Monitoring the Anesthetized Patient
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The word monitor comes from the latin word monere which means to warn. Since anesthetic drugs alter a patient’s normal physiology and the body’s ability to maintain homeostasis, the primary purpose of monitoring during anesthesia is to warn the anesthetist of changes in anesthetic depth or physiologic status of the patient to facilitate an early response.

When devising an intra-operative monitoring plan, it is necessary to take into account the patient’s pre-operative status and information including: a complete and thorough history and physical examination including age, breed and temperament, current medications, co-morbidities and risk factors, previous anesthesia and the procedure being performed.

The anesthetic record provides a legal record of events, prompts the anesthetist to observe, evaluate and record the patient’s status at least every 5 minutes and allows trends to be recognized. Information that should be included on the record include: the date, patient identification, physical exam parameters including heart rate, respiratory rate and body temperature, procedure, drugs administered including dose, route and time, endotracheal tube size, circuit (adult or pediatric circle vs NRB), ventilator settings etc. *Irreversible CNS & cellular changes occur within 3-5 min of cessation of blood flow* and so it is recommended to have written monitoring parameters at least every 5 minutes.

What do we monitor?
1. Anesthetic Depth: Too light of an anesthetic plane may result in arousal, awareness, movement and pain. Too deep of an anesthetic plane may result in anesthetic overdose, cardiovascular/respiratory compromise and slow recovery.
2. Oxygenation: Adequate oxygenation depends on both the circulatory and respiratory function of the patient
3. Ventilation: Adequate ventilation depends on the respiratory function of the patient
4. Circulation: Adequate circulation depends on the circulatory function of the patient
   a. Oxygenation, Ventilation & Circulation => All 3 together maintain tissue/organ perfusion with oxygenated blood - Adequate delivery of oxygen to tissues (DO2) is the key to patient survival and requires functioning of both the cardiovascular and respiratory systems.
5. Body Temperature

Anesthetic depth

Eye position, palpebral and corneal reflexes
Eye position can be a reliable method for monitoring anesthetic depth in dogs and cats. The globe rolls ventrally at a surgical plane of anesthesia. The globe is centered at both light and deep planes of anesthesia and therefore, the anesthetist needs to use the palpebral reflex to differentiate between the two. Centered globe + present palpebral reflex = light plane of anesthesia, Centered globe without a palpebral reflex = deep plane of anesthesia. Dissociative anesthetics such at ketamine and tiletamine may alter the eye position; expect the globe to be centered at all planes of anesthesia. The palpebral reflex is elicited in small animals by gently tapping on the skin near the medial canthus of the eye; it should be absent at a surgical plane of anesthesia. The corneal reflex is elicited by pressing on the cornea, causing the eye lids to close. It should ALWAYS be present in a live animal but, since damage to the cornea may occur, it should not be used in an animal believed to be alive.

Others: withdrawal reflex, jaw tone, movement
The withdrawal reflex is elicited by pinching the patient’s toe or toe web, if the patient withdraws its limb, then it is not at a surgical plane of anesthesia. Jaw Tone can also give an indication of anesthetic depth in dogs and cats as it will vary with depth of anesthesia. However, it is very subjective and may not be reliable with dissociative anesthetics which increase skeletal rigidity and well-muscled dogs such as pit-bulls, rottweillers etc. Patent movement is an obvious sign that anesthetic depth is inadequate but beware of other causes that may mimic patient movement such as surgeon manipulation, hyperventilation due to hypercarbia/hyperthermia and agonal breathing.

End-tidal carbon dioxide concentration (EtCO2) and end-tidal concentration of anesthetic gases & MAC
Inhalant anesthetics are dose-dependent respiratory depressants and therefore, will cause EtCO2 to increase. Normal EtCO2 = 40mmHg, anesthetized animals will be higher depending on their depth and the amount of respiratory depression. EtCO2 should be kept < 60mmHg.

The Minimum Alveolar Concentration (MAC) is the inhalant anesthetic concentration in the lungs required to prevent purposeful movement in 50% of animals in response to a noxious stimulus. MAC of Isoflurane in the dog = 1.28% and the cat is 1.63%. A surgical plane of anesthesia ~ 1.3 to 1.5 times MAC; 95% of patients are adequately anesthetized at 1.5 MAC. Remember that pre-medication drugs and analgesics will lower the MAC of inhalant. MAC represents the population of dogs/cats and not the individual,
therefore, inhalant gases should be titrated to the individual animal and procedure. Monitoring the End-tidal inhalant % is more precise than the vaporizer setting as it reflects the concentration in the brain.

**Circulation**

Clinical evaluation of circulation can include assessment of capillary refill time (CRT), auscultation of the heart beat and palpation of peripheral pulses. Normal CRT is <2 seconds; prolongation may indicate poor tissue perfusion or dehydration. Anesthetic drugs may interfere with interpretation due to vasodilation/constriction and so, is not very helpful during general anesthesia. Auscultation of the heart beat may be performed with a stethoscope, esophageal stethoscope or doppler. Heart rate may change with anesthetic depth in small animal patients, but is also altered by many anesthetic drugs, usually causing bradycardia. Palpation of peripheral pulses in dogs and cats is most commonly performed using the femoral, dorsal pedal or lingual arteries. Remember the pulse pressure reflects SAP – DAP and does not indicate MAP; it is also affected by anesthetic drugs.

Esophageal Stethoscope is inserted to the level of the heart and is an inexpensive method of monitoring heart rate and respiratory rate. Disadvantages are that it is only useful when earpieces are being used by the anesthetist and is difficult to use during certain procedures (ENT, endoscopy).

Electrocardiogram (ECG) monitors heart rate and rhythm, can definitively diagnose arrhythmias and monitor their treatment. It gives an audible beep with each R wave. The limitations are that it only gives electrical, not mechanical (cardiac output) information regarding the activity of the heart and therefore should not be used as a sole monitor during anesthesia.

- Lead Placement => 3 leads attached as either:
  - Limb leads: Lt, Rt forelimb, Lt hindlimb electrodes, with selection of lead II on ECG
  - Esophageal ECG - Rt forelimb & Lt hindlimb placed on esophageal probe, Lt forelimb on ear or neck, select lead II on ECG
  - Base apex- Rt forelimb & Lt hindlimb electrode attached to the right (preferred) or left (alternative) jugular furrow, Lt forelimb electrode attached to opposite thoracic wall caudal to the heart, lead I (negative deflection), or lead III (positive deflection) on the monitor

The advantage of esophageal or base-apex lead placement is that it avoids attachment to the hindquarters therefore gives anesthetist access to leads during the procedure and minimizes motion artifact.

Ultrasonic Doppler measures pulse rate, blood flow, and systolic blood pressure (SAP) when used with sphygmomanometer & cuff. The probe is placed over a peripheral artery (limb or tail) with the cuff placed proximal to the probe. Dopplers are inexpensive (~$900) and provide a measure of blood pressure along with pulse rate. The disadvantages are that BP needs to be measured each time by the anesthetist (it is not automatic), requires proficiency of use, the accuracy is dependent on correct cuff size and fit, there is a weak signal with vasoconstriction/hypotension.

Oscillometric Blood Pressure measures systolic, diastolic and mean arterial blood pressure at a time interval set by the anesthetist. The BP cuff may be placed on a peripheral limb or tail base. This methodology is easy to use and automatic. Newer veterinary specific models are more accurate for small sized patients and affordable. Disadvantages are that the technology is motion sensitive and has decreased accuracy during conditions of low BP, low/high heart rates or the presence of arrhythmias. Like the Doppler, accuracy is dependent on cuff size and fit. The cuff should measure 40% of limb circumference; if the cuff is too small, BP will be overestimated, if the cuff is too large BP will be overestimated.

Direct (invasive)BP measurement is the gold standard for measuring MAP, SAP, DAP. It uses an arterial catheter, BP transducer, +/- monitor to obtain continuous beat-to-beat pulse waves. The advantages are that it is accurate, continuous and allows ABG sampling. Disadvantages include: cost of the transducers and the skill required to place arterial lines. Complications include: infection, thrombosis, hematoma, air embolism, exsanguination, inadvertent drug injection. Common sites for arterial catheter placement in dogs & cats are the dorsal pedal and lingual arteries.

Ventilation – Clinical evaluation of ventilation may include observation of chest wall movements, excision of the rebreathing/reservoir bag, auscultation of lung sounds with a stethoscope or esophageal stethoscope. These give information about the presence, absence, regularity, frequency of ventilation and subjective information regarding the pattern, effort and depth of respiration.

Wright’s Respirometer is placed between the expiratory limb of the anesthetic machine and the ‘Y’ piece. It measures expiratory volume and/or minute volume (Minute volume = Tidal Volume x frequency). Normal TV = 10 – 15ml/kg, normal minute volume = 150-200 mg/kg/min

End tidal carbon dioxide (EtCO2) allows exhaled CO2 to be measured noninvasively which is a reflection of arterial CO2 (PaCO2). It is **Most useful for detection of apnea, hypoventilation** but also detects esophageal intubation, airway disconnection, airway obstruction, leak in endotracheal tube cuff, exhaustion of CO2 absorbent, incompetent one-way valve of anesthetic rebreathing circuit, inadequate O2 flow rate for NRB circuit (increased inspired CO2), indirect measure of cardiac output (eg, sudden, acute drops in CO associated with ↓ ETCO2 due to poor pulmonary circulation), ventilation, perfusion and metabolic status.

- Blood Gas Analysis can be used to evaluate the acid/base status of a patient (pH = acidosis or alkalosis)
  - PaCO2 - measure of ventilatory status of patient
- CO2 – hypoventilation, respiratory acidosis
  - Normal awake PaCO2 = 35-45 mmHg
  - Anesthetic drugs cause dose dependent respiratory depression
    - PaCO2 should be kept < 60 mmHg because this corresponds to ~ 7.2 pH (pH Δ 0.08/ every 10 mmHg ↑ PaCO2) and cellular enzymes malfunction outside a pH range of 7.2-7.5.

**Oxygenation**
Clinical Evaluation of oxygenation can be assessed via mucous membrane (MM) color: pale MM may be due to vasoconstriction (pain, drugs, blood loss), ↓ cardiac output, red blood cells or hypoxia (cyanosis > 5g/100ml reduced Hb), dark pink MM may indicate vasodilation, ↑ CO2, endotoxemia. MM is affected by anesthetic drugs.

**Pulse oximetry**
Provides pulse rate & noninvasive, continuous detection of pulsatile arterial blood in tissue bed. The percentage of oxyhemoglobin and reduced hemoglobin present in arterial blood is calculated & converted to % SpO2. The probe is usually attached to the patient’s tongue, lip, ear, interdigital space or prepuce. Pulse oximeter function may be affected by: motion artifact (shivering, body movement), fluorescent light, poor peripheral blood flow (hypotension, vasoconstriction), ↑ blood carboxyhemoglobin and methemoglobin levels, dark pigmentation of skin or tongue.

**Relationship Between SpO2 and PaO2:**
- Normal SpO2 in anesthetized patients breathing 100% oxygen = 98% to 100%
- Normal PaO2 in anesthetized patients breathing 100% oxygen should be > 200 mm Hg, as high as 650 mm Hg
- SpO2 of 90% corresponds to a PaO2 of 60 mmHg, which indicates hypoxemia (insufficient oxygenation of arterial blood)

In the clinical setting, PaO2 can be estimated using pulse oximetry: PaO2 = SpO2 – 30 (for pulse oximeter readings between 75% and 90%)
- The formula only applies to a certain range of pulse oximeter readings because of the linear relationship between PaO2 and SpO2 values on the mid portion of the hemoglobin disassociation curve. Outside of these values, this rule cannot be applied.

**Arterial blood gas analysis**
PaO2 – oxygenation of blood => Normal 95-100 breathing room air, 500-600mmHg breathing 100% O2
Normal PaO2 in the anesthetized patients breathing 100% oxygen should be > 200 mm Hg and can be as high as 650 mm Hg.

**Body temperature monitoring**
Body temperature may be monitored with a digital thermometer or a thermistor probe inserted into the esophagus or rectum. The causes of hypothermia include: decreased heat production, heat loss via an open body cavity and cold IV fluids or environment. The consequences of hypothermia include: decrease in MAC of inhalant anesthetics, increased risk of surgical infection, impaired coagulation, platelet function and wound healing. Cats are at increased risk for post-operative hyperthermia with the use of opioids if they are hypothermic intra-op.

The causes of hyperthermia include: excessive warming of patients, malignant hyperthermia, opioid use in cats. The consequences of hyperthermia include: increased metabolic rate and oxygen consumption leading to increase circulatory work and cellular hypoxia. Treatment should include active cooling and supplemental oxygen.