Perfusion is defined as the flow of fluid over or through a tissue or an organ. From a clinical perspective, tissues need to be perfused with blood to maintain delivery of oxygen and nutrients as well as to remove waste products, primarily carbon dioxide. At a cellular level, decreased perfusion leads to anaerobic metabolism, acid accumulation, and decreased ATP production—a state of shock. If this situation becomes extreme, enzyme systems cease to function normally, cellular membrane integrity cannot be maintained, muscles lose the ability to contract normally, and other enzyme-driven cascades (e.g., the coagulation cascade) become impaired. Hypoperfusion is associated with increased patient morbidity and mortality.

Poor perfusion associated with hypovolemia most commonly occurs secondary to blood loss, third-spacing of body fluids, or unreplaced fluid losses from vomiting or diarrhea. This article provides a general overview for treating poor perfusion; readers are referred to other references for information on treating specific diseases.

**DIAGNOSTIC CRITERIA**

**Historical Information**

**Age/Gender/Breed Predisposition**
None. Poor perfusion can occur in any animal.

**Owner Observations**
- Lethargy, weakness (especially in the pelvic limbs), and collapse may be seen in hypovolemic patients.
- Very observant owners may note increased respiratory rate and/or effort, cool extremities, and pale gums.
- Acute abdominal distention in breeds predisposed to diseases causing intraabdominal hemorrhage or bloat can cause perfusion abnormalities.

**Other Historical Considerations/Predispositions**
A recent history of trauma, excessive vomiting or diarrhea, or other diseases that may predispose a patient to third-spacing of fluids can all be associated with poor perfusion secondary to hypovolemia.

**Physical Examination Findings**
- Recumbency, extreme weakness, and/or altered mentation should alert clinicians to the possibility of hypovolemia and secondary poor perfusion.
- Weak central and weak or absent peripheral pulses are consistent with poor perfusion. Pulse palpation can be extremely misleading because palpation relies on pulse pressure (the difference between the systolic and diastolic pressures). Blood pressure should always be measured.
- Low rectal and/or toe web temperatures may be seen. A difference between rectal and toe web temperatures (ΔT) of greater than 7°F (about 4°C) indicates perfusion abnormalities.
- Prolonged capillary refill time indicates poor perfusion, but normal capillary refill time does not indicate normal perfusion.
- Pale, muddy, or cyanotic nail beds in patients that normally have pink nail beds indicate perfusion abnormalities to the affected paw.
- Other signs of shock, including increased respiratory rate and/or effort, tachycardia, decreased jugular distention and filling, and pale or muddy mucous membranes, typically indicate that poor tissue perfusion is present.
- Decreased urine output will be seen if renal perfusion is inadequate.
- The presence of blood in vomitus or stool in patients with other signs of perfusion abnormalities may indicate that the gut has been poorly perfused to the point that the mucosa is starting to slough.
- Signs of dehydration, such as skin tenting or tacky mucous membranes, may be associated with poorly perfusing tissues.

**Intraoperative Physical Examination Findings**
- Significant hypotension can lead to and be associated with perfusion abnormalities.
- Tachycardia may be associated with pain or may be a baroreceptor-triggered response to hypovolemia.
- Poor splanchnic circulation as evidenced by poor pulsation of the mesenteric blood vessels, decreased diameter of mesenteric vessels, or pale, muddy, or cyanotic color of the serosal surface of

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the intestine is consistent with a perfusion abnormality.
• Lack of urine production may indicate renal hypoperfusion.

**Laboratory Findings**

**Blood Gases**
• The presence of metabolic acidosis on a venous or arterial blood gas analysis is consistent with anaerobic metabolism secondary to poor tissue perfusion.
• A normal blood gas value does not imply normal tissue perfusion.

**Blood Lactate Concentrations**
• Blood lactate levels will be elevated (>2.5 mmol/L) if tissue perfusion is compromised.
• A normal lactate level does not imply normal tissue perfusion.

**Other Diagnostic Findings**

**Blood Pressure**
• Systolic blood pressure less than 110 mm Hg and/or diastolic blood pressure less than 75 mm Hg is an abnormal reading and may indicate that tissue perfusion is abnormal.
• Mean arterial blood pressure less than 60 mm Hg is consistent with severe hypoperfusion and may lead to organ failure if not corrected.
• Blood pressure can be measured indirectly using a Doppler ultrasonic flow detector or an oscillometric device. Doppler devices have the advantage of allowing clinicians to assess blood pressure (systolic and diastolic) as well as subjectively assess blood flow to the area. Oscillometric devices are less labor intensive and are easier to use but are frequently inaccurate in low-flow states.

**Central Venous Pressure**
• Central venous pressure is used as a reflection of preload.
• If preload is decreased, cardiac output generally will be decreased.
• If a central catheter is not available, jugular vein distention and filling when the vein is digitally occluded (held off) at the thoracic inlet should be assessed subjectively.

**Electrocardiography**
• The presence of tall T waves, premature ventricular contractions, or ventricular tachycardia may indicate myocardial hypoxia secondary to perfusion abnormalities.
• ST-segment elevation or depression may indicate myocardial hypoxia or ischemia.

**Capnometry**
• End-tidal carbon dioxide (ETCO₂) measurements of less than 15 to 18 mm Hg indicate significant pulmonary perfusion abnormalities.
• A difference of more than 5 mm Hg between ETCO₂ and arterial partial pressure of carbon dioxide indicates a ventilation-perfusion mismatch.

**Echocardiography**
• Abnormal cardiac output will affect tissue perfusion.

**Summary of Diagnostic Criteria**
• Weakness, collapse, and/or abnormal mentation.
• Weak or absent pulses, especially peripherally.
• Hypotension.
• Hypovolemia as measured by central venous pressure or estimated by jugular distention.
• Cool extremities.
• Decreased rectal temperature or increased ΔT.
• Muddy or cyanotic mucous membranes and prolonged capillary refill time.
• Evidence of metabolic acidosis or elevated lactate concentration.

**Differential Diagnosis**
• Congestive heart failure, cardiomyopathy, or pericardial effusion:
  — May cause perfusion abnormalities that are not associated with hypovolemia.
  — Patients typically have jugular veins that appear to have normal or even increased distention or a central venous pressure that is normal to elevated.
  — Lack of jugular vein distention or a low central venous pressure in these patients implies concurrent hypovolemia usually associated with excessive diuretic use.
• Absent pulses may be caused by thromboembolic disease. Typically these patients have signs of normovolemia or even hypervolemia, and pulses are palpable in at least one limb.
• Neurologic diseases (e.g., meningoencephalitis, postictal states, intervertebral disk disease, fibrocartilaginous embolus) may cause weakness, collapse, and/or changes in mentation without causing perfusion abnormalities.
• Chocolate mucous membrane color, which may be confused with muddy mucous membranes, may be caused by acetaminophen toxicity. Other signs of poor perfusion typically will not be present in the early stages of the toxicity.
• Elevated blood lactate concentrations as well as metabolic acidosis can be present following seizure activity. Perfusion abnormalities are unusual in these
Colloidal Fluids

- Colloids are indicated if there is evidence of significant hypovolemia or decreased oncotic pressure.
- If colloid osmotic pressure cannot be measured, patients with total protein concentration below 3.5 g/dl or albumin below 2.0 g/dl should be assumed to be hypooncotic (see box at left).
- Hetastarch can be administered in boluses of 5 ml/kg to a maximum of 20 ml/kg. The bolus can be repeated based on patient perfusion parameters.
- In dogs, boluses can be given as rapidly as the fluid can be infused.
- In cats, boluses should be given over 10 to 20 minutes.
- Constant-rate infusions (maximum dose: 20 ml/kg/day) may be required to help maintain tissue perfusion by helping to improve and/or maintain colloid oncotic pressure.

Hemoglobin-Based Oxygen Carrier (Oxyglobin, Biopure, Cambridge, MA) $–$$

- Boluses of 3 ml/kg of Oxyglobin can be administered to a maximum of 30 ml/kg (see box above). The bolus can be repeated based on patient perfusion parameters. Total doses of 7 to 8 ml/kg have been shown to be effective in restoring perfusion even in cases of severe hemorrhagic shock.
- The dose should be decreased by 50% to 70% in cats to avoid acute volume overload.
- Boluses in cats should be given over 10 to 20 minutes.
- Constant-rate infusions may be required to help maintain tissue perfusion. (Dose unknown; author’s patients unless a patient has been in status epilepticus for an excessive period of time.

TREATMENT RECOMMENDATIONS

Initial Treatment

Oxygen $

- Supplemental oxygen (3–10 L/min) should be provided immediately by flow-by or mask.
- Nasal oxygen (100 ml/kg/min) is indicated once other resuscitative measures have been provided.
- Supplemental oxygen probably is of benefit for at least 4 to 6 hours following resolution of the perfusion abnormalities.

Crystalloid Fluids $

- A buffered isotonic electrolyte solution (e.g., Normosol-R, Plasmalyte, Plasmalyte-A) should be infused via a large-bore peripheral catheter.
- An initial bolus of 30 ml/kg is recommended. The bolus can be repeated multiple times based on patient perfusion parameters.
- Excessive crystalloids should be avoided (see box above).
experience suggests that 8 ml/kg/day appears to be effective in many patients, assuming no ongoing hemorrhage.)

**Analgesics**
- Analgesics should be administered to all patients with a history of trauma or other painful conditions or to any patient showing signs of pain. Ideally, resuscitation should be started and the patient’s neurologic status assessed before any analgesic drugs are administered, but this is not always possible.
- From a perfusion standpoint, pain can cause excessive vasoconstriction.
- Parenteral opioids (preferably administered intravenously) are indicated.
- NSAIDs should be avoided in patients with abnormal perfusion.

**Assessment**
- Patient parameters (vital signs, blood pressure, central venous pressure) should be assessed after each bolus of fluids is administered.
- If parameters have not normalized, additional boluses of crystalloids and/or colloids should be given.

**Alternative/Optional Treatments/Therapy**

**Erythrocytes $$$$**
- To ensure adequate oxygen delivery, acutely anemic patients ideally should receive erythrocytes in the form of whole blood or packed erythrocytes to maintain a hematocrit of approximately 30%.
- Patients that receive Oxyglobin may not require erythrocytes on an emergency basis; however, because of the short half-life of Oxyglobin, erythrocyte transfusions are recommended in patients with hematocrits less than 25%.
- Patients receiving whole blood transfusions must be monitored closely for fluid overload if synthetic colloids have been administered.

**Plasma $$$$**
- Ideally, frozen or fresh-frozen plasma should be administered to maintain the serum albumin concentration above 2.0 g/dl.
- Fresh-frozen plasma should be administered to correct any coexisting coagulopathies.
- Coagulopathies can develop secondary to prolonged poor tissue perfusion or the underlying disease.

**Positive-Pressure Ventilation**
- Patients in severe shock that are not responding to supplemental oxygen and initial fluid therapy may need to be intubated and ventilated because severe hypoxemia and hypercarbia can worsen tissue perfusion.

**Supportive Treatment**
- Patients that are hypothermic (temperature <99.5°F in the author’s hospital) should be rewarmed. Core rewarming (warm fluids, warmed air to breathe) should be provided initially for severely hypothermic patients as external rewarming may cause excessive peripheral vasodilation. The goal is to ensure that patients are normothermic, and even patients with mild hypothermia should have their temperatures normalized.
- Unless contraindicated by the patient’s underlying disease, enteral nutrition should be provided as soon as the patient is normothermic and normotensive—ideally within 6 hours of admission to the hospital. Enteral nutrition is a very effective means of enhancing splanchnic circulation to the gastrointestinal mucosa.
- Poor perfusion to the gastrointestinal tract can lead to loss of the gut mucosal barrier and secondary endotoxin and bacterial translocation. If this is a potential concern, intravenous broad-spectrum antibiotics should be provided.
- If loss of the gastric mucosal barrier is suspected or has been diagnosed, gastric protectants, including antacids and sucralfate, may be indicated.
- Other treatments should be directed at the underlying injury or illness.

**Patient Monitoring**
- Vital signs, including temperature, pulse rate and quality, respiratory rate and effort, mucous membrane color, capillary refill time, blood pressure, and jugular filling or central venous pressure, should be monitored every 5 to 15 minutes until the patient has been resuscitated (see box on page 12). At that time, vital signs can be monitored at 30-minute to 4-hour intervals depending on the status of the patient and the underlying disease. Patient flow sheets are essential for recording data and monitoring trends of change.
Continuous electrocardiographic monitoring is indicated for every patient with arrhythmias. Monitoring a lead II rhythm strip for 2 minutes every 4 hours is adequate for patients without arrhythmias.

Urine output should be monitored hourly. Urine production of less than 1 ml/kg/hr may indicate inadequate renal perfusion.

Blood gases and/or lactate concentrations ideally should be monitored every 1 to 4 hours initially to ensure perfusion is improving. Once the patient has been stabilized, these parameters should be monitored every 12 hours.

Other laboratory tests should be monitored based on the patient’s underlying condition.

Home Management

- Long-term complications are unlikely but possible.
- If hypoperfusion caused tissue necrosis, outward signs might not develop for a number of days.
- Owners should be prepared to have the animal rechecked immediately if any abnormal signs are noted.

Milestones/Recovery Time Frames

Ideally, perfusion should be restored within the “golden hour” (i.e., the first hour following an injury or onset of serious illness). The longer oxygen debt persists, the higher the likelihood of complications, including organ failure.

Treatment Contraindications

- Drugs with vasoactive effects should be used with extreme caution in hypovolemic patients.
- NSAIDs should never be used in patients with poor perfusion.

PROGNOSIS

Favorable Criteria

- Restoration of normal vital signs, including blood pressure.

Checkpoints

Crystalloids vs. colloids: Considerable controversy still exists in human and veterinary medicine regarding the use of crystalloids versus colloids during fluid resuscitation. The use of colloids in hypovolemic patients appears to have short-term benefits but no long-term advantages over crystalloids. Similar clinical veterinary studies have not been performed.

Oxyglobin: Oxyglobin is associated with an increase in systemic vascular resistance by mechanisms that are not completely understood. There are concerns that this may compromise tissue perfusion, but no decrease in tissue oxygenation has been noted in research studies. The presence of Oxyglobin in serum will interfere with colorimetric laboratory analyzers, which may be of concern in certain patients.

- Resolution of lactic acidosis.
- Normal urine output.
- Normal mesenteric blood vessels (diameter, pulsation) and normal color of the serosal surfaces of the gastrointestinal tract when viewed intraoperatively.

Unfavorable Criteria

- Persistence of clinical signs of poor perfusion, including hypotension lasting longer than 1 hour after starting resuscitation.
- Persistence of lactic acidosis.
- Lack of urine output within the first 4 hours or decreasing urine output and increasing serum urea nitrogen and creatinine.
- Increasing amounts of blood in vomitus or stool.
- Signs of organ failure.

Recommended Reading


