MONITORING EQUIPMENT – WHAT WE SHOULD REALLY BE USING

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Monitoring Equipment

One of the best pieces of monitoring equipment is an experienced anesthetist! While it is obviously important to monitor blood pressure, oxygenation, etc. it is equally important to visually monitor the patient too. The anesthetist should regularly monitor palpebral reflex, toe pinch, jaw or beak tone, heart and respiratory rates, depth of the breath, capillary refill time or venous refill time, and mucus membrane color.

Monitoring a patient's vital signs under general anesthesia is extremely important. The extent of monitoring will depend on the ASA status of the patient and the procedure being performed. At a minimum, the heart rate, respiratory rate, pulse quality (if possible), mucus membrane color and capillary or venous refill time, core body temperature, and blood pressure (if possible) should be monitored continuously and recorded onto an anesthetic record every five minutes. Additional monitoring can include electrocardiography, capnography, pulse oximetry, arterial blood gas monitoring, direct arterial blood pressure, and central venous pressure monitoring. It is important to remember that anesthetic drugs can cause respiratory and cardiovascular depression in any patient regardless of age or disease status, therefore anesthetic monitoring is mandatory.

There are many multiparameter anesthetic monitors on the market today. A multiparameter monitor generally has all or most all of the common monitoring devices in one machine. While these machines often make monitoring anesthesia more convenient, they are not necessary if you have access to individual pieces of equipment that can be used to meet the needs of each patient.

Blood Pressure Monitoring

Blood pressure should be monitored in any patient undergoing general anesthesia (may not be possible in some exotic species). It is important to maintain normotension during the anesthetic period. Normal blood pressure helps ensure adequate tissue perfusion of the major organs. Untreated hypotension can lead to organ damage or failure, shock, or even death. Blood pressure can be obtained using either direct (invasive) or indirect (non-invasive) methods. Non-invasive blood pressure monitoring (NIBP) is most commonly utilized and can be accomplished using either the oscillometric or Doppler method. Oscillometric monitoring is often not viable in many exotic animals.

The Doppler method works by placing an ultrasonic probe over an artery. With proper placement, the "whooshing" sound of the heart should be audible. A blood pressure cuff is then placed proximal to the probe. The cuff is occluded using a sphygmomanometer until the sound of the heart in no longer apparent. The cuff is then slowly deflated until the heart sounds return. The first heart sound is considered the patient's systolic blood pressure. This is an easy and accurate way to obtain systolic blood pressure in both dogs and cats. This method also works well with smaller patients or those with short, stubby legs. Common sites used for Doppler probe placement include the metacarpal, metatarsal, and coccygeal arteries. Ideally the chosen area should be free of hair. Ultrasound gel between the skin and the probe will make the heart sounds audible.

The oscillometric method uses a machine (Cardell®, petMAP) to calculate the heart rate, systolic, diastolic, and mean arterial blood pressure. Machines can be programmed to check the blood pressure at specific time intervals. Oscillometric methods can give inaccurate readings. This is most often experienced in patients that have arrhythmias, severe hypotension, vasoconstriction, or those weighing less than 5kg.

Cuff size is important regardless of what indirect method is chosen. In canine patients, the width of the cuff should extend about 40% of the circumference of the limb or tail. In the feline patient, the cuff should extend about 30 to 40%. In exotic patients we use 30-40% the circumference of the limb.

Direct blood pressure is considered the "gold standard" technique. It is the only method that will give continuous, real time monitoring and it is the most accurate. Direct blood pressure monitoring does take specialized equipment and advanced training to properly catheterize the artery and maintain patency. Invasive blood pressure monitoring is suggested for patients that are critically ill or at an increased risk for complications. The arteries used for cannulation in the dog include the dorsal pedal, auricular, coccygeal, femoral, and palmar with the dorsal pedal artery being the most common. The dorsal pedal and coccygeal arteries are most commonly used in the feline patient. Regardless of species, the dorsal pedal artery is the easiest for maintaining post-operatively. In rabbits, the most common site is the auricular artery. In ferrets, the most common site is the coccygeal artery. In birds, the most common site is the cutaneous ulnar artery (basillic). Arterial catheters are not generally placed clinically in reptiles.

Regardless of how blood pressure is monitored, hypotension should be treated when present. Hypotension can be treated in several ways. In general, the first step is to decrease the vaporizer setting if possible. If this doesn't work or if the inhalant cannot be reduced, the patient can be administered a 10 to 20 ml/kg bolus of crystalloid fluids (if safe for the patient). Crystalloids do not stay in the vascular space for long periods of time and an increase in blood pressure may be short lived.

Colloids are also another option for the treatment of hypotension. Colloids contain large molecular weight substances that stay within the vascular space for longer periods of time compared to crystalloids. Colloids are often used as a bolus starting with 5 ml/kg. If other treatment options are not possible or have failed, positive inotropes can be employed and are administered as a constant rate infusion.

Capnography

Capnography provides a non-invasive method for measuring end-tidal carbon dioxide ($ETCO_2$). There are a few terms used to describe the various aspects of capnography. Capnometry is the numerical display of end-tidal CO_2 ($ETCO_2$). The capnogram is the graphical display of $ETCO_2$ and capnography or the capnograph is the technique or instrument used to measure $ETCO_2$. In many cases, people use the term capnography as an all-inclusive term for all of the above.

Capnography is a good tool to help assess ventilation in many species. Capnography is an indirect measurement of arterial CO_2. $ETCO_2$ correlates well with $PaCO_2$ (direct arterial measurement of CO_2). In mammals, the measurement of $ETCO_2$ can read about 2 to 5mmHg lower than actual $PaCO_2$. In birds the opposite is true. The anatomy and physiology of the avian lung is quite different than that of mammals. Bird lungs create an efficient cross-current exchange system which produces a higher concentration of CO_2 in expired gas compared to the actual arteries. This means that the $ETCO_2$ reading on the capnogram will be higher than the actual $PaCO_2$. In birds, it is estimated that the $ETCO_2$ reading will be about 5mmHg higher than the $PaCO_2$ reading.

In summary, $ETCO_2$ in the avian patient overestimates actual $PaCO_2$ by about 5mmHg which is opposite of what is observed in mammals. Capnography has many uses all species and can actually yield a lot of information if you understand and know how to read the numbers and graph. The website www.capnography.com is an excellent source for learning about capnography. This site is human based, but translates well to veterinary medicine.

The usefulness of capnography in reptiles may be limited. Unfortunately, there is evidence that suggests capnography in reptilian species may not demonstrate the same relationship as seen with birds and mammals. Does this mean capnography doesn't have a place in reptile anesthesia? No it doesn't. Capnography can still be extremely useful as it can demonstrate leaks in the endotracheal tube or circuit, airway obstruction, ventilator malfunction, potential V/Q mismatch, etc. Trends can be monitored and assessed over time. One phenomenon seen during reptile anesthesia is cardiac shunting. Reptiles can intermittently shunt blood away from the lungs. This can be observed during prolonged periods of apnea and during diving or a diving reflex/response. This response can be seen numerically on the capnograph. When this occurs, the $ETCO_2$ will start out in the "normal" range and then drop to numbers somewhere between 0 and 10 mmHg. In other species this would be a serious emergency. When this occurs, the anesthetist should check the overall vitals of the patient, ensure the endotracheal tube is still properly connected and that there are no major malfunctions with the equipment. If everything is in working order, this drop in $ETCO_2$ is most likely due to cardiac shunting.

Patients are considered hypercapnic (too much CO_2) when $ETCO_2$ is greater than 45 mmHg. Increased values indicate inadequate ventilation, rebreathing of CO_2, or hypoventilation. Prolonged values reading above 60 mmHg can lead to hypoxemia. Hypoxemia predisposes patients to arrhythmias, myocardial depression, respiratory acidosis, and is rare cases, heart failure. In these cases, patients should be manually or mechanically ventilated to decrease $ETCO_2$. Hypoventilation can also indicate too deep of an anesthetic plane. Vitals and depth should be assessed and anesthetic depth adjusted as needed.

$ETCO_2$ values that are less than 35 mmHg can indicate hyperventilation. These patients are considered hypocapnic (not enough CO_2). Ventilation may also be required to help regulate erratic breathing patterns such as tachypnea. Hyperventilation can also indicate a light anesthetic plane or pain. This should obviously be assessed and dealt with accordingly. Hypocapnia can also indicate other issues such as V/Q mismatch, decreased cardiac output, esophageal intubation, extubation of the patient, kink or mucus plug in the tube, apnea, and hypothermia.

There are two types of caponographs on the market; sidestream and mainstream. Sidestream capnography requires a sample line to be connected directly to the airway. This method offers continuous sampling by pumping gases through tubing into the measurement chamber. This is very effective but does have a higher chance of becoming kinked or clogged with blood, mucus, or moisture.

Mainstream capnography analyzes gas directly at the endotracheal tube where the device is attached. The mainstream device can increase dead space so it is important to use a pediatric piece when working with small patients. Mainstream monitors are less likely to become clogged and are often cheaper to maintain. The downside is that they are larger than side stream monitors and can pull or kink the endotracheal tube.

Electrocardiography

The electrocardiograph (ECG) is the only piece of equipment that will monitor both heart rate and rhythm. The ECG works by displaying a graphical representation of electrical activity in the heart. All mammals have a four-chambered heart. The initial electrical impulse starts in the sinoatrial (SA) node (heart's natural pacemaker) located in the right atrium and then travels to the atrioventricular (AV) node located between the atria and the ventricles. The electrical impulse then travels through the purkinje fibers and out through the ventricles. These electrical impulses produce the P-wave, QRS complex, and T-wave seen on the normal ECG.

The P-wave represents atrial depolarization. This occurs during contraction when blood is pumped from the atria into the ventricles. The QRS complex represents ventricular depolarization. This occurs when blood leaves the heart and travels to the lungs from the right ventricle or the rest of the body from the left ventricle. The T-wave represents ventricular repolarization. This occurs during relaxation when passive refilling of the ventricles take place.

In veterinary medicine, the most common ECG used for monitoring under anesthesia is the 3-lead system. There are various color schemes used for each lead, but most commonly a white lead is used for the right forelimb, a black lead is used for the left forelimb, and a red lead is used for the left hindlimb. These leads can be placed on the animal using an ECG sticky pad either attached to the foot or chest/abdominal wall. Alligator clips can also be used, but the teeth should be flattened out when possible to help prevent trauma. If thick scales are present or if the tissue is friable, a needle can be place through the skin and the alligator clip attached to the needle.

Pulse Oximetry

Pulse oximetry monitoring allows for noninvasive measurements of oxygen saturation of arterial hemoglobin. Common sites for probe placement include the pinna, foot, prepuce, vulva, lip, tongue, or anywhere there is a non-pigmented area of skin. Heavily furred and pigmented areas can affect the monitor's accuracy. Vasoconstriction, hypovolemic shock, dry mucus membranes, hypothermia, interference with ambient light, motion/shivering, and hemoglobin abnormalities can also cause inaccurate readings.

Oxyhemoglobin and deoxyhemoglobin are able to absorb infrared and red light at different wavelengths. A pulse oximeter probe emits both infrared and red light via two light-emitting diodes. When the probe is placed across an arterial bed, light is absorbed at the different wavelengths and the percentage of oxygenated hemoglobin to total hemoglobin is expressed. This is what we call SpO_2.

A saturation of 98% to 100% is normal for SpO_2. The SpO_2 corresponds to a specific number on the hemoglobin-oxygen dissociation curve. The curve slopes down drastically after the SpO_2 drops below 90%. An SpO_2 of 90% corresponds to 60 mmHg on the dissociation curve. At this point, the patient is considered hypoxemic and corrective action needs to be taken.

Pulse oximetry is often not affective in birds and reptiles due to differences in hemoglobin and calibration of the machine. You can still use it to look at trends rather than real numbers.

Temperature Monitoring

Core body temperature should be monitored in all patients under general anesthesia. A simple rectal or continuously reading rectal thermometer can be used in most patients. Rectal probes are ideal in patients undergoing endoscopic procedures dealing with the respiratory system, nasal, and/or oral cavities. Esophageal probes can be utilized when they are not directly interfering with endoscopic procedures. Esophageal probes give a continuous reading and in some cases are combined with an esophageal stethoscope. Core body temperature should be checked and recorded at least every 15 minutes.

Hypothermia is a by-product of anesthesia but can be prevented with the use of heating pads, forced warm air blankets, and covering the patients with basic items like fleece pads or bubble wrap. Hypothermia can lead to coagulopathies, increases oxygen consumption due to shivering, and prolonged recovery times and post-op healing time in general.

Basic Blood Gas Monitoring

Arterial blood gas monitoring is considered the "gold standard" method used to evaluate gas exchange and the acid-base status of the patient. There are many different blood gas analyzers on the market today ranging from large tabletop machines to handheld bedside machines. Both have their advantages and disadvantages, but honestly the end result is generally the same. Most blood gas analyzers provide at the minimum, values for pH, $PaCO_2$ (partial pressure of carbon dioxide), PaO_2 (partial pressure of oxygen), SaO_2 (oxygen saturation), and HCO_3- (bicarbonate level). Other common values include electrolytes, hemoglobin, base excess/deficit, and lactate. An entire chapter can be written on blood gas analysis therefore we will only cover the very basics.

The normal pH in mammals ranges from 7.35 to 7.45. Values below 7.35 indicate an acidosis and values above 7.45 indicate an alkalosis. As the pH increases, the $PaCO_2$ decreases and as the pH decreases the $PaCO_2$ increases. Therefore as the $PaCO_2$ levels become elevated (usually from poor ventilation), the pH decreases and the patient develops a respiratory acidosis.

Blood gas analysis values in birds and reptiles will vary greatly by species. This area is at its infancy and much more research is needed in this area.