressure [$PaCO_2$] values of 28 to 32 mm Hg) may protect against dangerous increases in cerebral blood flow and pressure. Care should be exercised not to negatively impact arterial blood pressure and cardiac output with positive-pressure ventilation. If the $PaCO_2$ is allowed to decrease below 25 mm Hg, there is a danger

that the affected area of the brain may become ischemic because of excessive constriction of cerebral arterioles. The use of hyperosmotic solutions may help to minimize intracranial pressure caused by tissue edema. Mannitol is an ideal drug for preventing or treating increased intracranial pressure and cerebral edema associated with global ischemia or neoplasia. However, it is *not* recommended for immediate use in patients with suspected intracranial hemorrhage (head trauma). Hemorrhage or leaking of hyperosmotic solutions into perivascular neural tissue would increase interstitial fluid volume and intracranial pressure.

Cervical trauma may injure the innervation to respiratory muscles (phrenic and intercostal nerves) such that oxygen therapy, tracheal intubation, and mechanical ventilation may be necessary. Spinal injury may also cause autonomic dysfunction, resulting in gastric bloat, bradycardia, and electrolyte imbalances. Thermoregulation may also be seriously impaired.

Thoracic and Abdominal Trauma

Penetrating trauma of the thorax and abdomen is usually obvious. Blunt trauma presents a greater diagnostic challenge, because external examination may reveal no obvious abnormalities. A chest radiograph is essential following any type of thoracic trauma. Lung contusions, broken ribs, and flail chest are common. Pulmonary contusions may not become apparent until 12 to 24 h after injury. Radiographic findings might not correlate with functional deficits; therefore, arterial blood-gas analysis is essential for evaluating patient status. Severe hypoxemia often results from extensive lung contusions, and ventilatory support or oxygen therapy may be required. Low inspiratory pressures (<12 cm of water) should be used if intermittent positive-pressure ventilation (IPPV) is deemed necessary in patients that have a pneumothorax or bullae. Any accessible gas should be removed prior to anesthesia or if respiratory difficulty develops. Intermittent thoracocentesis may be adequate, but an indwelling chest drain should be considered if respiratory difficulty continues to develop. Pulmonary lesions tend to worsen within 24 to 36 h after injury.[33] Lung contusions will usually resolve in 2 to 5 days.[1] Medical management of pulmonary contusions includes oxygen, corticosteroid, analgesic, and antibiotic administration, and diuretic therapy when pulmonary edema is present. When contusions are severe, anesthesia, intubation, and low-pressure mechanical ventilation may be necessary.[33]

In small animals, thoracic and abdominal injuries are commonly associated with blunt trauma rather than with penetrating objects. Common cardiac injuries include tamponade, contusion, and rupture. Patients with pericardial effusion and cardiac tamponade will manifest jugular vein distension, muffled heart sounds, and hypotension (Beck's triad) in addition to tachycardia and reduced pulse pressure. The administration of intravenous fluid and inotropic drugs (Table 46.5), and immediate pericardial drainage (pericardiocentesis), may be necessary to maintain an adequate cardiac output. It is best to avoid controlled IPPV in patients that have tamponade. An infusion of fentanyl (0.8 μg/kg/min IV) and midazolam (8 μg/kg/min IV) with orotracheal intubation and oxygen support, rather than an inhalant, may be used for anesthetic maintenance until the pericardium can be opened and cardiac output improved. Patients with myocardial contusions will often develop ventricular dysrhythmias, which appear to be most common 24 to 72 h after trauma. Arrhythmias require correct diagnosis and appropriate therapy with antiarrhythmic agents prior to and during the surgical period. Myocardial rupture usually causes death at the scene of the accident.

In the urban environment, the incidence of abdominal injury has been reported at 13% of all dog and cat trauma cases treated.[34] Blunt abdominal trauma can damage several vital organs by rupturing spleen and/or liver, or kidney and urinary bladder, or perforating the bowel or large abdominal vessels. In cases with a history of severe abdominal trauma, common sequelae are hypovolemic shock caused by organ or vessel rupture and/or septic shock resulting from septicemia. Abdominal ultrasound and radiographs should be used to evaluate abdominal injuries. Abdominal vascular injuries can be assessed by diagnostic peritoneal lavage. Although not organ specific, this technique is helpful in diagnosing unstable patients with a history of severe abdominal injury. Abdominal compression may reduce hemorrhage, but can also reduce vital tissue perfusion. Urinary catheterization will help to evaluate urinary tract injury and renal function.

Thermal/Burn Trauma

Although treatment of severely burned patients is uncommon, several factors important to intensive care management should be kept in mind. As is true with any trauma patient, initial treatment involves attention to airway, breathing, and circulation. If a patient is apneic or in stridor, or if the face is burned or the history indicates inhalation of steam, smoke, or toxic fumes, the trachea should be intubated immediately after sedation and induction.[1] Inhalation of carbon monoxide can cause severe tissue hypoxia even though mucous membranes and arterial oxygen partial pressure (PaO_2) may be near normal. Blood oxygen content can be drastically reduced because carbon monoxide has 200 times more affinity for hemoglobin than does oxygen. Since the majority of oxygen is carried on hemoglobin, and not in solution in the plasma (as measured with arterial blood gas), oxygen delivery to the tissues may be severely impaired. After intubation, the animal should be placed in an oxygen cage or ventilated mechanically with oxygen. After the airway has been secured, the burn patient will require large volumes of fluid. Fluid loss because of increased capillary permeability, protein loss into the interstitial tissues, and evaporative losses can be extensive, especially within the first 12 to 24 h after injury.[1] It has been suggested that only crystalloid solutions be administered during this time, because colloid solutions would likely rapidly extravasate. Volume replacement should be closely monitored by measuring urine output and hemodynamic parameters regularly. Burn patients are hypermetabolic and will often have increased temperatures, increased catabolism, and increased oxygen requirements. Tachypnea and tachycardia are common, and parenteral nutrition is usually necessary to overcome metabolic losses.

Providing anesthesia for burned and crushed patients presents some unique problems, but selection of anesthetics is not critical if done on a rational patient-by-patient basis. To enhance preoperative and postoperative analgesia, the use of opioids (e.g., fen-

tanyl patches placed on an area of nonburned skin) should be considered with any technique. Transdermal or topical medications should not be applied to damaged epithelial surfaces, because the pharmacokinetics of the drug may be significantly altered. If there are no contraindications, ketamine may provide some degree of somatic analgesia. Ketamine may be given as a low-dose infusion (0.5 mg/kg IV, followed by 2 to 10 µg/kg/min IV) as an adjunct to opioid analgesia.

Burn patients may not respond normally to muscle relaxants.[35] For example, within 24 h of injury, succinylcholine administration is associated with a rapid increase in serum potassium concentration, which can cause cardiac arrest (see Chapter 15). In contrast, burn patients may demonstrate increased resistance to nondepolarizing muscle relaxants (e.g., pancuronium and atracurium).

The principles of treatment for patients with electrical burns are similar to those for patients with thermal burns. If the burn is located in the oral cavity, severe swelling of pharyngeal tissues may complicate efforts to intubate. The extent of burn is often misleading. Small cutaneous lesions may overlie extensive areas of devitalized tissue and muscle. Accordingly, these patients should be carefully observed for myoglobinemia and renal failure, as well as neurological deficits and pulmonary edema.[1]

Anesthetic Management of Trauma and Critically Ill Patients

Most classes of anesthetic agents may be used in trauma and critically ill patients; however, the dosage requirement is usually reduced. Release of endogenous enkephalins, endorphins, and other amino peptides to reduce pain and stress may produce mild sedation and analgesia, reducing the dose requirement of anesthetic agents. Anesthetic management includes protection of the airway, provision for ventilatory support, and appropriate monitoring of the patient's condition. Premedicants may be advantageous to reduce anxiety and pain, and to offset anesthetic drug-induced adverse effects.

Premedication
During the preoperative period, vagal influences on cardiopulmonary function and excess secretions can be controlled by atropine or glycopyrrolate administration. Antimuscarinics are not routinely recommended for use in critically ill patients, though, because they often increase heart rate and myocardial oxygen consumption while decreasing the threshold for cardiac dysrhythmias.[36] Because the stomach may be full, measures to prevent regurgitation and aspiration before induction need to be considered. Aspiration of acidic gastric contents (pH < 2.5) will usually lead to pneumonitis and increased morbidity and mortality. When the risk of aspiration is high, several steps can be taken to minimize its occurrence and consequences, including glycopyrrolate administration to increase the pH of gastric contents, positioning of the animal to reduce gastric pressure, immediate intubation of the unconscious patient by using cricoid pressure and immediate inflation of the cuff, and the availability of suction to clear the pharynx of gastric reflux.[32,37]

When stabilization is necessary prior to surgery, analgesics and/or sedatives can be given to help alleviate pain, fear, and apprehension. Some clinicians apply partial (cats and small dogs) or full (large dogs) fentanyl patches (Duragesic; 25-, 50-, 75-, or 100-µg/h release rate) that provide continual release for transcutaneous absorption of fentanyl over several days. In cats, partial exposure to a 25-µg/h release patch results in lower plasma fentanyl concentrations (1.14 ± 0.86 vs. 1.78 ± 0.92 ng/mL for a full 25-µg/h patch).[38] All patients should be observed for either inadequate analgesia and signs of overdose. To allow time for efficacious blood fentanyl concentrations to develop, 12 to 24 h are required in most patients. Anesthetic induction and maintenance dose requirements may be lessened in patients who have had fentanyl patches applied long enough for effective blood concentrations to be achieved; however, anesthetic management is not usually altered unless obvious sedation is present before anesthetic induction. If an analgesic is needed for immediate pain relief, either butorphanol (0.2 mg/kg IV) or a µ-agonist such as oxymorphone (0.05 mg/kg IV) may be given in small incremental doses. When further CNS depression is desirable, diazepam (0.2 mg/kg IV) or midazolam (0.2 mg/kg IV or intramuscularly [IM]) can be combined with the opioid. Benzodiazepines are not usually administered alone because they can induce unpredictable behavior in both dogs and cats. In depressed dogs, however, lower doses have been associated with rapid and profound CNS depression.[39] If neurological status needs to be serially assessed, a fentanyl constant-rate infusion (1 to 4 µg/kg IV loading dose, followed by 2 to 6 µg/kg/h IV) may be used. By 30 min after discontinuation of the constant-rate infusion, the sedative effects have usually abated. If shock, severe blood loss, and clotting are not of concern, acepromazine (0.01 to 0.05 mg/kg, up to 1 mg maximum) can be combined with butorphanol or oxymorphone to induce neuroleptanalgesia. If there is no contraindication to its use, medetomidine (1 to 3 µg/kg/h) can also be used for additional sedation and analgesia. In critically ill cats, both oxymorphone and buprenorphine have proven to be useful and relatively safe analgesics.

Induction
Barbiturates may decrease myocardial contractility, depress baroreceptor reflexes, enhance respiratory depressants, and are poor analgesics.[40] When given intravenously for anesthesia, they can cause venodilation and usually decrease venous return, cardiac output, and blood pressure. In the presence of moderate blood loss, however, thiopental has been shown to increase renal blood flow.[41] The degree of myocardial depression induced is a function of dose and rate of injection, which together determine peak blood concentration following intravenous injection.[42] Barbiturates are highly bound to proteins, and their pharmacokinetics can be influenced by a patient's acid-base status, albumin concentration, and concurrent drug administration.[36] Trauma patients are often acidotic and hypoproteinemic, so the induction dose requirement may be greatly decreased and should be anticipated by clinicians. Because barbiturates can be arrhythmogenic, they should be used cautiously in patients with preexisting arrhythmias. In severely hypovolemic patients or when severe

cardiac disease and/or preexisting arrhythmias are present, other agents or induction combinations may prove safer. If barbiturates are used, simultaneous administration of adjuvant drugs such as diazepam (0.2 mg/kg) or lidocaine (2.0 mg/kg) will decrease the barbiturate requirement and the incidence of arrhythmias.[43] Propofol induces similar hemodynamic depressive effects to those of thiopental. Accordingly, propofol is not recommended as a primary induction agent in trauma patients unless cardiovascular stability has been restored.

Unlike injectable agents, inhalation agents are readily excreted via the lung should an adverse response (other than cardiac or respiratory arrest) result. Inhalation agents are equally hypotensive compared with barbiturates and are safer than some injectable induction agents only because homeostatic mechanisms have longer to compensate for the depressant effects of the anesthetic during induction. The disadvantage of inhalant anesthetic induction is that higher concentrations must be used for intubation than would be required for maintenance. Halothane, enflurane, isoflurane, and sevoflurane all induce dose-dependent cardiopulmonary depression. Isoflurane and sevoflurane are the least depressant to cardiac output at equipotent (e.g., 1.5 minimum alveolar concentration [MAC]) concentrations. If the traumatized or critically ill dog or cat is alert or likely to struggle, has a full stomach, or has severe pulmonary dysfunction, induction with an inhalation agent alone is not recommended. Intravenous inductions in traumatized or critically ill patients may be preferred so that the airway may be controlled rapidly. Mask inductions are strictly contraindicated in patients that are vomiting or have been recently fed.

When planning anesthesia for trauma patients, there is a tendency to choose an anesthetic that is an adrenergic stimulant or is associated with minimal hypotensive effects. However, there are limited data to suggest the superiority of stimulant drugs for maintenance of anesthesia during severe hypovolemic shock or in patients with severe CNS injury.[1] For example, in hypovolemic pigs, ketamine's overall cardiovascular effects are similar to those of thiopental.[44]

Ketamine is one of the few anesthetic agents with indirect cardiovascular stimulant properties. In healthy patients, it increases blood pressure, heart rate, and cardiac output secondary to increased sympathetic activity.[45] However, ketamine induces a direct myocardial depressant effect in patients whose sympathetic system is maximally stressed by hemorrhagic shock.[44] This is often the case in severely traumatized or critically ill patients. In patients with hypertrophic or restrictive cardiomyopathy (e.g., cats with idiopathic cardiomyopathy and normal left ventricular contractility), ketamine is contraindicated because it may induce tachycardia and decrease preload.[36] In patients with mitral regurgitation, ketamine is contraindicated because it may increase the regurgitant fraction through increased afterload. In contrast, in large-breed or giant-breed dogs suffering cardiogenic shock and myocardial failure as defined by poor contractility (dilated cardiomyopathy), ketamine may be a good choice for inducing anesthesia. When given alone, ketamine does not provide good muscle relaxation, and spontaneous movement is common. Because of their propensity to increase intracranial pressure, dis-

sociatives are not recommended for patients with severe closed head injury or open eye injury (e.g., corneal laceration).

Benzodiazepines enhance muscle relaxation and sedation when combined with ketamine, barbiturates, or opioids. Small intravenous doses of ketamine (5.5 mg/kg) combined with diazepam (0.27 mg/kg) titrated to effect can be administered to some high-risk patients if there are no contraindications to the use of ketamine. Lower intravenous doses of diazepam (0.2 mg/kg) and ketamine (2 to 3 mg/kg) may be given in rapid sequence to induce anesthesia in either traumatized or critically ill dogs or cats. If a patient is not sufficiently depressed after diazepam-ketamine administration, additional ketamine or delivery of low concentrations of sevoflurane or isoflurane by face mask will complete the induction. Isoflurane and sevoflurane are less arrhythmogenic and act faster than halothane and thus are the preferred agents in any trauma patient exhibiting arrhythmias or suspected of having myocardial injury.[46,47]

Induction of anesthesia with opioids usually necessitates concomitant use of an adjunctive tranquilizer-sedative or inhalation agent. Because most opioid agonists can depress respiration and slow heart rate, intravenous administration should be preceded by preoxygenation, and an antimuscarinic should be available for rapid administration in the event that severe bradycardia is induced. In dogs, intravenously administered meperidine and morphine can be associated with a dose-dependent histamine release, which can cause severe hypotension. Cautious, slow administration is acceptable if blood pressure is monitored. In contrast, intravenous administration of oxymorphone, hydromorphone, or fentanyl has not been associated with histamine release and has proven relatively safe in critically ill patients. A μ opioid receptor agonist may be combined with a benzodiazepine for induction in critically ill patients. Oxymorphone or hydromorphone is commonly given intravenously in small increments (0.05 mg/kg) along with diazepam (0.2 mg/kg) until intubation is possible. Alternatively, intravenous midazolam (0.2 mg/kg) and fentanyl (5 to 10 μg/kg) may be used. Because opioids and benzodiazepines given together do not cause myocardial depression or vasodilation, they make a good induction combination in patients in hypovolemic, cardiogenic, or septic shock, and in dehydrated patients. Nevertheless, because opioid inductions are slower than those achieved with barbiturates, nonbarbiturate hypnotics, or dissociatives, they are *not* recommended if rapid intubation of the airway is a necessity for patient survival.

For arrhythmic patients and patients with severe cardiac disease, etomidate is perhaps the safest drug for inducing anesthesia while maintaining cerebral and hemodynamic homeostasis. In doses of 0.5 to 2.0 mg/kg, etomidate produces minimal hemodynamic alterations and cardiac depression in animals.[48–50] Adrenal cortical suppression may follow anesthesia induction, but this suppression is of limited concern when etomidate is administered as a single bolus to a hemodynamically unstable patient.[1] Etomidate is a rational selection for anesthesia induction in patients in compensated or decompensated (congestive) heart failure, whether caused by acquired chronic atrioventricular valvular disease or myocardial failure (dilated cardiomyopathy). To minimize side effects such as retching and myoclonus, etomidate in-

jection should follow the administration of a benzodiazepine and/or an opioid. With repeated use of etomidate in cats, hemolysis caused by the propylene glycol vehicle has been observed.

Anesthetic Maintenance

Along with proper monitoring, the first priority during maintenance of anesthesia is adequate oxygenation, which may require controlled ventilation of the lungs for normal gas exchange. Blood oxygen saturation can be easily monitored by pulse oximetry using a buccal mucosa, vulva or prepuce, tongue, toe, or ear site. Ventilation is monitored by using capnometry or capnography. Preservation of hemodynamic stability, which is also essential, is achieved by providing adequate intravascular volume, which can be monitored by placing central venous and arterial pressure catheters, by using inotropic agents if necessary (Table 46.5), and by maintaining proper anesthetic dose and ventilator settings.[18]

Opioids such as oxymorphone (0.1 mg/kg IV), hydromorphone (0.1 to 0.2 mg/kg IV), or fentanyl (0.005 mg/kg IV) combined with ketamine can be administered in small aliquots along with diazepam or midazolam to maintain brief periods of anesthesia. Administration of ketamine should be repeated at an approximate dosage of 1 to 2 mg/kg IV every 20 to 30 min or as necessary to maintain anesthesia. Administration of diazepam or midazolam can also be repeated (0.2 mg/kg IV) every 30 to 60 min or as necessary to relax muscles adequately. Recovery can be prolonged with repeated injections of benzodiazepines. Anesthesia should be limited to less than 2 h. Long recoveries may be problematic in cats because they metabolize benzodiazepines more slowly than do dogs. Flumazenil may be administered to antagonize benzodiazepines once the effects of the ketamine have worn off. Similarly, tiletamine plus zolazepam (Telazol) may be useful when given in low doses for minimal restraint. These injectable regimens are often supplemented with low concentrations of sevoflurane or isoflurane if anesthesia must be extended. For airway examinations or diagnostic procedures that are not painful, propofol may be used as an infusion (0.04 mg/kg/h IV) in patients in stable hemodynamic condition. Since propofol is relatively noncumulative in dogs, recoveries are similar to those from an induction dose. Recoveries are longer in cats than in dogs when infusion lasts longer than 30 min (probably because of decreased glucuronide conjugation). Cats are comparatively intolerant of phenols, which are linked to oxidative injury of feline hemoglobin. The safety of consecutive-day propofol administration (a propofol bolus and 0.2 to 0.3 mg/kg/min IV for 30 min) has been evaluated in cats.[51] After 3 days, recovery times were prolonged, and there was a significant increase in Heinz bodies; by day 5, cats did not appear to feel well, were anorexic, and had diarrhea. Accordingly, propofol should not be administered continuously nor repeatedly at short intervals in cats.

When administered to hypovolemic animals, nitrous oxide does not appear to offer any hemodynamic advantage over halothane.[52] Because trauma patients frequently have pulmonary contusions with increased venous admixture, nitrous oxide is not routinely recommended, and it is contraindicated if blunt tho-racic trauma is suspected or either pneumothorax or hemothorax is present. Similarly, the use of nitrous oxide should be avoided in patients with a distended abdomen or diaphragmatic hernia that has caused respiratory compromise. Nitrous oxide is a known stimulant of cerebral metabolism and causes increased cerebral blood flow and intracranial pressure.[53] Therefore, it is not recommended for trauma patients with severe head or open eye injury.

Isoflurane and sevoflurane are equally hypotensive but do not sensitize the myocardium to the arrhythmogenic effects of catecholamines to the same extent as halothane.[54] Sevoflurane is less soluble than isoflurane and provides a potentially faster and smoother induction and recovery than isoflurane. When an inhalant anesthetic agent is used, myocardial depression and hypotension can be minimized by using as low a concentration as possible. In people, it is common to administer a muscle relaxant to help prevent patient movement when using low inhalant concentrations. Unfortunately, some human patients have recalled surgical events under these conditions.[1] Preanesthetic or intraoperative administration of an opioid or benzodiazepine tranquilizer with or without a muscle relaxant can help assure adequate CNS depression during low-dose inhalation anesthesia. In hypovolemic anesthetized patients, fentanyl, oxymorphone, butorphanol, or diazepam are preferred for reduction in inhalant requirement. Continuous-rate intravenous infusions of fentanyl, fentanyl-midazolam, ketamine, or lidocaine may be used to decrease the inhalant requirement. Acepromazine is not a good choice in these circumstances because it may increase vascular capacity, reducing blood pressure. In hypovolemic patients, compensatory vasoconstriction is often present preoperatively due to increased catecholamine activity. When anesthesia is induced, compensatory mechanisms may be blocked or fail, resulting in profound hypotension and reduced preload and cardiac output, especially if acepromazine has been administered. On the other hand, if adequate volume replacement has been achieved prior to acepromazine administration and inotropic support is available as needed, decreasing arterial resistance (α-adrenergic blockade) may improve perfusion (e.g., to kidneys and intestines).

Regional Anesthesia

Performing epidural or intrathecal blocks is contraindicated in patients that are septic or have a bleeding diathesis. Epidural or spinal blocks are contraindicated in hypovolemic patients because of the potential for profound sympathetic blockade induced by these techniques when using local anesthetics. Epidural administration of opioids (0.1 mg/kg of preservative-free morphine) or low doses of α2-adrenergic agonists (e.g., 1 to 3 µg/kg medetomidine) may prove to be effective alternatives to local anesthetics in providing regional analgesia with minimal sympathetic blockade.[55,56] In severely depressed patients, or in patients administered neuroleptanalgesia, superficial lacerations and wounds of the extremities can be managed with infiltration of local anesthetic or by performing peripheral nerve blocks. Local anesthetics may not be as effective when deposited in infected tissue because of ongoing inflammation and pH alterations.

Adjunctive regional therapy using a local anesthetic improves

analgesia while lowering the inhalation agent requirement. Intercostal nerve blocks (0.5 to 1.0 mL per site in dogs) with 2% lidocaine or 0.5% bupivacaine can be performed to control postoperative thoracotomy pain, as well as pain associated with fractured ribs. Interpleural administration of local anesthetics is also effective as an adjunct for thoracotomy and cranial abdominal pain associated with pancreatitis or with diaphragmatic hernia repair. With regional techniques, care should be taken to avoid exceeding the toxic local anesthetic dose for a given species. The maximum dose of bupivacaine is approximately 2 mg/kg in dogs and 1 mg/kg in cats. The maximum dose may be diluted, if necessary, for more complete coverage.

Intraoperative Support

Documentation of the medical history of each patient evaluated should include previous drug administration, because concomitant drug therapy must be considered when anesthetizing a patient. Adverse cardiovascular drug interactions are increasingly being reported. Examples of commonly administered cardiovascular drugs will be illustrated here, but a more complete discussion is available elsewhere.[57] Many cardiovascular drugs are metabolized in the liver through the several different isoforms of the cytochrome oxidase system. Drugs may either induce the isoforms, thereby decreasing the plasma concentrations of certain drugs, or inhibit the isoforms, thereby increasing the plasma concentrations of drugs. One of the first known interactions resulted from the decreased rate of hepatic metabolism of lidocaine when cimetidine was concurrently administered, leading to potential lidocaine toxicity. Cimetidine also increases plasma concentrations of quinidine, verapamil, and propranolol. Ranitidine inhibits fewer isoforms and is less likely to cause such interactions. Cimetidine also increases plasma concentrations of procainamide by inhibiting clearance by the kidneys. The likelihood of lidocaine toxicity increases when a β-adrenergic antagonist is administered with lidocaine. During the coadministration of agents that depress sinoatrial nodal function, lidocaine may cause sinoatrial arrest.[57] β-Adrenergic stimulants, such as dobutamine, decrease potassium concentrations and should be administered cautiously to patients receiving potassium-losing diuretics. Coadministration of captopril with hydralazine or procainamide may precipitate neutropenia because of impaired immune status. Nonsteroidal antiinflammatory drugs may attenuate the antihypertensive effects of β blockers.[57] Many companion animals are administered herbal formulations that may interact with anesthetic, cardiovascular, tricyclic antidepressant, and monoamine oxidase–inhibitor drugs. The aforementioned interactions are representative of the many potential adverse interactions possible.

Perioperative Fluid Support

Several choices of fluids are available for use in traumatized patients undergoing anesthesia and surgery. With hemorrhage, there is contraction of extracellular volume as the intravascular compartment deficit is replaced with interstitial fluid. Administration of a physiological salt solution such as lactated Ringer's restores this depletion and also expands intravascular volume to help maintain cardiac output. In general, patients should be administered 20 to 40 mL/kg intravenously prior to anesthetic induction. An exception is when patients are severely anemic or hypoproteinemic, have poor myocardial contractility, or have advanced valvular heart disease. Patients in hypovolemic shock can be given up to 1 blood volume (60 to 90 mL/kg) of isotonic electrolyte solution in the first hour. Many more animals have experienced problems after anesthetic drug injection, when compensatory mechanisms failed and underlying hypovolemia was unmasked, than have developed problems when crystalloid fluids were administered unnecessarily at these rates.[36] During anesthesia, hypotension caused by volume depletion often responds to replacement of one-quarter of the blood volume in 15 min as an intravenous fluid challenge. Replacement solutions should be isotonic, but not all isotonic solutions are optimal. Although 5% dextrose in water and lactated Ringer's with 2.5% dextrose are isotonic, once glucose is metabolized the remaining fluid is hypotonic and contains either all (5% dextrose) or half (2.5% dextrose) free water, which rapidly leaves the vascular compartment and may contribute to microvascular edema.[17] In general, even optimal isotonic physiological salt solutions remain in the intravascular space for only 30 to 60 min before redistributing throughout the entire extracellular space.[58]

Plasma expanders such as colloid solutions maintain intravascular volume for 2 to 5 h, but may have associated complications (Table 46.3). Dextran solutions can cause bleeding disorders and allergic reactions, and must be stored at stable temperatures (25°C) to prevent precipitate formation.[59,60] Protein solutions can impair pulmonary function if they extravasate into damaged lung.[61] Hydroxyethyl starch (6% solution in 0.9% sodium chloride) is a glucose polymer that has proven useful as a volume expander when the dose is limited to less than 20 mL/kg in dogs and 12 to 15 mL/kg in cats.[62] Because colloid solutions can be hypertonic, they must be administered slowly to avoid rapid fluid shifts and volume overload.[16]

When extreme blood loss occurs, red cells must eventually be infused. Fresh whole blood (less than 6 h old) is preferable. After 1 day of storage, only 12% of the original platelets remain in human whole blood. Similar reductions may occur in stored blood of domestic animals. Regardless of its age, whole blood is preferred over packed red blood cells.[1] Fresh-frozen plasma should be reserved for specific coagulation disorders.[63] In acute trauma, the large majority of clotting disorders are secondary to large-volume fluid replacement that causes dilutional thrombocytopenia. If possible, surgery and anesthesia should be delayed until the PCV can be increased to above 20% and platelet abnormalities addressed. When ongoing losses and replacement occur simultaneously, the best method of assessing adequate blood volume replacement is to assess urine output (1 to 2 $mL \cdot kg^{-1} \cdot h^{-1}$ is optimal), serial hematocrits, and total protein. Some questions remain with regard to optimum fluid management of severely traumatized patients in the perioperative period, including (a) the best methods of using non-erythrocyte-containing fluids in trauma resuscitation, (b) feasibility of systemic oxygen delivery (DO_2) and consumption-oriented resuscitation in high-risk surgical patients, and (c) the effects of fluid therapy on cerebral hemodynamics.[64]

With regard to nonblood fluid resuscitation, if membrane permeability is normal, fluids containing colloids (albumin, dextran, and hydroxyethyl starch) expand plasma volume (PV) rather than interstitial fluid volume (IFV) or intracellular volume (ICV). Each gram of intravascular colloid can draw and hold approximately 20 mL of water (e.g., 16 to 17 mL of water per gram of hydroxyethyl starch) in the vascular space. To estimate the effects of fluid infusion on PV, the following formula can be used: PV = volume infused $\times$ (PV/V_d), where V_d = distribution volume. In mature animals, total body water accounts for 60% of the total body weight. The ICV is 40%, the extracellular volume (ECV) is 20%, the IFV is 16%, and the PV is 4% of total body weight. If an acute blood loss of 500 mL is to be replaced using the preceding formula and 5% dextrose, which contains no sodium, the remaining water after glucose metabolism, distributes throughout the total body water. For a 70-kg dog where plasma volume of 500 mL is to be replaced, the volume of 5% dextrose infused is 500 mL = volume infused $\times$ (3 L/42 L), or approximately 7 L. In contrast, 500 mL of blood loss can be replaced with lactated Ringer's solution (LRS), for which the V_d is equal to the ECV or only 20% of the body weight (3 L/14 L) with just 2.3 L of LRS. If hyperosmotic fluids such as hypertonic saline (HS) are used, blood volume increases primarily by endogenous fluid PV expansion. These fluids come from the IFV initially and are transient in their duration of effect on PV. The immediate effect of 7.5% HS is to increase plasma volume by 2 to 4 mL for each milliliter infused. Thus, 500 mL of PV may be replaced with only 150 to 200 mL of HS. However, following equilibration, 7.5% saline increases PV by only approximately 1.0 mL for each milliliter infused. Small volumes of hyperosmotic solutions transiently restore hemodynamic function during shock, but because improved PV and flow decrease rather rapidly following resuscitation with hypertonic fluids, ongoing attention to maintenance of intravascular volume is necessary.[64] To prolong the initial improvement seen with hyperosmotic solutions beyond 30 to 60 min, continued infusion with a hypertonic solution, blood (if PCV is below 20%), or conventional fluids, or the addition of colloids, should be considered. One suggested protocol for volume resuscitation combines bolusing a synthetic colloid solution (1 to 5 mL/kg) with a replacement crystalloid solution (15 mL/kg). The dose of colloid solution should not exceed 20 mL/kg in dogs and 12 to 15 mL/kg in cats within the first 24 h. Rapid fluid loading is often associated with dilutional thrombocytopenia, hypoglycemia, and/or hypokalemia, and fluids should be supplemented to maintain serum levels within normal ranges.[5]

Studies in dogs have documented that HS may have a negative inotropic effect, whereas hyperosmotic dextrose produces a positive inotropic action.[65] Rapid (<30 s) administration of 2 to 4 mL of HS is also associated with an acute transient period of hypotension.[65] Infusion over a 3- to 4-min period will diminish this initial response. HS likely exerts its beneficial effect in treating hemorrhagic or endotoxic shock by rapidly increasing preload, whereas hyperosmotic dextrose solutions exert their beneficial effects by transiently increasing both preload and contractility.[65]

In high-risk traumatized patients who survive, it has been doc-

umented that average blood flow and DO_2 are greater than in those patients that did not survive.[66] Survival is correlated with a DO_2 that is at least 600 mL $O_2 \cdot min^{-1} \cdot m^{-2}$ (Table 46.1). When DO_2 is maintained at this level, complications are also reduced. To implement DO_2 goal-oriented fluid resuscitation, cardiac output, hemoglobin content, and oxygen-hemoglobin saturation must be continually monitored. In many traumatized patients, improvement of overall systemic DO_2 may be less critical than the immediate restoration of adequate oxygen delivery to selected vital organ systems.

With respect to the effects of fluid therapy on cerebral hemodynamics, it appears that, in some subsets of traumatized patients (severe head injury), initial fluid therapy with 7.5% saline in 6% dextran improves patient survival (32%) when compared with those treated with conventional LRS (16%).[64] Concerns over adverse neurological sequelae with hypertonic solutions have not proven valid, with the exception of hyperosmotic resuscitation in canine experimental models of uncontrolled hemorrhage where hyperosmotic solutions actually increase bleeding tendency.[67]

Commonly, trauma cases will present with nonrespiratory acidosis caused by shock and generalized stress. Ventilation of the lungs to induce a mild respiratory alkalosis will help normalize blood pH for the short term. With time, improved tissue perfusion and renal and hepatic function should resolve the problem. Treatment of metabolic acidosis with bicarbonate or other buffers should be carefully considered. More important measures in treating metabolic acidosis are fluid resuscitation, adequate ventilation, and rewarming. It is possible for patients with normal liver function to develop metabolic alkalosis 6 to 24 h after large-volume replacement with LRS.

Inotropic Support

Drugs commonly used to enhance myocardial contractility and increase cardiac output are listed in Tables 46.4 and 46.5.[18] Ephedrine has proven an effective alternative to dopamine or dobutamine when administered during inhalation anesthesia to enhance cardiac output.[68] A 0.1-mg/kg intravenous dose of ephedrine transiently increases arterial pressure, cardiac index, stroke volume, arterial oxygen content (CaO_2), and oxygen delivery in dogs anesthetized with isoflurane (1.5 MAC). A intravenous dose of 0.25 mg/kg causes a greater and prolonged increase in arterial pressure while actually decreasing heart rate.[68] This presumably results from a reflex bradycardia associated with an acute increase in arterial pressure. The higher dose of ephedrine also increases hemoglobin concentration and CaO_2, resulting in a 20% to 35% increase in oxygen delivery for at least 1 h. Increased hemoglobin concentration likely results from contraction of the spleen and increased circulating red blood cells. Splenic contraction results from either ephedrine's direct α-agonist effects or enhanced norepinephrine release. Because ephedrine can be administered as a convenient intravenous bolus with an onset of less than a minute, it is a useful for inotropic support of anesthetized patients. Dopamine and dobutamine have short half-lives and require constant infusion (Table 46.5). Close monitoring for development of arrhythmias is necessary, and, with dopamine, to avoid intense α receptor–mediated vasocon-

striction. In refractive cases, inotropic doses of dopamine and dobutamine may be supplemented with the coadministration of ephedrine to reduce vascular compliance and improve preload and stroke volume.[69]

In septic shock, vasopressin has been used for unresponsive hypotension. During anesthesia, vasopressin has also been used to support blood pressure. It is a peptide hormone stored in the posterior pituitary and synthesized in the supraoptic and periventricular nuclei of the hypothalamus. The release of vasopressin can result from an increased plasma osmolarity, decreased blood volume or pressure, nausea, pain, endotoxemia, cytokines, and other stimuli. Either low secretion or excessive secretion leading to depletion causes a deficiency in vasopressin. Vasopressin may be effective in situations where severe refractory hypotension no longer responds to adrenergic agonists. Intravenous infusion of 0.25 to 1.0 mU/kg/min increases blood pressure and urine flow in many patients. Vassopressor therapy has been reviewed elsewhere.[70]

Temperature, Oxygen, and Renal Support

Hypothermia should be treated vigorously because it is associated with reduced kidney function, poor platelet function, impaired glucose utilization, shivering and increased oxygen consumption by nonvital tissues, and decreased metabolism of anesthetics.[1] Bradyarrhythmias that do not respond to anticholinergics and spontaneous fibrillation may occur in hypothermic patients. Warming fluids and blood before administration helps maintain body temperature, reduces blood viscosity, and improves tissue blood flow. Warm-water blankets and heat lamps may help prevent further heat loss, but may not effectively rewarm patients because of inadequate body-surface-area contact and poor skin blood flow. Forced-air blankets will increase body temperature, but slowly. Maintenance of body temperature and rewarming may be easier when animals are anesthetized, because of high skin blood flow following inhibition of vasomotor control by anesthetics. Intense vasoconstriction after recovery from anesthesia may slow surface-rewarming efforts.

To prevent acute oliguric renal failure in severely traumatized patients, every effort should be made to maintain normal renal function. Unfortunately, there is no way to predict the degree of hypoperfusion that will result in renal failure in a given patient. Myoglobinemia must be treated by vigorous diuresis after muscle damage or electrocution. Once fluid volume and blood pressure have been normalized, furosemide (1 mg/kg) and dopamine (2 to 5 μg/kg/min) have been used together to increase renal blood flow and water and solute excretion, but renal therapy strategy remains somewhat controversial. Maintaining a functional renal system is essential for a favorable outcome following massive tissue damage.[1]

Questions regarding perioperative renal function and renal physiology in critically ill patients remain.[71] It is common for severely traumatized, critically ill patients to produce inadequate urine output. These patients are often given a "renal dose" of dopamine in an attempt to improve urine production and prevent oliguria. Dopaminergic receptors (DA_1 and DA_2) increase glomerular filtration rate (GFR) and inhibit proximal tubular re-

absorption of sodium. This combination of effects increases sodium excretion in euvolemic patients, but this action is diminished with prolonged infusion. Furthermore, in critically ill patients, dopamine's natriuretic action is not always apparent, because antinatriuretic factors (antidiuretic hormone and aldosterone) may be elevated to induce sodium conservation. With lower-than-normal levels of GFR, low doses of dopamine become less effective. This lack of response may be caused by exhaustion of the renal reserve system, where low renal blood flow may have already caused a shift of blood flow to the inner cortex in an adaptive response to loss of nephron renal function. Hence, dopamine's actions produce little additional urine. Despite these problems, dopamine can increase urine output in oliguric patients and in patients that are adequately hydrated. Several studies have also shown that dopamine improves urine output in patients that have not responded to fluid expansion or furosemide alone. By increasing renal flow, dopamine may improve delivery of furosemide to its site of action in the nephron.[71]

It is unclear whether dopamine is advantageous in the treatment of oliguric renal failure. Dopamine appears to be no better than saline in protecting renal function. In fact, dopamine-induced natriuresis may cause intravascular volume depletion, making the kidney even more susceptible to ongoing ischemic injury. Questions remain as to the clinical implication of increasing renal perfusion when there is decreased systemic blood volume. The routine administration of dopamine in severely traumatized patients should be carefully considered in the perioperative period.[71]

Urine flow, regardless of the quantity, indicates there is blood flow to the kidney, because, without it, urine production would cease. Numerous studies have shown, however, that there is no correlation between the urine volume produced and histological evidence of acute tubular necrosis, GFR, creatinine clearance, blood urea nitrogen levels, and creatinine levels in burn patients, trauma patients, or shock states.[71,72] The control of blood flow to the kidney, the fraction filtered, and the volume returned to the systemic circulation are all regulated by a variety of mechanisms in an attempt to preserve filtration function during compromised circulation. These compensatory mechanisms have limits, and excessive vasoconstriction may eventually decrease filtration. This shift from compensation to decompensation may be prevented or exacerbated by pharmacological manipulations. The cortical-to-medullary redistribution of renal blood flow is designed to protect vulnerable medullary oxygen supply and demand balance at the expense of urine formation. Reduced GFR may reduce medullary tubular workload and oxygen consumption. Oliguria may be viewed in some circumstances (e.g., anesthesia) as a sign of normal protective compensatory mechanisms at work. Thus, an acute reduction in urine output could be either the result of acute renal failure or the consequence of normal compensatory mechanisms induced to prevent oliguria.[71]

Traditionally, inadequate urine production or oliguria has been defined as a urine output of less than 0.5 mL · kg^{-1} · h^{-1}. Oliguria may, however, reflect a variety of factors independent of inadequate glomerular filtration. Thus, normal hourly urine output does not rule out impending renal failure any more than

lower-than-normal hourly urine output predicts renal failure. Reduced urine output during the anesthetic period in euvolemic patients is usually of little consequence to long-term renal function. It is more likely to be the result of compensatory renal mechanisms than a consequence of acute tubular damage or necrosis.[71]

Recovery

In postoperative patients, bowel and bladder function, pulmonary function, and skin integrity should be addressed. Patients that cannot turn themselves should be turned every 2 to 4 h. Bandages should be kept clean and dry; dried blood and soap should be removed. Eyes should be lubricated. Oxygen should be supplemented as needed. The environment should be quiet. Patients that are hospitalized for extended periods have special needs for appropriate social interaction.

References

1. Priano LL. Trauma. In: Barash PG, Cullen BF, Stoelting RK, eds. Clinical Anesthesia. Philadelphia: JB Lippincott, 1989:1365–1377.
2. Drobatz KJ, Powell S. Global approach to the trauma patient. In: Proceedings of the Fourth International Veterinary Emergency and Critical Care Symposium, San Antonio, TX, September 29 to October 2, 1994:32–36.
3. Purvis D, Kirby R. Systemic inflammatory response syndrome: Septic shock. Vet Clin North Am Small Anim Pract 24:1225–1247, 1994.
4. Shoemaker WC. Resuscitation of the trauma patient: Restoration of hemodynamic functions using clinical algorithms. Ann Emerg Med 15:1437–1444, 1986.
5. Hardie EM. Life-threatening bacterial infection. Compend Contin Educ 17:763–777, 1995.
6. Brady CA, Otto CM. Systemic inflammatory response syndrome, sepsis, and multiple organ dysfunction. Vet Clin North Am Small Anim Pract 31:1147–1162, 2001.
7. Stamp G. Metabolic responses to trauma. In: Zaslow I, ed. Trauma and Critical Care. Philadelphia: Lea and Febiger, 1984:25–63.
8. Gallagher TJ, Banner MJ, Barnes PA. Large volume crystalloid resuscitation does not increase extravascular lung water. Anesth Analg 64:323–326, 1985.
9. Smiley LE. The use of hetastarch for plasma expansion. Probl Vet Med 4:652–667, 1992.
10. Garzon AA, Cheng C, Lerner B, Lichtenstein S, Karlson KE. Hydroxyethyl starch (hes) and bleeding: An experimental investigation of its effects on hemostasis. J Trauma 7:757–766, 1967.
11. Karlson KE, Garson AA, Shafton GW, Chu CJ. Increased blood loss associated with administration of certain plasma expanders: Dextran 75, dextran 40, and hydroxyethyl starch. Surgery 62:670–678, 1967.
12. Layon J, Duncan D, Gallagher TJ, Banner MJ. Hypertonic saline as a resuscitation solution in hemorrhagic shock. Anesth Analg 66:154–158, 1987.
13. Bitterman H, Triolo J, Lefer AM. Use of hypertonic saline in the treatment of hemorrhagic shock. Circ Shock 21:271–283, 1987.
14. Lopes OU, Velasco IT, Guertzenstein PG, et al. Hypertonic sodium restores mean circulatory filling pressure in severely hypovolemic dogs. In: Proceedings Supplement 1, Hypertension, Inter-American Society, 1986:I195.
15. Muir WW III, Sally J. Small volume resuscitation with hypertonic saline solution in hypovolemic cats. Am J Vet Res 50:1883–1888, 1989.
16. Garvey MS. Fluid and electrolyte balance in critical patients. Vet Clin North Am Small Anim Pract 19:1021–1058, 1989.
17. Layon AJ, Kirby RR. Fluids and electrolytes in the critically ill. In: Civetta JM, Taylor RM, Kirby RR, eds. Critical Care. Philadelphia: JB Lippincott, 1988:451–474.
18. Schwinn DA. Cardiovascular pharmacology. In: IARS 1994 Review Course Lectures, Supplement to Anesthesia and Analgesia, Orlando, FL, March 5–9, 1994:154–164.
19. Cote E. Cardiogenic shock and cardiac arrest. Vet Clin North Am Small Anim Pract 31:1129–1145, 2001.
20. Mizock BA, Falk JL. Lactic acidosis in critical illness. Crit Care Med 20:80–93, 1992.
21. Bakker J, Coffernils M, Leon M, Gris P, Vincent JL. Blood lactate levels are superior to oxygen-derived variables in predicting outcome in septic shock. Chest 99:956–962, 1991.
22. Muir WW, Sams RA. Pharmacology and pharmacokinetics of antiarrhythmic drugs. In Fox PR, ed. Canine and Feline Cardiology. New York: Churchill Livingstone, 1988:309–334.
23. Plumb DC. Drug monographs. In: Veterinary Drug Handbook, 3rd ed. Ames: Iowa State University Press, 1999:1–652.
24. Hamlin RL. Current uses and hazards of ventricular antiarrhythmic therapy. In: Kirk RW, Bonagura JD, eds. Current Veterinary Therapy XI. Philadelphia: WB Saunders, 1992:694–699.
25. Bar-Joseph G, Abramson NS, Jansen-McWilliams L, et al. Clinical use of sodium bicarbonate during cardiopulmonary resuscitation: Is it used sensibly? Resuscitation 54:47–55, 2002.
26. Dybvik T, Strand T, Steen PA. Buffer therapy during out-of-hospital cardiopulmonary resuscitation. Resuscitation 29:89–95, 1995.
27. Ammari A, Schulze K. Uses and abuses of sodium bicarbonate in the neonatal intensive care unit. Curr Opin Pediatr 14:151–156, 2002.
28. Hartsfield SM. Sodium bicarbonate and bicarbonate precursors for treatment of metabolic acidosis. J Am Vet Med Assoc 179:914–916, 1981.
29. Debaveye YA, Berghe GH. Is there still a place for dopamine in the modern intensive care unit? Anesth Analg 98:461–468, 2004.
30. Flournoy WS, Wohl JS, Albrecht-Schmitt TJ, Schwartz DD. Pharmacologic identification of putative D_1 dopamine receptors in feline kidneys. J Vet Pharmacol Ther 2003;26:283–290.
31. Rockoff MA, Shapiro HM. Barbiturates following cardiac arrest: Possible benefit or Pandora's box? Anesthesiology 49:385–387, 1978.
32. Evans T. Anesthesia and monitoring for trauma and critical care patients. In: Slatter DH, ed. Textbook of Small Animal Surgery, 1985:2702–2711.
33. Hackner SG. Emergency management of traumatic pulmonary contusions. Compend Contin Educ 17:677–686, 1995.
34. Kolata RJ, Kraut NJ, Johnston DE. Patterns of trauma in urban dogs and cats: A study of 1,000 cases. J Am Vet Med Assoc 164:499–502, 1974.
35. Martyn J. Clinical pharmacology and drug therapy in the burned patient. Anesthesiology 65:67–75, 1986.
36. Bednarski RM. Anesthesia and pain control. Vet Clin North Am Small Anim Pract 19:1223–1238, 1989.
37. Salem MR, Wong AY, Mani M, Bennett EJ, Toyama T. Premedicant drugs and gastric juice pH and volume in pediatric patients. Anesthesiology 44:216–219, 1976.
38. Davidson CD, Pettifer GR, Henry JD. Plasma fentanyl concentrations and analgesic effects during full or partial exposure to trans-

dermal fentanyl patches in cats. J Am Vet Med Assoc 2004;224: 700–705.

39. Haskins SC, Farver TB, Patz BA. Cardiovascular changes in dogs given diazepam and diazepam-ketamine. Am J Vet Res 47:795–798, 1986.

40. Bernards C, Marvone B, Priano L. Effect of anesthetic induction agents on baroreceptor function [Abstract]. Anesthesiology 63:A31, 1985.

41. Priano LL. Renal hemodynamic alterations following administration of thiopental, diazepam, or ketamine in conscious hypovolemic dogs. Adv Shock Res 9:173–188, 1983.

42. Roberts JG. Intravenous anesthetic agents. In: Prys-Roberts C, ed. The Circulation in Anesthesia: Applied Physiology and Pharmacology. London: Blackwell Scientific, 1980:311–327.

43. Rawlings CA, Kolata RJ. Cardiopulmonary effects of thiopental/lidocaine combination during anesthetic induction in the dog. Am J Vet Res 44:144–149, 1983.

44. Weiskopf RB, Bogetz MS, Roizen MF, Reid IA. Cardiovascular and metabolic sequelae of inducing anesthesia with ketamine or thiopental in hypovolemic swine. Anesthesiology 60:214–219, 1984.

45. Haskins SC, Farver TB, Patz JD. Ketamine in dogs. Am J Vet Res 46:1855–1860, 1985.

46. Harvey RC, Short CE. The use of isoflurane for safe anesthesia in animals with traumatic myocarditis or other myocardial sensitivity [Abstract]. Canine Pract 10:18, 1983.

47. Hubble JAE, Muir WW, Bednarski RM, Bednarski LS. Change of inhalation anesthetic agents for management of ventricular premature depolarizations in anesthetized cats and dogs. J Am Vet Med Assoc 185:643–646, 1984.

48. Robertson S. Advantages of etomidate use as an anesthetic agent. Vet Clin North Am Small Anim Pract 22:277–280, 1992.

49. Gooding JM, Corssen G. Effect of etomidate on the cardiovascular system. Anesth Analg 56:717–719, 1977.

50. Pascoe PJ, Ilkiw JE, Haskins SC, Patz JD. Cardiopulmonary effects of etomidate in hypovolemic dogs. Am J Vet Res 53:2178–2182, 1992.

51. Andress JL, Day TK, Day DG. The effects of consecutive day propofol anesthesia on feline red blood cells. Vet Surg 24:277–282, 1995.

52. Weiskopf RB, Bogetz MS. Cardiovascular action of nitrous oxide and halothane in hypovolemic swine. Anesthesiology 63:509–516, 1985.

53. Sakabe T, Kuramoto T, Inone S, Takeshita H. Cerebral effects of nitrous oxide in the dog. Anesthesiology 48:195–200, 1978.

54. Joas TA, Stevens WC. Comparison of the arrhythmic doses of epinephrine during Forane, halothane, and fluroxene anesthesia in dogs. Anesthesiology 35:48–53, 1971.

55. Tung AS, Yaksh TL. The antinociceptive effects of epidural opiates in the cat: Studies on the pharmacology and the effects of lipophilicity in spinal analgesia. Pain 12:343–356, 1982.

56. Valverde A, Dyson DH, McDonell WN. Epidural morphine reduces halothane MAC in the dog. Can J Anaesth 36:629–632, 1989.

57. Opie LH. Adverse cardiovascular drug interactions. Curr Probl Cardiol 25:621–676, 2000.

58. Cervera LA, Moss G. Crystalloid distribution following hemorrhage and hemodilution. J Trauma 14:506–520, 1974.

59. Giesecke AH Jr. Anesthesia for trauma surgery. In: Miller RD, ed. Anesthesia. New York: Churchill Livingstone, 1981:1247–1264.

60. Giesecke AH, Jenkins MT. Fluid therapy. Clin Anesth 11:57–69, 1976.

61. Holcraft JW, Trunkey DD, Carpenter MA. Sepsis in the baboon: Factors affecting resuscitation and pulmonary edema in animals resuscitated with Ringer's lactate versus Plasmanate. J Trauma 17: 600–610, 1977.

62. Munoz E, Raciti A, Dove DB, et al. Effect of hydroxyethyl starch versus albumin on hemodynamic and respiratory function in patients in shock. Crit Care Med 8:255–263, 1980.

63. Baldini M, Costea N, Dameshek W. The viability of stored human platelets. Blood 16:1669–1692, 1960.

64. Prough DS. Controversies in perioperative fluid management. In: IARS 1994 Review Course Lectures, Supplement to Anesthesia and Analgesia, Orlando, FL, March 5–9, 1994:16–24.

65. Constable PD, Muir WW, Binkley PF. Hypertonic saline is a negative inotropic agent in normovolemic dogs. Am J Physiol 267: H667–H677, 1994.

66. Kovacic J. Management of life-threatening trauma. Vet Clin North Am Small Anim Pract 24:1057–1094, 1994.

67. Gross D, Landau EH, Klin B, Krausz MM. Treatment of uncontrolled hemorrhagic shock with hypertonic saline solution. Surg Gynecol Obstet 170:106–112, 1990.

68. Wagner AE, Dunlop CI, Chapman PL. Effects of ephedrine on cardiovascular function and oxygen delivery in isoflurane-anesthetized dogs. Am J Vet Res 54:1917–1922, 1993.

69. Raffe M. Anesthetic management of the unstable trauma patient. In: Proceedings of the Fourth International Veterinary Emergency and Critical Care Symposium, San Antonio, TX, 1994:281–287.

70. Palmer J. When fluids are not enough: Inopressor therapy. In: Proceedings of the Eighth International Veterinary Emergency and Critical Care Symposium, San Antonio, TX, 2002:669–673.

71. Aronson S. Controversies: Should anesthesiologists worry about the kidney? In: IARS 1995 Review Course Lectures, Supplement to Analgesia and Anesthesia, Honolulu, HI, March 10–14, 1995:68–73.

72. Kellen M, Aronson S, Roizen-Thisted R. Predictive and diagnostic tests of acute renal failure: A review. Anesth Analg 78:134–142, 1994.