The main fundamental aspects of anesthetic monitoring are:
1. Oxygenation (circulatory and respiratory function)
2. Ventilation (respiratory function)
3. Circulation (circulatory function with an emphasis on cardiac output).

These three elements work simultaneously in order to maintain adequate tissue and organ perfusion with oxygenated blood. Oxygenation and ventilation are essential for maintaining a high oxygen level in the blood, while cardiac output plays a pivotal role in maintaining tissue and organ perfusion with highly oxygenated blood. In this way, oxygenation, ventilation, and circulation each play a critical role in providing oxygen to tissues.

PHYSIOLOGY FUNDAMENTALS
Oxygen Delivery
Oxygen delivery is a product of blood oxygenation and cardiac output. Oxygenation and ventilation are essential for maintaining a high oxygen level in the blood, while cardiac output plays a pivotal role in maintaining tissue and organ perfusion with highly oxygenated blood. In this way, oxygenation, ventilation, and circulation each play a critical role in providing oxygen to tissues.
When heart rate or stroke volume or a combination of both is low, cardiac output is reduced. When blood volume returning to the heart is low due to dehydration or acute blood loss, stroke volume is decreased. If peripheral vascular resistance or blood viscosity (ie, vasoconstriction or polycythemia, respectively) is increased, cardiac output is reduced. In addition, excessively high heart rate (lack of ventricular filling for preload) and profound peripheral vascular dilation (lack of venous return due to peripheral pooling of blood) also reduce cardiac output.

Application to Anesthesia
Acute changes in ventilation or oxygenation can have dramatic effects on oxygen delivery; thus, in addition to monitoring circulatory function (see CIRCULATION, below), it is important to carefully monitor:

- Saturation level of oxygen in hemoglobin via SaO$_2$ (measured by blood gas analysis) or SpO$_2$ (measured by pulse oximetry)
- Hematocrit (an important indicator of hemoglobin concentration; hemoglobin concentration equals approximately $\frac{1}{3}$ of the hematocrit)
- Partial pressure of oxygen in arterial blood (PaO$_2$)

When oxygen delivery is inadequate, cells seek alternative ways to supply energy (ATP). The body then converts to anaerobic metabolism, producing lactate as a metabolic by-product and utilizing it as an alternative energy source. Measuring a series of blood lactate concentrations provides a trend for assessing tissue perfusion.

Following is a categorization of anesthetic monitoring equipment by physiologic function. See Table 1 and Figure 1 for an outline of anesthetic monitoring equipment and its purposes.

CIRCULATION
Monitoring circulation during general anesthesia is aided by the use of electrocardiography (ECG) and blood pressure (BP) monitoring as well as patient assessment.

Electrocardiography
Electrocardiography is easy to perform and should be used continuously during the perioperative period to obtain quick, real-time information about heart rate and rhythm.

Placement
The majority of ECGs used in veterinary hospitals have 3 leads and attach to the skin surface.

- The 3 leads can be placed as either:
  - Limb leads: Left and right forelimb and left hindlimb electrodes attached to the limbs as indicated, with selection of lead II during recording
  - Base-apex leads: Right forelimb and left

Table 1. Anesthetic Monitoring Equipment

<table>
<thead>
<tr>
<th>Circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrocardiography (ECG):</td>
</tr>
<tr>
<td>• Monitors heart rate and rhythm</td>
</tr>
<tr>
<td>• Definitively diagnoses arrhythmias</td>
</tr>
<tr>
<td>• Monitors progress of cardiac arrhythmia treatment</td>
</tr>
<tr>
<td>Ultrasonic Doppler blood flow detector:</td>
</tr>
<tr>
<td>• Measures blood flow, pulse rate, and systolic blood pressure (BP) when used with sphygmomanometer</td>
</tr>
<tr>
<td>Oscillometric BP measurement:</td>
</tr>
<tr>
<td>• Uses a BP cuff on the limb to obtain systolic, diastolic, and mean arterial BP at a set time interval but not continuously</td>
</tr>
<tr>
<td>Invasive BP measurement:</td>
</tr>
<tr>
<td>• Uses arterial catheter, BP transducer, and monitor to obtain continuous beat-to-beat pulse waves</td>
</tr>
<tr>
<td>• Gold standard for measuring systolic, diastolic, and mean BP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respirometer:</td>
</tr>
<tr>
<td>• Measures respiratory rate and tidal volume (minute volume)</td>
</tr>
<tr>
<td>Arterial or venous blood gas:</td>
</tr>
<tr>
<td>• Measures partial pressure of CO$_2$ (PaCO$_2$ or PvCO$_2$)</td>
</tr>
<tr>
<td>Capnography:</td>
</tr>
<tr>
<td>• Noninvasively measures end-tidal CO$_2$ concentration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oxygenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse oximetry:</td>
</tr>
<tr>
<td>• Noninvasively measures saturation of oxygen bound to hemoglobin (SpO$_2$)</td>
</tr>
<tr>
<td>Arterial blood gas:</td>
</tr>
<tr>
<td>• Measures partial pressure of oxygen (PaO$_2$) in arterial blood samples</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectal thermometer</td>
</tr>
<tr>
<td>Esophageal temperature probe</td>
</tr>
<tr>
<td>Infrared thermometer:</td>
</tr>
<tr>
<td>• Measures tympanic membrane temperature</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of Anesthesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anesthetic gas analyzer:</td>
</tr>
<tr>
<td>• Measures expiratory inhalant concentration (allows anesthetist to estimate depth of anesthesia together with other vital variables mentioned in this table)</td>
</tr>
<tr>
<td>Bispectral index (BIS) monitor:</td>
</tr>
<tr>
<td>• Algorithmic analysis of a patient’s electroencephalogram during general anesthesia</td>
</tr>
</tbody>
</table>

BIS = bispectral index; BP = blood pressure; CO$_2$ = carbon dioxide; ECG = electrocardiography; PaCO$_2$ = partial pressure of carbon dioxide in arterial blood; PaO$_2$ = partial pressure of oxygen in arterial blood; PvCO$_2$ = partial pressure of carbon dioxide in venous blood; SpO$_2$ = saturation level of oxygen in hemoglobin as measured by pulse oximetry
Table 2. Cardiorespiratory & Physiologic Parameters in the Anesthetized Dog & Cat

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference Interval (Dogs)</th>
<th>Reference Interval (Cats)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats per min)</td>
<td>60–120</td>
<td>120–160</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>90–140</td>
<td>90–140</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>60–90</td>
<td>60–90</td>
</tr>
<tr>
<td>Mean arterial blood pressure (mm Hg)</td>
<td>70–90</td>
<td>70–90</td>
</tr>
<tr>
<td>Ventilation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory rate (breaths per min)</td>
<td>8–16</td>
<td>12–24</td>
</tr>
<tr>
<td>Tidal volume (mL/breath)</td>
<td>10–15</td>
<td>10–15</td>
</tr>
<tr>
<td>Arterial blood pH</td>
<td>7.35–7.45</td>
<td>7.35–7.45</td>
</tr>
<tr>
<td>PaCO₂ (mm Hg)</td>
<td>35–45</td>
<td>35–45</td>
</tr>
<tr>
<td>Bicarbonate (mmol/L)</td>
<td>22–26</td>
<td>22–26</td>
</tr>
<tr>
<td>End-tidal CO₂ (mm Hg)</td>
<td>35–45</td>
<td>35–45</td>
</tr>
<tr>
<td>Oxygenation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SpO₂ (%)</td>
<td>≥ 95</td>
<td>≥ 95</td>
</tr>
<tr>
<td>PaO₂ (mm Hg)</td>
<td>≥ 100</td>
<td>≥ 100</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body temperature (°F)</td>
<td>98–101</td>
<td>98–101</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>34–59</td>
<td>28–47</td>
</tr>
<tr>
<td>Total protein (mg/dL)</td>
<td>5–8.3</td>
<td>5.9–8.4</td>
</tr>
<tr>
<td>Blood glucose (mg/dL)</td>
<td>90–150</td>
<td>90–150</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)</td>
<td>&lt; 2</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Urine output (mL/kg/H)</td>
<td>1–2</td>
<td>1–2</td>
</tr>
</tbody>
</table>

CO₂ = carbon dioxide; PaCO₂ = partial pressure of carbon dioxide in the arterial blood; PaO₂ = partial pressure of oxygen in the arterial blood; SpO₂ = saturation level of oxygen in hemoglobin as measured by pulse oximetry.

Figure 1. A schematic representation of clinical anesthesia monitoring equipment to ensure proper tissue perfusion with well-oxygenated blood. Continuous systemic surveillance can provide an early warning system, prompting immediate intervention.
hindlimb electrodes attached to the right (preferred) or left (alternative) jugular furrow, and left forelimb electrode attached to the opposite side of the thoracic wall caudal to the heart (Figure 2). Select either lead I (negative deflection) or lead III (positive deflection) on the monitor for recording.

- The advantage of using base-apex lead placement is that it avoids attachment to the hindquarters, minimizing artifact motion during abdominal and hindlimb surgical manipulation.
- The application of conduction gel and/or medical alcohol on the ECG electrodes minimizes artifact and background electrical noise on the monitor.

**Limitations**

ECG indicates electrical activity but does not offer information about the mechanical function of the heart (i.e., pumping activity). A form of cardiac arrest called electromechanical dissociation can occur where there is electrical activity of the heart but no pulse present. Therefore, ECG should not be used as a sole monitoring tool for circulatory function perioperatively.

**Invasive Blood Pressure Measurement**

The gold standard for BP measurement is an arterial catheter connected to a monitor via a pressure transducer (Figure 3). Invasive (direct) BP monitoring provides beat-to-beat information about BP and heart (pulse) rate and rhythm. Arrhythmias can be identified by changes in arterial wave form on the monitor, which may also be accompanied by acute reductions in BP values. Information on arrhythmias diagnosed by ECG, coupled with changes in BP values, allows the anesthetist to determine the severity of the arrhythmias and whether to initiate crucial therapeutic actions.

**Placement**

Arterial catheter placement is usually in the dorsal pedal/metatarsal, femoral, or palmar artery. In dogs with large ears, such as basset hounds, the catheter may be placed in the auricular artery. In cats, arterial catheters are most frequently placed in the dorsal pedal artery.

**Advantages & Disadvantages**

**Advantages:**
- Accurate pressure readings with beat-to-beat information
- Arterial blood sampling for blood gas analysis, packed cell volume (PCV), glucose, and lactate measurement.

**Disadvantages:**
- Technical skill required to place the catheter
- Expense of equipment required
- Frequent maintenance (of pressure transducer, pressure tubing, saline flushing) and calibration
- Potential hematoma formation and thrombosis (rare)
- Infection at the catheter insertion site and acute blood loss if an inadvertent disconnection occurs between the catheter and artery (rare).

**Noninvasive Blood Pressure Measurement**

BP monitoring is more commonly accomplished through noninvasive (indirect) BP monitoring using a Doppler ultrasound or oscillometric method.

**Ultrasonic Doppler Method**

The ultrasonic Doppler method involves placing a probe on top of an artery with conduction gel applied between the skin and the probe (Figure 4). The probe uses ultrasonic waves to detect pulsatile blood flow or vessel wall motion and converts this to an audible signal.

**Placement**

Any superficial artery can be used (usually limb extremities or ventral tail base) for detection of blood flow. A blood pressure cuff is placed proximal to the ultrasonic probe and is inflated to the point where it exceeds systolic blood pressure, which silences the Doppler signal. The cuff is then gradually deflated until the first noise signal is audible. The blood pressure registered on the sphygmomanometer at this time is the systolic blood pressure.

**Advantages**
- Continuous flow noise is produced.
- Systolic BP measurement is relatively accurate compared with direct BP monitoring.
- Equipment cost is low.

**Disadvantages**
- This method only measures systolic blood pressure.
BP has to be measured each time by the anesthetist because the equipment cannot be set for automatic measurements.

When vasoconstriction or hypotension occurs, the signal can be relatively weak and difficult to obtain.

### Oscillometric Method

Oscillometric BP monitoring (Figure 5) is used to measure systolic, diastolic, and mean arterial BP. Depending on the algorithm used, some devices directly measure systolic and diastolic blood pressure and calculate to yield mean arterial blood pressure, while others measure mean arterial blood pressure directly and then calculate systolic and diastolic blood pressures.

**Placement**
The BP cuff is inexpensive and placed on a limb extremity or the base of the tail and leveled with the heart during measurement. The width of the blood pressure cuff should be 40% of the limb circumference.

**Advantages**
- This method is inexpensive and easy to use.
- The machine can be set to take automatic measurements at specified time intervals.

**Disadvantages**
- Technology is motion sensitive and has difficulty reading BP if patient movement, hypotension, bradycardia, or arrhythmias are present.
- Method is less accurate compared to ultrasonic Doppler and invasive BP monitoring.
- Variable size and shape of limbs can contribute to inaccuracies, especially in smaller patients (cats and small dogs).

Recent advances in technology are producing improved software and hardware capable of overcoming many of these disadvantages.

### VENTILATION

Various aspects of respiratory function can be measured using a respirometer, capnometry, and/or blood gas analysis.

**Respirometer**

Respirometry assesses tidal volume and minute volume in the anesthetized patient. Minute volume (mL/min) is the product of tidal volume (mL) and respiratory rate of the patient:

\[
\text{minute volume} = \text{tidal volume} \times \text{respiratory rate}
\]

A respirometer measures expiratory volume and can be placed between the expiratory limb of an anesthetic machine and the anesthetic breathing hose. Alternatively, it can be connected to a tightly-fitting face mask.
mask and used to assess ventilation in a nonintubated, sedated patient (Figure 6).

The true usefulness of respirometry is to pinpoint whether respiratory rate and/or tidal volume are inadequate (based on the equation of minute volume) when end-tidal CO$_2$ or PaCO$_2$ is elevated.

**Blood Gas Analysis**

Arterial blood gas analysis and resultant partial pressure of CO$_2$ in arterial blood (PaCO$_2$) can be used to assess ventilation in the anesthetized patient. The arterial blood sample is collected directly from an artery or through a preplaced arterial catheter (Figure 3).

Although more accurate than a respirometer, PaCO$_2$ measurement requires a blood gas analyzer and arterial blood samples. If arterial blood samples are not available, venous blood samples may be used instead.

Results from several human and animal studies show that venous blood sample pH is an acceptable substitute for arterial measurement, and venous CO$_2$ (PvCO$_2$) may be used to detect hypercarbia. However, there may not be sufficient agreement between arterial and venous PCO$_2$ to allow use of venous blood samples for clinical evaluation of ventilatory function.

Handheld blood gas analyzers, such as the iStat system (abaxis.com), VetStat system (idexx.com), and VitalPath analyzer (heska.com), make blood gas analysis more practical and available for veterinary practices.

**Capnometry**

End-tidal carbon dioxide (ETCO$_2$) monitoring allows exhaled CO$_2$ to be measured noninvasively and reflects PaCO$_2$. Monitoring ETCO$_2$ is useful for:

- Determining optimal ventilation efficiency
- Diagnosing respiratory, airway, or device problems, such as apnea, hypoventilation, airway disconnection, airway obstruction, leak in the endotracheal tube cuff, exhaustion of CO$_2$ absorbent, and incompetent one-way valve of anesthetic rebreathing circuit
- Reflection of adequate cardiac output production (eg, sudden, acute drops in cardiac output are associated with decreases in ETCO$_2$ measurements due to poor pulmonary circulation).

Capnometry is the measurement and numerical display of ETCO$_2$ during the respiratory cycle (inspiration and expiration). A capnometer measures and displays the readings without a graphic presentation; capnography refers to the comprehensive measurement of CO$_2$ using a graphic recorder that displays CO$_2$ concentration in real-time, throughout the respiratory cycle (Figures 7 and 8).

---

**Figure 6.** A respirometer attached to the face mask of a dog to measure tidal volume and respiratory rate.

**Figure 7.** Side-stream capnography: Notice the adaptor (white color) is connected between a breathing circuit and the endotracheal tube to sample the inspired and expired gas (via the transparent tubing); the sample is analyzed in the monitor. Also visible is an esophageal stethoscope (black tubing) inserted into the esophagus of the dog for auscultation of heart and lung sounds, and a pulse oximeter probe (white tubing) on the patient’s tongue.

**Figure 8.** A main-stream anesthetic agent analyzer, with an adaptor connected between a breathing circuit and the endotracheal tube, analyzes isoflurane concentration (inspired concentration of 1.6% and expired concentration of 1.3%) and end-tidal CO$_2$ (ETCO$_2$ of 36 mm Hg, respiratory rate of 17 breaths/min) of the anesthetized dog. Notice the main-stream adaptor is bulkier than the side-stream adaptor (Figure 7) and the exhaled gas is analyzed (blue light) within the adaptor using infrared technology.
This technique:
• Is relatively inexpensive.
• Allows for continuous monitoring of ventilation.
• Limits the need for invasive procedures, such as arterial blood gas sampling.
• Provides valuable information on the respiratory status of the patient, including whether the patient has had an inadvertent esophageal intubation.
• Identifies if the patient is rebreathing carbon dioxide (e.g., too much dead space within breathing circuit, inadequate oxygen flow rate used for non-rebreathing circuit, CO2 absorbent exhausted, or a mechanical problem with one-way valve of anesthetic rebreathing circuit).

**What the Numbers Mean**

ETCO₂ measurements usually underestimate actual PaCO₂ measurements by 5 to 10 mm Hg. The discrepancy between ETCO₂ and PaCO₂ measurements is due to alveolar dead space. In the conscious patient, ETCO₂ and PaCO₂ measurements are very similar. However, the anesthetized patient has increased alveolar dead space, which results in lower ETCO₂ measurements.

- Normal PaCO₂ measurements in the anesthetized dog and cat are equal to 35 to 45 mm Hg.
- ETCO₂ (and PaCO₂) values higher than 45 mm Hg are consistent with hypoventilation. They alert the anesthetist that the patient may need to breathe more frequently and/or with a larger tidal volume. Hypoventilation is usually associated with anesthetic-induced respiratory depression.
- ETCO₂ (and PaCO₂) values lower than 35 mm Hg may be evidence of hyperventilation. Hyperventilation is often associated with pain, light plane of anesthesia, and/or increased body temperature.

For a complete list of normal cardiorespiratory and physiologic parameters in the anesthetized patient, see Table 2, page 25.

**OXYGENATION**

A patient’s oxygenation status can be measured by blood gas analysis for PaO₂ (see Blood Gas Analysis under VENTILATION), hemoximetry, and pulse oximetry. Hemoximetry and pulse oximetry both analyze hemoglobin saturation in oxygen, with hemoximetry providing a more precise measurement. However, it is unusual to use hemoximetry in veterinary practice.

**Pulse Oximetry**

Pulse oximetry (Figure 9):
- Calculates the percentage of oxyhemoglobin and reduced hemoglobin present in arterial blood
- Provides noninvasive, continuous detection of pulsatile arterial blood in the tissue bed (probe is usually attached to the patient’s tongue, lip, ear, or interdigital space)
- Provides the pulse rate of the patient.
- Pulse oximeter function may be affected by many factors, including:
  • Motion artifact (e.g., shivering or body movement)
  • Ambient light (e.g., fluorescent light affecting proper reading of pulse oximeter)
  • Poor peripheral blood flow due to hypotension or vasoconstriction
  • Electrical noise from surgical instruments (e.g., electrocautery)
  • Increased blood carboxyhemoglobin and methemoglobin levels
  • Dark pigmentation of the skin or tongue.

**Relationship Between SpO₂ and PaO₂**

- Normal pulse oximeter readings (SpO₂) in anesthetized dogs and cats breathing 100% oxygen should be 98% to 100%.
- Normal PaO₂ in the anesthetized dog and cat breathing 100% oxygen should be greater than 200 mm Hg and can be as high as 650 mm Hg.
- A SpO₂ of 90% corresponds to a PaO₂ of 60 mm Hg, which indicates hypoxemia. Hypoxemia is insufficient oxygenation of arterial blood and is considered to be present if:
  » PaO₂ is less than or equal to 60 mm Hg
  » SpO₂ is less than or equal to 90%.

In the clinical setting, PaO₂ can be estimated using pulse oximetry:

\[
\text{PaO}_2 = \text{SpO}_2 - 30
\]

(for pulse oximeter readings between 75% and 90%)

This formula only applies to a certain range of pulse oximeter readings because of the linear relationship between the PaO₂ and SpO₂ values on the mid portion of the hemoglobin dissociation curve. Outside of these values, this rule cannot be applied.
DEPTH OF ANESTHESIA

An anesthetic gas analyzer (Figure 8) measures end-tidal inhalant concentration (halothane, isoflurane, sevoflurane, or desflurane). While this value is not a direct representation of the depth of anesthesia, it provides a more precise method for determining the patient’s uptake of anesthetic, in comparison to the vaporizer dial setting.

Minimum alveolar concentration (MAC) is the inhalant anesthetic concentration in the lungs required to prevent purposeful movement in 50% of animals (dogs or cats) in response to surgical (skin incision) stimulus. Understanding MAC in combination with end-tidal anesthetic gas concentration can help the anesthetist avoid too light or deep anesthesia in a patient.

A surgical plane of inhalant anesthesia is usually 1.3 to 1.5 times MAC. Dogs or cats that are maintained on greater than 1.5 to 2 times MAC (one MAC of isoflurane = 1.28% for dogs and 1.63% for cats) of any given inhalant are likely to be in a very deep plane of anesthesia (especially in the premedicated patient). Evaluating MAC can prompt the anesthetist to assess the patient and ensure that the cardiorespiratory functions are appropriate and not severely depressed by the inhalant.

BODY TEMPERATURE

Monitoring body temperature in order to prevent hypothermia and hyperthermia is vital. Body temperature should be monitored perioperatively every 5 to 10 minutes until the patient has recovered to sternal recumbency and body temperature is maintained between 99°F to 102°F.

Hypothermia may result in inability to metabolize anesthetic drugs, prolonged recovery, and impairment of wound healing. Hyperthermia may result in neurologic damage or death if not treated aggressively and in a timely manner; it also results in the patient becoming hypermetabolic, which increases the need for oxygen and glucose.

Body temperature can be monitored continuously with an esophageal temperature probe that measures the temperature of blood flowing through the aorta. Alternatively, a rectal or tympanic temperature can be obtained with a regular thermometer.

LABORATORY ANALYSIS

Hematocrit & Total Protein

Hematocrit (PCV) not only reflects the blood’s oxygen carrying capacity, in certain surgical cases, monitoring perioperative serial PCVs coupled with serial total protein levels can also aid the anesthetist in proper fluid management, including crystalloid, colloid, and blood transfusion therapy. Anemic patients (perioperative PCV < 20%) have low oxygen content (decreased oxygen carrying capacity due to low hemoglobin concentrations) and, therefore, lower oxygen will be delivered to tissues despite normal cardiac output.

Blood Glucose

Blood glucose monitoring provides vital information about a patient’s glycemic stage. This is particularly important in the pediatric, diabetic, or septic patient. Blood glucose levels that are too high or too low can contribute to prolonged recovery from anesthesia. Monitoring blood glucose levels throughout the perioperative period helps the anesthetist make appropriate decisions regarding dextrose supplementation and/or insulin dosing.

Blood Lactate

Normal lactate concentration is less than 2 mmol/L. As previously mentioned, blood lactate concentration will increase if tissue perfusion is inadequate, or if oxygen supply is insufficient to meet the tissue oxygen demands.

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demand. An elevated lactate level in a patient during the perioperative period requires immediate evaluation of both cardiac output and oxygenation; it also aids the anesthetist in determining appropriate corrective actions.

Lactate is produced when oxygen delivery cannot meet tissue oxygen demands, and the compensatory increase in oxygen extraction is not sufficient to sustain aerobic metabolism. Cells will use anaerobic metabolism as an alternative energy source, producing the by-product lactate.

Blood lactate concentration can be easily measured with a single drop of blood (Figure 10) using a validated lactate meter for dogs (Lactate Pro hand-held analyser, kdk.com).

**Urine Output**
Under general anesthesia, normal urine output (1–2 mL/kg/H) represents adequate kidney perfusion and assumes proper perfusion of other organs as well. For patients with renal failure, severe dehydration, or acute hemorrhage, it is important to monitor and check urine output during surgery and recovery. If a urinary catheter is not preplaced, palpation of the animal’s bladder or visual estimation of the volume of urine voided can provide a crude estimate of urine production.

Lack of urine production represents hypoperfusion of the kidneys and other tissues, as well as possible kidney failure. Until adequate urine production is achieved, rehydration and an inotropic agent may be used to treat hypotension or tissue hypoperfusion during anesthesia and the recovery period. Patients that have low urine output with normal tissue perfusion and blood pressure may be in renal failure and might require treatment with diuretics.

The next and final article in this series will discuss corrective actions necessary to address abnormalities detected by anesthetic monitoring equipment in order to achieve the goal of safe anesthesia.

BP = blood pressure; CO₂ = carbon dioxide; ECG = electrocardiography; ETCO₂ = end-tidal carbon dioxide; MAC = minimal alveolar concentration; PaCO₂ = partial pressure of CO₂ in arterial blood; PaO₂ = partial pressure of oxygen in arterial blood; PCO₂ = partial pressure of CO₂; PCV = packed cell volume; PvCO₂ = partial pressure of CO₂ in venous blood; SaO₂ = percentage of available hemoglobin saturated with oxygen; Spo₂ = saturation level of oxygen in hemoglobin as measured by pulse oximetry

**References**