ICU Patient Monitoring: Show Me the Numbers

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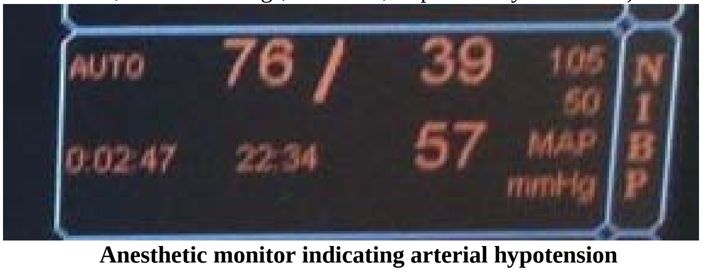
Most veterinary practice have an anesthetic monitor that provides important digital data about the patient's condition. However, there are so many beeps, numbers, charts and graphs that it can be difficult to keep everything straight. This lecture will serve to review the basic physiology of the monitoring device and briefly discuss troubleshooting when problems occur. Monitoring implementations covered in this talk will be: blood pressure, pulse oximetry, electrocardiography (ECG), end-tidal CO2 monitoring, and temperature.

Blood pressure

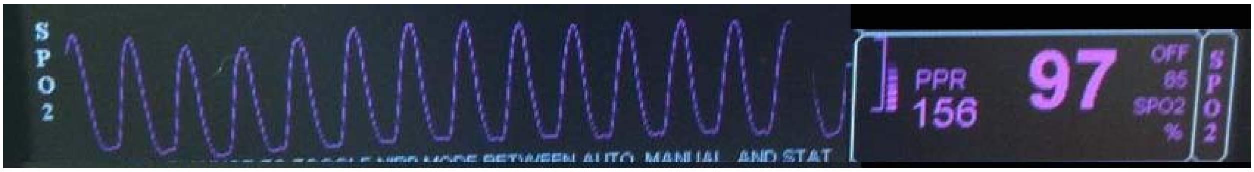
Arterial blood pressure is defined in the following equation: ABP = CO x SVR, where CO = Cardiac output and SVR = Systemic vascular resistance. CO is further differentiated into heart rate (HR) and stroke volume (SV). Stroke volume can, finally, be sub-divided into preload, afterload, and contractility. Thus, there are many factors that affect arterial blood pressure. These include: blood volume/viscosity (preload), arterial tone (vasoconstricton or vasodilation), tachycardia, bradycardia, or decreased cardiac contractility. Since there are many things that can cause hypo or hypertension, the veterinary technician anesthetist should be diligent in investigating what the cause of the derangement of blood pressure is. Normal arterial blood pressure is approximately: Systolic: 100-150 mmHg, Diastolic 90-95 mmHg, and mean arterial pressure: 80-100 mmHg. Measurement of blood pressure is typically done in three different ways in veterinary medicine: doppler ultrasound measurement, oscillometric methods, or direct monitoring (using an arterial catheter and transducer). While direct monitoring is gold standard, most clinics do not have this capability. The Doppler unit has been shown to be the most accurate in critical patients, but oscillometric methods should suffice for most surgeries. With both of those methods, cuff placement is very important. The cuff should be the appropriate size, and placed in a variety of spots, but the measurements should trend logically and not jump around. The systolic value is the pressure in the artery at maximal cardiac contraction, and the diastolic is the measurement in the artery at maximal cardiac relaxation. A patient with a slightly vasodilated artery but increased contractility could drive their blood pressure to normal. The mean arterial pressure is important in organ perfusion as it represents an average pressure across the cardiac cycle. Most organs need a minimum mean pressure to create a physiologic pressure gradient to deliver blood to the organ or tissue. The most common abnormality experienced in anesthesia is hypotension (due to inhalants, anesthetic drugs, fluid loss, or potentially blood loss).



Anesthetic monitor indicating arterial hypotension

Pulse oximetry

A pulse oximeter measures the saturation of red blood cells with oxygen and reports this in a percent. It also measures heart rate as it needs to work over a peripheral artery. This machine is non-invasive, real-time and provides information on oxygenation vs. ventilation. It works by shining two wavelengths of light (red and infrared) through one side of the emitter, through the tissue bed, and to the receiver side of the clip. Hemoglobin absorbs both red and infrared light, but it does so differently whether it is oxygenated or de-oxygenated. The amount of unabsorbed light is also detected by the machine. Pulse oximetry does NOT measure actual oxygen content of the arterial blood or partial pressure of absorbed oxygen gas. But with the exception of rare conditions, inability to oxygenate should be reflected on the pulse oximeter. However, these numbers need to be interpreted with caution. As oxygen enters the lungs, it traverses the capillary-alveolar barrier and diffuses into the blood. It is then absorbed into the hemoglobin molecule. As inhaled oxygen concentrations increase (to 100% under anesthesia), so should both the pulse oximetry reading and the partial pressure (dissolved oxygen). If the dissolved oxygen level does not increase or is lower than physiologically acceptable, the same dramatic change may NOT be represented as a dramatic change on the pulse oximeter. Pulse oximeter readings on room air should be 94% or greater. Under anesthesia they should be 98% or greater. Changes from 98% to 94% can represent a multiple-fold decrease in plasma oxygen levels and can represent serious hypoxemia in an anesthetized patient.



Pulse oximeter reading with waveform

End-tidal carbon dioxide monitoring

As pulse oximetry measures oxygenation in a non-invasive way, ventilation (clearance of CO2) can be measured non-invasively as well using a capnometer. The capnometer measures the CO2 level in an exhalation at the very end, hopfully mimicking the content of arterial carbon dioxide. This is done by attaching a T-piece adapter between the endotracheal tube and the anesthetic circuit. The resulting capnograph represents the exhalation cycle and carbon dioxide levels. Important information can be gathered by interpreting the capnograph. Hypoventilation is very common under anesthesia for a variety of reasons. Patients can be under the influence of respiratory depressant agents (inhalant or injectable medications), be on their side, or laying on their backs with their abdominal viscera encroaching on normal chest wall movement, or potentially be paralyzed for a special procedure. Ventilatory changes do NOT have the same drawbacks as the pulse oximeter in terms of reporting hypo or hyperventilation. A normal end-tidal CO2 reading should be a few mmHg less than arterial blood. So typically 30-35 mmHg (arterial of 35-40) is considered normal. And, because the end-tidal readings are also in real time, any reading <30 indicates hypocarbia and potentially hyperventilation, and any reading >35 indicates hypercarbia and hypoventilation. Typically hypoxemia, often NOT reflected on the pulse oximeter, can be corrected by enhancing ventilation under anesthesia (sigh breaths, intermittent positive pressure ventilation, or initiating mechanical ventilation). In addition, the end-tidal CO2 monitor is very sensitive in detecting cardiac arrest; the capnogram will reveal a 0 mmHg end-tidal reading as when there is no perfusion there is no gas exchange. This will occur much more quickly than potential ECG or pulse oximetry readings.

Normal capnograph and end-tidal CO2 reading

ECG

The electocardiograph (or gram) measures the electrical conduction of the heart. Most ECG's used in small animal anesthesia measure a Lead II reading, which looks at the heart's conduction system from a specific direction. In this lead, the p-wave should always be positive. The QRS can be variable, but typically the Q-wave is negative, the R wave is positive, and the S-wave is negative. The T-wave can be positive, negative, or biphasic. The normal cardiac conduction cycle should begin with the p-wave indicating depolarization of the sinoatrial (SA) node and atrial depolarization (corresponding to atrial contraction). The depolarization wave should pass across the atria and travel to the atrioventricular (AV) node where it slows and is directed to the bundle of His. Here the signal splits into two bundle branches, both innervating a specific ventricle. Blood has been pushed through the right and left atria, through the tricuspid and mitral valves into the right and left ventricles. As the signal travels down each bundle branch, it continues to the terminal Purkinje fibers which innervate just about every cardiac cell in the ventricles. This whole cycle corresponds to the QRS complex on the ECG and comprises ventricular depolarization (corresponding with contraction). Every muscle cell in the body that receives an electrical (nervous) stimulus, must "reset" before it can contract again, and so a repolarization wave then crosses over the ventricles (the T-wave) before the next p-wave occurs. Arrhythmias are abnormal rate, rhythm, or cardiac conduction that can be detected by the ECG. Typical examples include: rate (tachycardia, bradycardia), rhythm (premature, paroxysmal, etc), or cardiac conduction (atrial, ventricular, junctional arrhythmias). Common anesthetic arrhythmias include: sinus tachycardia (from sympathetic stimulation, pain, hypovolemia, light anesthetic depth), ventricular premature contractions (from pain, shock, hypoxia, etc), and some AV-blocks indicating slowed conduction through the AV node (typically from anesthetic drugs).

Temperature

Although temperature seems like temperature is simplistic to measure and monitor, not all monitors continuously measure temperature and it is an important anesthetic parameter. Monitors that utilize an esophageal ECG often have a temperature function, but a continuous rectal temperature, or intermittent monitoring (with a digital thermometer) should be done routinely with the patient under anesthesia. Hypothermia is a common occurrence under anesthesia, and derangements in temperature can affect the cardiac cycle, blood pressure, and even coagulation.

References available upon request.