Monitoring the Critically Ill Animal Using The Rule of 20

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Last full review/revision Nov 2020 | Content last modified Nov 2020

Anticipation, not reaction, is the key to successful management of critically ill animals. Animals must be effectively treated and actively monitored to detect or prevent organ compromise *before* organ failure occurs. This often requires aggressive and repeated fluid resuscitation, close patient monitoring, and support throughout the course of definitive therapy.
Tissue hypoxia and organ compromise or failure can be a direct result of the primary disease or can be secondary to a complication of the primary disease or even due to therapy. Organs frequently affected include the heart and blood vessels, kidneys, lungs, GI tract, and liver. When the disease process is multisystemic, problems such as malnutrition and coagulopathies must be anticipated. Optimal care requires a thorough and methodical approach to diagnostic procedures, monitoring, specific therapeutics, and supportive care.
The Rule of 20 is a list of 20 critical parameters that should be **evaluated at least daily** in all critically ill animals; many of these should be assessed several times per day. Using the Rule of 20 ensures that the clinical status and therapeutic strategy for each animal is comprehensive and meets the animal's ongoing needs. Like any monitoring tool, the Rule of 20 is not a static concept but a dynamic one; the specifics of each parameter will change with advancements in laboratory testing, understanding of disease pathology, and current concepts in critical care. In addition, the systems examined in the Rule of 20 are not singularities; each is impacted by and can impact other parameters, so each parameter should be assessed while considering the patient as a whole.
Some more recent applications of the Rule of 20 include monitoring of blood lactate levels, adrenal function, body fluid glucose levels, advanced coagulation testing, and ultrasonographic assessment techniques. Diagnostic tools currently being investigated and may apply to the Rule of 20 in the future include biomarkers such as cardiac troponins, C-reactive protein, and more. Various **scoring systems** help to monitor critically ill patients, such as the Animal Trauma Triage score, Modified Glasgow Coma Scale (MGCS), and the Glasgow Composite Measure Pain Scale.

Fluid Balance

The goal of fluid therapy is to provide adequate perfusion (intravascular volume) and hydration (interstitial volume) without overloading the interstitial space. Peripheral perfusion can be assessed by physical parameters such as heart rate, mucous membrane color, pulse quality, and mentation, as well as by measured parameters such as blood pressure, central venous pressure, urine output, and blood lactate measurements. Hydration can be assessed by physical parameters such as mucous membrane and corneal moistness and skin turgor, and by measured values such as body weight and PCV/total solids.
Animals with systemic inflammatory response syndrome (SIRS) diseases may require more fluid than expected because of peripheral vasodilation and loss of endothelial integrity, making the administration of colloids with crystalloid solutions optimal. When treating fluid deficits , intravascular deficits should be addressed rapidly first; interstitial deficits should be treated using standard calculations to correct dehydration and monitor ongoing losses. Like any drug, choice and amount of fluid may have detrimental effects if administered inappropriately, so fluid prescription must be appropriate for the patient's needs.

Oncotic Pull/Albumin

Albumin provides the major intravascular oncotic pull in the normal vasculature. In conditions in which there has been massive blood loss or leakage of plasma proteins due to an exudative process, albumin is lost from the intravascular space. This loss of intravascular oncotic pressure combined with increased capillary permeability associated with many systemic inflammatory response syndrome (SIRS) diseases requires treatment using synthetic colloids that have a higher molecular weight than that of albumin. Colloid oncotic pull (COP) can be measured with colloid osmometry but is not commonly available in veterinary practice. Formulas are available to calculate COP based on plasma protein levels, but they are not reliable predictors of measured COP. Normal COP in dogs is ~20 mmHg. In patients with moderate to severe decreases in COP or in total proteins, natural and synthetic colloids should be administered. Examples of natural colloids include plasma products, concentrated or lyophilized human or canine albumin, and stroma-free hemoglobin. Examples of synthetic colloids include dextrans and hydroxyethyl starches.
Traditional understanding of transcapillary fluid shifts was described in Starling's model, focusing on intravascular and interstitial COP and hydrostatic pressures. The discovery of the endothelial glycocalyx has led to a revision of Starling's principles of transcapillary fluid shifts. In the endothelial glycocalyx model, the vascular system does not absorb fluid from the interstitial space; rather, fluid is returned to the vasculature through the lymphatic system. As our understanding of endothelial cell function and the impact of the endothelial glycocalyx advances, novel therapeutic options or shifts in best practices in oncotic therapy will likely follow.
Part of the oncotic activity normally provided by albumin can be provided by synthetic colloids, but only albumin can perform other functions such as drug, cation, and hormone transport, free radical scavenging, and acid/base balance. Albumin can be lost with a variety of diseases (GI, renal, or SIRS); it is also a negative acute-phase protein, so production of albumin drops during critical illness. Interstitial albumin stores may be drawn upon to replace serum albumin; however, this "autotransfusion" effect is now thought to be quite limited. Albumin levels <2 g/dL have been associated with a poor prognosis; however, it is not known whether restoring albumin levels improves survival. Plasma and albumin transfusions are often administered to supplement the albumin to reach a target of 2 g/dL, but large volumes of plasma are required. Lyophilized canine serum albumin is now available in 100-g vials, making replacement of albumin more cost-effective and with lower total volumes than plasma transfusions. Human albumin products have been used in critically ill dogs but may result in severe organ dysfunction when given to healthy dogs. Interstitial albumin stores must be replenished as well as intravascular levels, so multiple units of plasma or albumin may be necessary to increase serum albumin levels.

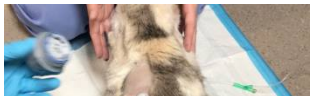
Glucose

The **goal** is to maintain **glucose between 80 and 120 mg/dL (approximately 4.4–6.6 mmol/L)**. Severe hypoglycemia can cause hypotension or neurologic dysfunction ranging from weakness to stupor or seizures. Conditions that can result in hypoglycemia include sepsis, inadequate nutrition (in young or critically ill), glycogen storage diseases, heat stroke, small size, severe renal or hepatic disease including portosystemic vascular anomalies, certain types of neoplasia (insulinoma), hypoadrenocorticism , toxicities (xylitol , some medications), and iatrogenic insulin administration.
Dextrose supplementation is warranted in any animal that is hypoglycemic. Solutions with a dextrose concentration >5% are best administered through a central line. Animals with clinical hypoglycemia despite administration of solutions with high dextrose concentrations should be assessed for insulinoma and may benefit from glucagon infusions. A difference of >20 mg/dL (1.1 mmol/L) in blood glucose values and abdominal fluid glucose values has high sensitivity and specificity for septic peritonitis in animals who have not recently had surgery.

Continuous glucose monitor, Boston Terrier

COURTESY OF DR. ANDREW LINKLATER.

Continuous glucose monitor, cat



COURTESY OF DR. ANDREW LINKLATER.

Insulin treatment of hyperglycemia in diabetic animals is important to offset diabetic ketoacidosis or hyperosmolar complications. Constant-rate infusion (CRI) of regular insulin can result in the slow and controlled lowering of blood glucose (to help avoid rapid changes of blood osmolality); close monitoring of blood glucose levels should be performed. Aggressive insulin therapy (short- and long-acting insulin administered together for patients with diabetic ketoacidosis) resulted in faster resolution of pH and ketosis in one study.
Tight control of increased blood glucose has improved neurologic outcome after head trauma in critical human surgical patients but not in human medical patients; in addition, increased incidences of hypoglycemia may occur with tight glucose control. Acutely traumatized animals are prone to insulin resistance because of large amounts of circulating cortisol and epinephrine and may develop hyperglycemia severe enough to require treatment with insulin. The benefit of tight blood glucose control has not been clearly demonstrated in veterinary medicine.
Patients on aggressive insulin therapy should be monitored closely. Continuous glucose monitors (CGMs) that have been developed for human diabetic patients are now more practical and affordable for veterinary patients and have proven useful in monitoring patients with glucose disorders. They have specific advantages over traditional (ear prick) glucose curves: CGMs provide more information, minimize patient discomfort, eliminate concern of iatrogenic anemia, are well tolerated, and may detect periods of low or high blood sugar that were not previously recognized.

Electrolytes

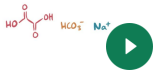
Hypokalemia can be a contributing factor in weakness and ileus of critically ill animals. These animals commonly have reduced oral intake and/or increased GI and urinary losses of potassium that require potassium supplementation in the IV fluids. **Hyperkalemia** can be a life-threatening complication of urinary tract rupture or obstruction, renal failure, reperfusion injury, or massive cellular death. Hyperkalemia commonly results in bradyarrhythmias and can be temporarily treated with calcium gluconate and insulin, concurrently with dextrose and/or sodium bicarbonate. The underlying pathology that led to hyperkalemia must be addressed.
Other **important electrolytes to monitor include sodium, ionized calcium, phosphorus, magnesium, and chloride**; all can be increased or decreased in critically ill animals and may affect other body systems (such as neurologic, serum osmolality, the cardiovascular system, RBCs, and acid-base balance).

Acid-Base Balance

Acid-base assessment in critically ill patients is often complex. There are several ways it can be assessed: the traditional (or Henderson-Hasselbach) approach, the strong ion approach, or the semiquantitative approach.
The traditional approach involves assessment of the pH, determination of the metabolic and respiratory components and determination if the process is compensated or mixed, and assessment of anion gap (AG).
The most common cause of **metabolic acidosis** is lactic acidosis caused by poor perfusion leading to anaerobic metabolism. Lactate production results in an equimolar production of hydrogen ions and subsequent alterations in blood gas values (metabolic acidosis). Lactate measurements can be easily performed with handheld or benchtop analyzers. Resolution of hyperlactatemia with adequate fluid resuscitation is often associated with improved survival. Treatment involves maximizing blood flow and tissue oxygen delivery. Rarely is the administration of sodium bicarbonate ($NaHCO_3$) warranted for perfusion-related acidosis. Once perfusion and hydration are corrected, the acid-base status is reassessed.

Overview of Plasma Anion Gap

VIDEO



If severe metabolic acidosis (as occurs with ketosis or uremia) persists and HCO_3 remains below ~12 mEq/L after perfusion has been restored, slow administration of fluids with $NaHCO_3$ supplementation is warranted, restoring serum values to >15 mEq/L. The dosage of $NaHCO_3$ is calculated as follows:

mEq $NaHCO_3$ = 0.3 × (target $NaHCO_3$ [eg, 15] - patient $NaHCO_3$) × body weight in kg

Serum bicarbonate levels are carefully monitored to meet patient requirements. Other disorders include metabolic alkalosis, and respiratory acidosis, and alkalosis that can be evaluated on a blood gas.
The AG can be calculated when blood electrolytes are measured:

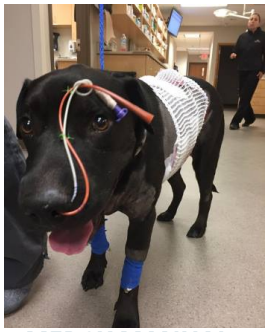
AG = [Na] + [K] – [HCO_3] – [Cl]

The normal AG is 12–24 mEq/L. An increased AG indicates there is some unmeasured anion present in the blood, which may include ketones, lactate, uremic compounds, or toxins (eg, salicylates, ethylene glycol, ethanol, methanol, indomethacin, isoniazid, paraldehyde, propylene glycol).
In the semiquantitative acid-base analysis, which is an expansion of the strong ion difference evaluation, there are several factors examined, each of which have an impact on acid-base status: Na/free water, chloride, phosphate, albumin, lactate, and unmeasured anion effects. Each of these factors has a quantifiable effect on acid-base status evaluation of a patient and need to be considered individually to determine the magnitude of their effects on base excess. This particular assessment may tease out which components are contributing to acid-base balance but is more cumbersome to calculate on the clinic floor.

Oxygenation and Ventilation

Pulmonary function can be compromised in critical illness for a variety of reasons (pneumonia, acute respiratory distress syndrome, thromboembolism, congestive heart failure, etc). Early diagnostic tests (eg, imaging, blood work, tracheal washes, urine blastomycosis antigen testing, etc) and targeted therapeutics will help limit extension of pulmonary disease.

Nasogastric tube and nasal oxygen line, dog



Preoperative brachycephalic dog

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Aspiration pneumonia is a particular challenge, because it is most commonly a "second hit" disease (secondary to another systemic illness); veterinarians must be diligent to prevent it. Therapeutics (such as antiemetics, prokinetics, or use of nasogastric tubes) to prevent aspiration pneumonia should be used whenever appropriate.

Arterial blood gas measurement is the "gold standard" method to detect hypoxemia or hypercarbia. **Pulse oximetry** (SpO_2) is a noninvasive way to determine the oxygen saturation of hemoglobin and is widely available. Supplemental oxygen and/or therapeutic ventilation may be indicated with SpO_2 values <96%. **Hypercarbia** can be detected using end-tidal CO_2 through an endotracheal tube or nasal catheter and has been shown to correlate with arterial CO_2 levels in animals. Serial monitoring is recommended in the initial management of animals with respiratory compromise to determine the adequacy of oxygen supplementation and the need for mechanical ventilation.

If hypoxemia is unresponsive to oxygen supplementation (PaO_2 <60 mm Hg or SpO_2 <90%) or hypercarbia (hypoventilation) is present ($PaCO_2$ >60 mm Hg), or if respiratory effort (work of breathing) is substantially increased, manual or mechanical ventilation is necessary. Ventilation should not be delayed until respiratory failure or arrest. Prognosis for animals that require ventilation is variable; those with hypoxemia from congestive heart failure or hypoventilation from metabolic disease (eg, hypokalemia), cervical spinal disease, or anesthesia have a better prognosis than those that require ventilation for hypoxemia due to primary pulmonary disease. Invasive (arterial blood gas) and noninvasive ($ETCO_2$/SpO_2) monitoring should be performed during mechanical ventilation to determine need for adjustment of the ventilator settings.

Neurologic Status

A decline in an animal's level of consciousness warrants investigation to exclude metabolic causes, such as hypoglycemia, hyperglycemia, hepatic encephalopathy, acidosis, electrolyte or osmotic derangements, or sudden development of hypertension, hypotension, or shock.

An increase in intracranial pressure can result from intracranial hemorrhage, fluid overload (cerebral edema), primary brain/meningeal disease, and/or ischemia. The drugs the animal is receiving should be carefully evaluated for adverse effects that can lead to altered mentation or level of consciousness.

Cerebral edema may be responsive to medical management with furosemide and mannitol therapy. Steroids may be indicated in certain inflammatory diseases (eg, meningitis, neoplasia), and antibiotics in infectious disease (eg, toxoplasmosis). Craniotomy may be needed in animals not responsive to medical management.

Cerebral perfusion pressure = mean arterial pressure – intracranial pressure

Elevating the head 15° and avoiding procedures that may increase venous pressure and subsequently intracranial pressure is essential. Maintaining normal oxygenation/ventilation, blood pressure, glucose level, and serum osmolality is essential for animals with brain disease. Neurologic status may be evaluated using a scoring system assessed on a regular basis, such as the MGCS, which can provide an objective assessment and help identify when intervention is necessary; lower MGCS scores are associated with a poorer prognosis.

Spinal injury that is severe enough to cause paralysis (particularly with lack of deep pain sensation) and inability to ventilate and ambulate, and that has not responded to medical management (such as anti-inflammatory medications) warrants immediate advanced imaging and surgical intervention. Loss of deep pain is associated with a poor return to function. Serial neurologic examinations should be performed in any animal with neurologic disease.

Blood Pressure

Blood pressure should be monitored via direct or indirect methods. The minimum goal is to maintain organ perfusion by maintaining a mean arterial blood pressure >60 mmHg (systolic >90 mmHg); however, a normal blood pressure is considered an ideal goal. In hypotensive animals with adequate cardiac function, treatment consists of intravascular volume infusion , oxygen administration, and pain control.

Hypotension unresponsive to intravascular volume replacement can be due to one or more of a variety of causes: hypoglycemia, acidosis, alkalosis, electrolyte disorders (eg, potassium, calcium, magnesium), brain-stem pathology, cardiac arrhythmias, metabolic toxins (eg, hepatic, renal), ongoing fluid loss, relative hypoadrenocorticism (eg, cortisol deficiency), heart or pericardial disease, excessive vasodilation, and excessive vasoconstriction. Patient assessment for these causes should be performed and immediately addressed. (Also see Assessment of Resuscitation Efforts in Animals .)

The need for cardiovascular support with positive inotropes or vasopressors is considered when the above listed causes are ruled out. An experienced ultrasonographer may be able to assess ventricular contractility and/or capacitance vessel size to provide an estimate of preload. Once intravascular volume (central venous pressure >8 cm H_2O (although this is measured less commonly) and cardiac function are assessed as adequate, vasopressor therapy with CRI of dopamine (5–15 mcg/kg/minute), norepinephrine (0.05–2 mcg/kg/minute), epinephrine, or other pressor agents is instituted. A CRI begins at the lower end of the dosage range and increased incrementally until blood pressure goals are reached. Objective measurements of global perfusion may also include lactate monitoring; animals with a significantly increased lactate concentration may have a poorer prognosis. Studies have demonstrated that serial lactate monitoring is more useful than a single measurement. Central venous oxygen measurement is another objective measurement of global perfusion; normal values are 70–80 mm Hg, whereas lower values may indicate increased oxygen extraction.

Hypertension is not a common condition in veterinary medicine, but it can lead to catastrophic problems. The American College of Veterinary Internal Medicine classifies **risk of target-organ damage from hypertension** into four categories based on systolic blood pressure:

- I: <150 mmHg = minimal risk
- II: 150–159 mmHg = mild risk
- III: 160–179 mmHg = moderate risk
- IV: >180 mmHg = severe risk

Hypertension can lead to retinal detachment or to neurologic derangements from intracranial hemorrhage and can exacerbate proteinuria in animals with chronic kidney disease. Moderate to severe hypertension can be treated with oral antihypertensive agents such as angiotensin-converting enzyme inhibitors (eg, benazepril) in nonazotemic animals, calcium channel blockers (eg, amlodipine), direct arterial dilators (eg, hydralazine), or systemic injectable antihypertensive agents such as nitroprusside (0.5–10 mcg/kg/minute), titrated to effect. Blood pressure must be monitored continuously to assess response to therapy. Chronic hypertension that is rapidly decreased may result in decreased renal perfusion; the goal should be to decrease blood pressure by no more than 25% in the acute setting.

Heart Rate, Rhythm, and Contractility

The **electrical** and **mechanical** systems of the heart should be evaluated separately. Electrocardiogram assessment is necessary to identify arrhythmias and to institute specific antiarrhythmic therapy.

Arrhythmias can occur for a variety of reasons, such as SIRS diseases, splenic disease, organ torsion (eg, gastric dilatation-volvulus), and electrolyte abnormalities (eg, hyperkalemia); the underlying condition must be identified and treated concurrently. Oxygen, fluids, and analgesia are considered first-line agents to treat underlying conditions and rule out common causes of sinus tachycardia.

An arrhythmia requires treatment when it results in decreased cardiac output and clinical signs of shock. Some ventricular rhythms (such as ventricular premature contractions and accelerated idioventricular arrhythmias) may not necessarily require immediate therapy if cardiac output is not significantly reduced.

Indications for treatment of a ventricular rhythm include:

- tachycardia (rates >160 bpm)
- clinical signs of poor perfusion (low blood pressure, poor pulse quality, etc)
- multiform arrhythmias
- R-on-T phenomenon or Torsade des pointes

Other tachyarrhythmias may respond to class I, II, III, or IV antiarrhythmics; bradyarrhythmias can be challenging to treat medically. If a bradyarrhythmia does not respond to beta-agonists or parasympatholytics (eg, atropine), pacemaker placement may be necessary.

An echocardiogram can be performed to evaluate cardiac contractility in SIRS diseases and to detect underlying cardiac diseases such as dilated cardiomyopathy. If cardiac contractility is decreased, dobutamine at 5–10 mcg/kg/minute (dogs) or 2.5–5 mcg/kg/minute (cats) is given to provide inotropic support if there is evidence of poor cardiac output. Recent studies have demonstrated that dogs with mitral valve disease and dilated cardiomyopathy have a poorer prognosis if their cardiac troponins (cTnI) and/or natriuretic peptide (NT-pro-BNP) is increased. However, these tests are not available in all hospitals and do not necessarily direct therapy, or diagnose or differentiate disease processes.

Temperature

Body temperature is considered part of the initial database and should be measured regularly in every critically ill animal. A variety of diseases can result in increased or decreased body temperature. Temperature is measured most accurately and consistently with a rectal thermometer. Axillary or auricular temperatures are less accurate but may be considered to monitor trends in patients that do not tolerate rectal monitoring.

Increased temperatures can be seen with environmental exposure (eg, heat stroke), increased activity (eg, exercise, excitement), and infectious, inflammatory, or neoplastic diseases. Severe increases of temperature (>105.5° [40.8°C]), particularly when prolonged, can lead to severe metabolic disease such as hemorrhagic diathesis, disseminated intravascular coagulation, and SIRS diseases, which may lead to multiorgan dysfunction. Effective means of cooling animals include fluid therapy , using wet towels with fans, and placing alcohol in paw pads. Animals should not be immersed in cold water, because this causes peripheral vasoconstriction and decreases core heat dissipation. Fever of unknown origin warrants a systemic evaluation.

Hypothermia is most commonly associated with anesthesia in small animals; however, severe systemic disease (particularly in cats) and environmental exposure may be contributing factors. Mild hypothermia can be a common sequela of severe cardiovascular disease and is a prognostic marker in cats with hindlimb thromboembolism. Temperature is a vital parameter to monitor and treat in cats with clinical signs of shock, and active warming is an essential component of therapy. Therapeutic hypothermia may have some neuro-sparing effects in animals with traumatic brain injury or in postresuscitation (CPR) care; however, further investigation is needed. In animals with induced hypothermia, blood flow to most organs can be significantly decreased, and coagulation may be affected.

Altered body temperature is part of the definition of SIRS-type diseases; other parameters include an increased or decreased heart rate, increased or decreased WBC count, and an increased respiratory rate.

Coagulation

Disseminated intravascular coagulation (DIC) can develop in any animal that has undergone a period of relative vascular stasis as occurs during shock, severe tissue or capillary damage such as that which occurs with trauma, exposure of capillary endothelial cells to circulating inflammatory mediators as occurs during sepsis or SIRS, or moderate to severe alterations in body temperature. In the early stages of DIC, there may be few or no clinical signs. However, as DIC progresses, its effects are obvious and catastrophic. The goal is to detect DIC in the early stages and to slow or prevent its progression.

Early DIC is characterized by a hypercoagulable stage in which serum antithrombin (AT) levels are decreased and the coagulation cascade is activated by any of the precipitating causes. Activation of the coagulation cascade throughout the body rapidly depletes the clotting factors and the blood platelet count as platelets are incorporated into the clots. At this stage, the prothrombin time and partial thromboplastin time may be decreased, but this is a challenging stage to identify and diagnose. However, this rapidly progresses to a hypocoagulable stage as the coagulation factors are consumed. In this late stage, the prothrombin time and partial thromboplastin time (or activated clotting time) are prolonged, and fibrinogen degradation products are increased. DIC can be very challenging to diagnose early in the course of disease: thrombocytopenia is common, but D-dimers may not be commonly available. Use of more recently available viscoelasting testing (thromboelastography) may help identify patients at risk for thromboembolism or those in early stages of DIC.

Treatment of DIC focuses on treating the underlying disease and removing the stimulus for continued activation of the coagulation cascade. In the early hypercoagulable stages, treatment focuses on maximizing the function of AT, which is the most abundant natural inhibitor of the serine proteases of the coagulation cascade. When AT levels are adequate, heparin can be administered SC (50–100 U/kg, three times a day). If AT levels are <60% of normal, then plasma transfusions should also be given to increase the level to ≥80%. In animals with diseases known to predispose to DIC, coagulation parameters and platelet counts should be monitored. Thromboelastography provides another means of global assessment of the clotting cascade and may be a useful tool with suspected hypo- or hypercoagulable states; hypercoagulable states are challenging to diagnose, and thromboelastography is one of the few methods that may provide an accurate assessment.

Thrombosis occurs without DIC when there are alterations in Virchow's triad: endothelial injury, blood stasis, and hypercoagulable states. Abnormalities in one or more of these components may be seen with:

- vascular anomalies
- atrial enlargement (cats)
- severe systemic illness (SIRS, immune-mediated hemolytic anemia)
- trauma
- neoplasia
- renal disease
- protein-losing renal and GI disease
- hyperadrenocorticism
- as a primary disease in Greyhounds

The most common severe manifestations of hypercoagulability are aortic and pulmonary thromboemboli. Pulmonary thromboemboli should be suspected when significant hypoxemia is present with minimal lung changes on thoracic radiographs. Anticoagulation therapy and oxygen support should be implemented, and oxygenation and ventilation monitored. Arterial thromboembolism can occur in cats with underlying heart disease. Antithrombotics are warranted in these cases; options include aspirin and/or clopidogrel, heparin (low molecular weight or unfractionated), rivaroxaban, or warfarin. Most of these drugs require close monitoring of clotting times to achieve therapeutic goals. This disease can be painful, and opioid medications are often warranted, as well as monitoring for reperfusion injury.

Disease states that result in relative hypocoagulability may include anticoagulant rodenticide ingestion , fulminant liver failure, severe thombocytopenia, snake bites , dilutional hypocoagulability from fluid and colloid administration, and congenital defects in the coagulation cascade such as von Willebrand disease, hemophilia A or B platelet defects (Boxers), or hyperfibrinolysis (Greyhounds). Therapy should be specific to the inciting cause; plasma products are often necessary to correct life-threatening coagulopathies.

Our understanding of coagulation has now expanded to identify a new cause of hypocoagulation: hyperfibrinolysis (rapid clot breakdown). There are certain breeds (Greyhounds) and certain disease states (trauma) that can result in excessive bleeding after clot formation has occurred. This syndrome can be identified or diagnosed with viscoelasting testing and is treated with either tranexamic acid or epsilon-aminocaproic acid.

Red Blood Cell and Hemoglobin Concentration

Because Hgb carries most of the oxygen in the blood, maintaining adequate Hgb levels is essential to maintaining adequate oxygen delivery. When anemia is associated with clinical signs of tachycardia, increased respiratory rate, altered mentation, severe lethargy/weakness, and hypotension, then packed RBCs, whole blood, or hemoglobin-based oxygen carriers (HBOCs) should be administered to bring the PCV to a minimum of 20% or the Hgb level to a minimum of 7 g/dL. In some cases of hemolytic or chronic anemia, the PCV can be maintained at a lower percentage before transfusion is required if there are no corresponding clinical signs. In animals that require multiple blood sampling (such as diabetic patients) or very small animals, blood sampling should be minimized to prevent iatrogenic blood loss; this can be performed using CGMs in diabetic patients. Optimal Hgb target levels have not been determined; however, conservative transfusion management in people (Hgb goal of 7 g/dL or PCV of 20%) has improved survival benefit over more liberal transfusion goals (Hgb of 10 g/dL or PCV of 30%).

Except in the case of acute, life-threatening hemorrhage, before an RBC blood product is administered, a type and crossmatch should be performed to minimize adverse transfusion reactions and to maximize RBC lifespan. Even type-specific or "A-negative" blood may not be antigenically appropriate for some dogs, because many antigens are present on canine RBCs. Only type-specific blood should be administered to cats. In dogs and cats with acute cavitary (pleural or peritoneal) hemorrhage, blood may be salvaged from the cavity with aspiration (via centesis or exploratory surgery when indicated) and an autologous blood transfusion administered through a blood filter. Xenotransfusions have been performed in some veterinary patients.

Rarely, disease states may result in altered hemoglobin (such as methemoglobinemia) or altered oxygen-carrying capacity (such as carboxyhemoglobinemia), often recognized by altered mucous membrane color (muddy or brick-red, respectively). Despite normal measured hemoglobin concentrations, oxygen is not being delivered to tissues in these animals, and oxygen supplementation is necessary along with treatment of the underlying disease.

An alternative means to increase oxygen-carrying capacity of the blood is a commercial HBOC such as Oxyglobin®. However, this is not currently available in the USA. Monitoring PCV is not an adequate assessment of oxygen delivery after use of HBOCs.

Animals with a PCV >55% (other than sight hounds and at high altitudes) may have microvascular sludging (due to the altered blood rheology) and hypertension (which impairs microvascular delivery of oxygen to the tissues). This occurs most commonly with acute hemorrhagic diarrhea syndrome , previously termed hemorrhagic gastroenteritis. Treatment with IV fluids, and phlebotomy in cases of absolute polycythemia, are performed to improve microvascular flow and oxygen delivery to the tissues.

Renal Function

In animals that have had a hypotensive episode, are receiving potentially nephrotoxic medications, or have primary renal compromise, renal function should be evaluated daily. Urinalysis is ideally performed before fluid administration to assess renal function. Normal urine output is 1–2 mL/kg/hour and can be closely monitored with an indwelling urinary catheter. Animals in polyuric renal failure are most often managed medically; however, animals in oliguric (<0.8 mL/kg/hour), anuric (<0.03 mL/kg/hour), or relative oliguric (less than expected) renal failure may require peritoneal or hemodialysis to maintain fluid and electrolyte balance. If monitoring urine output with a catheter is not possible, then estimating urine output by measuring absorbent pads or litter boxes is necessary. Body weight should be recorded regularly. Serial measurement of serum BUN, creatinine, electrolytes, and phosphorus will detect changes and help guide therapy. Measurement of symmetric dimethylarginine is a recently developed test that may help detect renal dysfunction before changes in creatinine. Serial urinalyses to detect glucosuria, proteinuria, or renal tubular casts help evaluate acute tubular injury before the damage progresses to overt renal failure and azotemia.

Additional diagnostic tests may include urine culture and susceptibility testing, urine protein to creatinine ratio, or specific testing for renal-specific disease (eg, ethylene glycol, leptospirosis). Animals may also be monitored using a scoring system to provide additional "objective" monitoring: the International Renal Interest Society has a staging system to monitor dogs and cats with chronic renal disease based on serum creatinine, blood pressure, and proteinuria.

Infection Identification/Prevention and Treatment and Immune Status

Infection Identification/Prevention and Treatment and Immune Status

Strict aseptic technique should be observed when examining or treating animals that are neutropenic or receiving immunosuppressive drugs. These animals should be isolated from other animals and handled by a single person who adheres to appropriate barrier nursing techniques (washes hands, wears gloves and gown before handling the animal, etc). All veterinary staff should be encouraged to wash hands between patients, treat wounds in a clean manner, and administer IV injections only after swabbing an IV port with an alcohol swab. Educating hospital staff on appropriate patient handling techniques may help limit development of nosocomial infections, which develop 48 hours after hospital admission.
Ultimately, antibiotic selection should be based on the results of culture and susceptibility testing, but empiric treatment, based on site of infection and suspected type of bacteria, is necessary pending these results. Empiric therapy may be based on common organisms found at the affected site and/or Gram stain and cytologic examination, which should be performed immediately. Repeat culture and susceptibility testing may be necessary in animals not responding to therapy as expected or if prolonged antibiotic therapy is anticipated.
In animals that have sustained a hypotensive episode or have a GI disease that would allow bacterial translocation, broad-spectrum bacterial coverage should be provided until the results of culture are available or the risk of systemic infection has passed.
An **antibiotic protocol** should be established for veterinary hospitals to minimize the number of antibiotics administered empirically on a routine basis to reduce the development of resistant organisms in the hospital environment and to improve their susceptibility patterns. Hand washing and use of an antibiotic stewardship guideline (limiting use of specific classes of antibiotics) have been demonstrated to limit development of microbial resistance. Facility-specific monitoring of culture and susceptibility results for evidence of nosocomial infections and bacterial resistance patterns can help identify and control sources of infection and limit development of resistance. If multiple antibiotics are started, the antimicrobial spectrum should be narrowed and the antibiotic choice adjusted as soon as the organism's susceptibility pattern is identified (de-escalation). Recurrent infections should be investigated for an underlying pattern of resistance, nidus of infection, or immune-compromising disease. Empiric therapy, even for a septic patient, should not continue for more than 3 days, and antibiotics should be de-escalated to the lowest-tier, single agent as soon as culture results are available.
The advantages and disadvantages of each antimicrobial agent that is administered should be closely considered. Cost, tissue penetration (volume of distribution), site of infection, adverse effects, and disease process that is present should all be considered. Some **options for first-line, broad-spectrum coverage include**:

- First-generation cephalosporins (eg, cefazolin, 22 mg/kg, three times daily) provide good gram-positive and gram-negative coverage. This may be paired with metronidazole (7.5–15 mg/kg, three times daily) to help cover anaerobic infections.
- Aminopenicillins with a beta-lactamase inhibitor (eg, ampicillin/sulbactam, 30 mg/kg, three times daily)provide good gram-negative, gram-positive, and anaerobic coverage.
- For gram-negative infections, fluoroquinolones (eg, enrofloxacin at 5 mg/kg, IV, daily)

Newer generations and classes of antibiotics, such as carbapenems (eg, imipenim), third-generation cephalosporins (eg, ceftazidime), and vancomycin should be reserved for use in animals with bacterial infections demonstrated to be resistant to other antibiotics.
WBC counts performed on a semiregular basis (every 2–3 days) may indicate an appropriate response to infection/inflammation, resolution of disease, or patient deterioration.
Various molecular or "bio" markers have been investigated in SIRS-type diseases to help understand and stratify disease. High mobility group box 1 protein and C-reactive protein have been associated with poor outcome or diagnosis of SIRS-type disease; however, how that information affects therapy has yet to be determined. Plasma interleukin 1B and IL-6 have been demonstrated to have some prognostic value in cats with sepsis.

GI Motility and Mucosal Integrity

Critically ill animals, even those without a primary GI disease, are prone to gastric atony, ileus, and gastric ulceration. Auscultation for bowel sounds should be performed three times a day. Metoclopramide (1–2 mg/kg/day as a CRI) is useful because of its central antiemetic effects and its ability to increase progressive gastric and intestinal motility. Other motility modifiers to consider include cisapride, ranitidine, and erythromycin. Motility modifiers should be avoided if gastric or intestinal obstruction is suspected or has been confirmed.
Placement of a **nasogastric tube** to allow removal of accumulated gas and fluid reduces the possibility of aspiration of refluxed gastric contents and allows continuous decompression. The nasogastric tube also can be used to introduce small amounts of a glucose and electrolyte solution or a liquid diet to provide nutrition directly to enterocytes, which helps prevent gastric ulceration and intestinal mucosal compromise with secondary bacterial translocation.
Antiemetics are used in animals that continue to vomit frequently despite placement of a nasogastric tube, thus improving patient comfort and reducing the incidence of aspiration, vagal-induced collapse, and bradycardia that can accompany the vomiting reflex. Metoclopramide blocks the dopaminergic receptors in the chemoreceptor trigger zone (CRTZ) and central vomiting center and acts peripherally by promoting gastric emptying. Ondansetron and dolasetron are potent antiemetics that block serotonin receptors and act at the CRTZ and the central vomiting center; they are administered at 0.6–1 mg/kg/day. Maropitant is an NK_1 receptor antagonist that blocks vomiting at the CRTZ, vomiting center, and peripheral receptors, administered at 1 mg/kg/day, SC. Chlorpromazine (dogs: 0.05–1 mg/kg, IV, every 4–8 hours; cats: 0.01–0.025 mg/kg, IV, every 4–8 hours) can be used in patients with normal blood pressure. A combination of antiemetics that have different mechanisms of action may be required to arrest refractory emesis in severe illness. If a patient requires multiple antiemetics, GI obstruction must be ruled out.
GI ulceration often accompanies critical diseases such as hypotension, hypergastrinemia associated with liver and other diseases including drug toxicities, neurologic disease, and respiratory disorders requiring ventilation. $Histamine_2$-receptor antagonists such as ranitidine and famotidine, and proton-pump inhibitors such as omeprazole and pantoprazole are commonly administered. Note that changing the pH of the stomach can result in an altered microbial flora. Agents such as sucralfate and barium bind to esophageal and gastric erosions and ulcers. Misoprostol may help prevent NSAID-induced ulceration when toxic levels of NSAIDs are ingested.

Drug Dosages and Metabolism

An active medications list should be kept with each animal's medical record and carefully reviewed daily for potential drug interactions, drug dosages, and possible adverse effects. Each drug administered parenterally should be assessed for its compatibility with other fluids and drugs. If renal or hepatic function is compromised, or if protein (albumin) binding capacity is decreased, some drug dosages should be decreased to account for altered metabolism, elimination, or protein binding. The daily review also should ensure that the dosage has been calculated correctly and that it is appropriate for the animal's current weight and body condition score. The sudden onset of any new clinical signs should be investigated in light of the medications and their potential adverse effects.

Nutrition

When nutritional needs are not met, animals rapidly develop a negative energy balance, which can result in GI dysfunction, organ dysfunction, poor wound healing, and even death. Direct enteral nutrition is always preferred because it will improve the normal GI barrier, function, and motility;most animals tolerate trickle flow feeding techniques through a temporary feeding tube.
Short-term options include syringe or forced feeding; however, this can lead to food aversion and is not comfortable for most animals. Easy to place and well-tolerated, short-term feeding tubes that allow trickle feeding include nasogastric, nasoesophageal, and nasojejunal. Nasogastric tubes also allow gastric suctioning to monitor GI function and may help to limit continued vomiting and risk of aspiration pneumonia; nasojejunal tubes can be challenging to place.
Long-term feeding tubes include esophagostomy, pharyngostomy, gastrostomy, or jejunostomy tubes. Each of these tubes are well tolerated by most animals, and all require anesthesia to place; the esophagostomy is a minor surgical procedure, and gastrostomy tubes can be placed with endoscopic assistance.
Feeding by trickle flow is initiated with small volumes of a dilute veterinary liquid diet solution. If an animal has been starved for an extended period of time, nutrition should start at 25%–33% of the daily caloric requirement and increase by 25%–33% of daily caloric requirements per day to avoid the refeeding syndrome, which can result in hyperglycemia, hypokalemia, hypophosphatemia, and hypomagnesemia.
Before each bolus feeding and every 6 hours during a CRI, the feeding tube should be suctioned to determine residual gastric volume. After suctioning or administering a liquid diet, the tube should be flushed with saline or water.
If this initial feeding is not tolerated, the patient should be re-evaluated for underlying disease, have prokinetics added, and diet volume decreased or the diet diluted with water or an electrolyte solution. As the animal recovers and is able to tolerate at least 50% resting energy requirements, bolus feeding can be introduced by gradually decreasing meal frequency and increasing volumes.
Appetite stimulants, such as the serotonin antagonist cyproheptadine, the serotonin agonist mirtazapine, and the ghrelin agonist capromorelin are commonly used but with varying success; topical mirtazapine is available for cats. Oral benzodiazepines may cause hepatotoxicity in cats and are not good alternatives; injectable benzodiazepines or propofol may be used as a short-term solution for animals with rapidly resolving disease. The use of appetite stimulants provides inconsistent food intake and is not recommended as the primary way to administer nutrition in critically ill animals.
When nutritional needs cannot be met by enteral feeding, parenteral feeding is used. Partial parenteral nutrition, consisting of amino acid and carbohydrate solutions, can be infused through a peripheral vein, providing part of the animal's caloric requirements in a readily metabolizable form. Total parenteral nutrition (including the lipid component) must be delivered through a central venous catheter, because high osmolarity of the solutions may cause phlebitis and RBC lysis. In animals with prolonged anorexia, vitamin supplementation may also be necessary.

Pain Control

Pain activates the stress hormone systems of the body and contributes to morbidity and mortality.
Signs of pain are quite variable in animals and may include:

- decreased normal behavior (decreased appetite, ambulation, grooming, etc)
- development of abnormal behaviors (vocalizing, inappropriate urination, altered posture, signs of agitation or aggression, etc)
- reaction to touch or abnormal body posture
- altered objective physical parameters (increased heart rate, pale mucous membranes, dilated pupils, etc), which can mimic signs of shock

Animals that may not show obvious signs of pain but are known to have a painful condition should receive analgesics as part of their treatment. (Also see Systemic Pharmacotherapeutics of the Nervous System .) Preemptive administration of analgesics is recommended, when possible. Pain should be assessed using a validated pain assessment tool and monitored on a regular basis during the course of hospitalization to ensure adequate analgesia. Monitoring using a scoring system such as the Composite Glasgow Pain Scale is a useful tool to help determine need and response to analgesia.

Analgesia in critically ill animals can safely be provided by opioids titrated to effect. Opioids provide potent analgesia (given IV, IM, or SC) with minimal cardiovascular adverse effects, and their actions are reversible with antagonists (eg, naloxone). Long-acting opioids are best avoided in unstable animals. Reports of IV morphine causing hypotension due to histamine release do not seem to be clinically significant if the drug is given over 5–10 minutes or as a CRI. Other medications such as hydromorphone, oxymorphone, and fentanyl can be given without this risk. CRI provides constant analgesia and is often more convenient and less painful than intermittent IM or SC injections. In cats, injectable buprenorphine is absorbed systemically after sublingual administration. Neuroleptanalgesia can be provided by combination of an opioid with a sedative (eg, benzodiazepine) or tranquilizer (eg, acepromazine) in animals without contraindications to these medications.

For longterm control of pain, transdermal fentanyl patches or repository fentanyl injections are used but require up to 12 hours to reach therapeutic blood levels; analgesia must be provided by injection until adequate blood levels have been reached.

If pain is not adequately controlled with opioids alone, then ketamine, an NMDA receptor antagonist, can be delivered by CRI with the opioids. Ketamine may have variable effects on the cardiovascular system, making patient selection crucial, and it should not be used as a sole agent for pain relief. Dexmedetomidine, administered as an intravenous CRI or on the buccal mucosa, may provide additional analgesia but has significant sedative and cardiovascular effects. Lidocaine, a local anesthetic, can be used as an adjunct for systemic pain relief when delivered as a CRI and combined with ketamine and/or an opioid. Some investigation into using maropitant as an adjunctive analgesic agent is promising, because it decreased anesthetic requirements during noxious stimuli in dogs.

Local pain relief can be provided using local infiltrative or nerve blocks on extremities. Intermittent infusions of bupivicaine administered through thoracotomy tubes or abdominal catheters can provide pleural and peritoneal analgesia. Epidural injections by needle or infusion soaker catheters can provide pain relief from pelvic, limb, and abdominal injuries or disease.

NSAIDs are not as commonly used in critically ill animals because of their effects on the GI tract, kidney, and liver; however, they may be appropriate in animals with significant fevers or orthopedic injury that are not systemically ill. Other oral classes of medication that are well tolerated for mild to moderate pain include tramadol, amantidine, and gabapentin. Acetaminophen may have some value in dogs, but its effect as an analgesic in this species is not well known; acetaminophen is toxic to cats and should not be used in this species. Adjuvant methods of pain relief may include placing ice packs on regions of swelling, acupuncture, laser therapy, therapeutic pulsed electromagnetic field devices, massage, and other adjuvant analgesic techniques.

Wound Care and Bandages

It is essential to have appropriate wound care in the critically ill patient. This applies not only to traumatic wounds but surgical wounds and iatrogenic wounds created for necessary therapy, such as IV catheter sites, drains, stoma sites for various tubes, etc. Each of these sites should be properly prepared, covered, and monitored.

Bandages provide a variety of therapeutic benefits by preventing contamination and/or further infection, applying light compression (to minimize seroma formation or edema), preventing self-inflicted injury, and minimizing movement (reducing pain).

Bandages must be changed whenever they become soiled or wet, with appropriate bandage materials applied directly to the wound. Initial traumatic or infected wounds many require bandage changes several times per day. All open wounds should be bandaged on arrival to prevent further contamination or nosocomial infection until wound assessment and surgical debridement can be performed. Areas of skin swelling or bruising should be marked to determine progression or resolution of the pathology.

The severity of wounds has been associated with increased risk for infection and in some cases (burns) associated with outcome and therapy. Several patient factors can also impact the ability of wounds to heal, including age, underlying disease processes, foreign material, infection, blood supply, and severity of initial injury.

Veterinary Nursing Care and Tender, Loving Care

Providing nursing care to critically ill animals requires a skilled, knowledgeable, attentive, and highly trained nursing staff. Nursing care must be tailored to the specific condition(s). A well-trained nursing staff can recognize deterioration or alterations in an animal often before the attending clinician because of the substantial amount of hands-on time they spend with patients. Veterinary nursing staff play a vital role in the veterinary profession and are effective patient advocates, often recommending therapy that may have been omitted by a veterinarian.

Recumbent animals should be turned from one side to the other every 4 hours or maintained in variations of sternal recumbency to prevent decubital ulcers and atelectasis. Physical therapy 3–4 times a day is important to maintain range of motion and muscle tone and blood flow; this can be provided through massage, passive range of motion, encouraged activity, etc.

Activity may also improve GI motility, help minimize pain, improve joint mobility, and provide a time when animals can urinate and defecate outside of their kennel. Various mobility devices (harnesses) and patient hoists are available to help mobilize patients without taxing staff excessively.

Catheters should be labeled and marked with the date of placement, and catheter sites should be inspected on a routine basis for signs of infection or displacement or if a new fever develops. When catheters are removed, the entrance site should be inspected for inflammation/infection.

Urine and fecal soiling should be immediately cleaned. Recumbent animals require regular inspection and cleaning to prevent urine scalding of the skin; tail wraps minimize contamination from diarrhea. Urinary catheters and rectal catheters (for liquid feces) are available for recumbent patients to minimize soiling.

Owner visits should be encouraged, depending on the demeanor of the patient. Animals should be handled and spoken to kindly to minimize stress and anxiety. Having familiar items such as toys or blankets from home are helpful for some pets. Consolidating several treatments at one time and turning down the lights at night, when the animal's condition permits, allow the animal some time to rest and sleep undisturbed.

For More Information

- Also see pet health content regarding emergency monitoring for dogs and cats .