VETERINARY HEALTH SCIENCES
OKLAHOMA STATE UNIVERSITY

ANESTHETIC MONITORING

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MONITORING ANESTHETIC DEPTH

- The central nervous system is progressively depressed under general anesthesia.
- Different stages of anesthesia will accompany different physiological reflexes and responses (see table below, Guedel's signs and stages).

Table 1. Guedel's (1937) Signs and Stages of Anesthesia based on 'Ether' anesthesia in cats.

Stages		Description
1		Inducement, excitement, pupils constricted, voluntary struggling
2		Obtunded reflexes, pupil diameters start to dilate, still excited, involuntary struggling
3	Planes	There are three planes- light, medium, and deep
	Light	More decreased reflexes, pupils constricted, brisk palpebral reflex, corneal reflex, absence of swallowing reflex, lacrimation still present, no involuntary muscle movement.
	Medium	Ideal plane for most invasive procedures, pupils dilated, loss of pain, loss of palpebral reflex, corneal reflexes present.
	Deep (early overdose)	Respiratory depression, severe muscle relaxation, bradycardia, no reflexes (palpebral, corneal), pupils dilated
4		Very deep anesthesia. Respiration ceases, cardiovascular function depresses and death ensues immediately.

- Due to arrival of newer inhalation anesthetics and concurrent use of injectable anesthetics and neuromuscular blockers the above classic signs do not fit well in most circumstances.
- Modern concept has two stages simply dividing it into 'awake' and 'unconscious'.
- One should recognize and familiarize the reflexes with different physiologic signs to avoid any untoward side effects and complications
- The system must be continuously monitored, and not neglected in favor of other signs of anesthesia.
- Take all the information into account, not just one sign of anesthetic depth.
- A major problem faced by all anesthetists is to avoid both 'too light' anesthesia with the risk of sudden violent movement and the dangerous 'too deep' anesthesia stage.

Relating changes of reflexes to anesthetic depth

- Palpebral reflex: varies between species. Dogs may have no reflex at adequate surgical depth although complete loss in horses indicates moderately deep anesthesia
- Corneal reflex: does not disappear until deep anesthesia. Should always be present
- Nystagmus: usually indication of excitement and light anesthesia. However, dissociative anesthetics (e.g., Ketamine) cause nystagmus at moderate anesthetic depth. In horses, central stimulation induced by severe hypoxia or hypercapnia also causes this phenomenon, and should not be confused with light plane of anesthesia as animals are perishing!
- Lacrimation: Parasympathetic stimulation, usually signs of light plane of anesthesia
- Medioventral eye ball position: the most desirable position in most species with the exception in horses (central)
- Jaw tone: moderate to loose, most desirable

Most Reliable Signs of Anesthetic Depth

- Gross purposeful movement
- Reflex movement in response to stimulation
- Immediate hemodynamic response to stimulation; sudden marked increase in heart rate or blood pressure.
- Immediate respiratory response to stimulation; sudden marked increase in respiratory rate or depth of breathing.
- Response to stimulation prior to actual incision (such as clipping, surgical preparation, drape, clamps).

Reliable Signs of Anesthetic Depth

- History of vaporizer setting
- Muscle tone (e.g. jaw tone)
- Pupillary light reflex
- Palpebral reflex
- Corneal reflex
- Moist cornea (lacrimination or tears)
- Position of the eyeball

Less Reliable Signs of Anesthetic Depth

- Heart Rate: may increase or decrease with increased depth of anesthetic plane. At deep plane it may accompany bradycardia, but also severe cardiovascular depression may increase heart rate to compensate for fall in stroke volume. (differentiate from noxious stimulation induced increase; less marked in changes).
- Respiration rate: may increase or decrease with deepening anesthesia. At deep plane, it may accompany apnea, but also may initiate a rapid shallow breath following a period of apnea as a compensation. (similar to hemodynamics, fall in tidal volume tends to increase respiration rate.)
- Blood pressure is similar to heart rate, but probably more reliable. In general, the volatile anesthetics; halothane, isoflurane, sevoflurane, and desflurane produce a dose-dependent decrease in arterial blood pressure and many anesthetists use this depression to assess the depth of anesthesia.

Clinical Notes

- The experienced anesthetist relies most of the time on animal's response to stimuli produced by the surgeon or procedure to indicate adequate depth of unconsciousness.
- The most effective depth is taken to be that which obliterates the animal's response to noxious stimuli without depressing circulatory and respiratory systems.

ANESTHETIC MONITORING OF PHYSIOLOGIC FUNCTION

- The primary goal of monitoring anesthetized animals is to ensure adequate tissue perfusion with oxygenated blood.
- Monitoring circulation, oxygenation, ventilation and body temperature in the anesthetized patient allows the veterinary anesthetist to identify problems early, institute treatment promptly, and thus avoid irreversible adverse outcomes.
- The ACVA published a guideline for standards of monitoring during anesthesia and recovery (JAVMA 1995). The guideline recommends continuous monitoring of the patient by the anesthetist and adequate record keeping of the procedure.
- In addition, it recommends patients should be monitored by clinical observations (color, respiratory movement, auscultation etc.), continuous monitoring devices (ECG, BT, pulse oximeter, capnography) and intermittent monitoring devices (Esophageal stethoscope, BP).
- Adequate monitoring is needed even for brief anesthetic periods, during the transport of patients, and with sedation that might cause cardiovascular or respiratory complications.
- Pulse oximetry, capnography and non-invasive blood pressure monitoring represent three current non-invasive monitoring techniques available to use in the anesthetized patient.
- When pulse oximetry and capnography are used together, a beat-to-beat and breath-to-breath non-invasive cardiorespiratory monitoring is provided.
- In general, monitoring the physiologic function is divided into 'subjective' or 'objective' monitoring.
- Subjective monitoring involves using the anesthetist's visual, touch, and auditory senses to assess the patient's vital signs.
- Objective monitoring involves monitoring animal's physiologic function using mechanical devices to amplify the signals that are hard to discern or analyze by human senses, which are then quantified in numeric/graphical forms.

Circulation (cardiovascular) monitoring

- The goal of monitoring the circulatory system is to ensure adequate blood flow to tissues during all anesthetic procedures.

Subjective methods

- Palpation of peripheral pulse, palpation of the heart beat through the chest wall, and auscultation of heart beat.
- Use of a regular stethoscope, esophageal stethoscope, or other audible heart sound monitor aids the anesthetist in assessing the 'presence', 'absence', 'regularity' or 'irregularity' of a patient's heart beat.
- Palpation provides a subjective feeling of 'presence' or 'absence'; 'strong' or 'weak'; 'regular' or 'irregular' peripheral pulse.
- Assessing capillary refill time (CRT) provides a subjective assessment of tissue perfusion. A prolonged CRT suggests poor tissue perfusion.

Objective methods

- Include electrocardiography (ECG), monitoring of arterial blood pressure, cardiac output, and central venous pressures.

Electrocardiography (ECG)

  - Measures electrical activity of cardiac cells

- Other circulatory information including blood pressure, stroke volume and cardiac output is not provided by the ECG.
- The ECG leads are positioned usually near the elbow and stifle using a three lead configuration.
- Alligator clips are used most commonly to attach the electrode tips to the patient. These can be very traumatic when they are attached for prolonged period of time.
- Body position and precise lead placement are not important for monitoring purposes when the primary objective is to describe the electrical pattern in a general manner and monitor for changes that may signal the deterioration of the patient.
- In the horse the right arm lead is placed over the heart (right or left side), while the exact location is not important, the left leg and left arm leads are placed in the jugular furrow and the point of the shoulder.
- There must be a good contact between the ECG leads and skin, and gels are applied to increase the conduction of the electrical signals.
- Alcohol provides for good contact but it evaporates so rapidly as to require frequent application, and is not suitable for long-term monitoring.

Arterial blood pressure

- This provides information regarding the adequacy of blood flow to the patient's tissue.
- At a mean arterial blood pressure below 60 mmHg, organ and tissue perfusion is inadequate.
- In addition to mean arterial blood pressure, systolic and diastolic blood pressure provide useful information concerning peripheral vascular resistance, stroke volume, and intravascular volume.

$$\text{MABP} = \frac{\text{Pulse pressure (Systolic} - \text{Diastolic)}}{3} + \text{Diastolic} = \frac{1}{3}\text{Systoic} + \frac{2}{3}\text{Diastolic}$$

- The systolic blood pressure is determined by a combination of peripheral vascular resistance, stroke volume, and intravascular volume whereas diastolic blood pressure primarily arises from peripheral vascular resistance.
- Clinically, the pulse pressure (systolic-diastolic) allows the anesthetist to estimate the stroke volume.
- When palpating the peripheral pulse, a progressively weakening pulse may correlate with decreased pulse pressure and reduced stroke volume.
- Normal systolic blood pressure range for anesthetized dogs and cats is between 90 mmHg and 120 mmHg, diastolic blood pressure ranges between 55 mmHg and 90 mmHg.

Non-invasive methods:

- A Doppler ultrasound probe coupled with a pressure cuff and sphygmomanometer or an automated oscillometric device (e.g., Dinamap®, Criticon, Tampa, FL).
- The advantage of automated oscillometric detector device over Doppler ultrasonic detector is that the oscillometric is automated and requires neither experience nor labor of the operator.
- The measurement intervals may be adjusted from continuous to 120 minute measurement intervals (I usually set at 3-5 minute intervals).
- The disadvantage of oscillometric detector is decreased accuracy or unreliability when used on a hypotensive or a small patient (less than 5 kg body weight).
- The advantage of the Doppler technique is that it can be applied to any sized animal (from a rat to a horse) and is relatively inexpensive.
- The disadvantage of the Doppler technique is the requirement for operator experience and labor intensity.

Invasive method:

- A catheter is placed into an artery and then connected to a pressure transducer and monitor/recorder.
- The 'gold standard' against which all other methods are compared.
- Provides a continuous, beat to beat assessment of the patient's blood pressure, is more accurate in hypotensive situations, and provides access to an arterial blood sampling site for blood gas analysis.
- Less practical in the clinical setting, requiring more expensive equipment, demands skills in placement of a catheter, and potentially increases the risk of infection and air embolism.

Cardiac output (CO)

- No widespread application by the practicing veterinarian, but the concept of cardiac output is extremely important in the generation and treatment of cardiovascular disease.
- CO is diminished by influences which decrease contractility and by inadequate end-diastolic filling volume (decreased preload).
- Inadequate circulatory blood volume and venous return, especially in conjunction with vasodilating anesthetics may be the most common cause of cardiovascular inadequacy.
- CO is the main determinant of oxygen delivery when the PaO_2 is above 60 mmHg.

Central venous pressure (CVP)

- CVP is the luminal pressure of the cranial vena cava or right atrium.
- It monitors the adequacy of venous return, intravascular blood volume and right ventricular function.
- It should be measured whenever heart failure is suspected, whenever rapid changes in blood volume are expected, or there is a danger of volume overload (e.g., renal failure).
- Normal CVP is 0 to 10 cmH_2O. Measurements in the range of 15 to 20 cm H_2O are too high and efforts should be made to determine and treat the cause of the deviation.
- High normal CVP values do not contraindicate the administration of fluids when other parameters indicate hypovolemia.
- Verification of a well-placed, unobstructed catheter can be ascertained by observing distinctive pressure wave characteristics on the monitor

Oxygenation monitoring

- The goal of monitoring oxygenation in the anesthetized patient is to ensure adequate oxygen concentration in the patient's arterial blood.

Subjective methods

- Clinically, the presence of pink mucous membranes in an anesthetized patient is subjectively indicative of acceptable oxygenation.
- However, oxygenation is either difficult or not possible to assess in anemic patients or patients with peripheral vasoconstriction. These patients usually have pale mucous membranes.

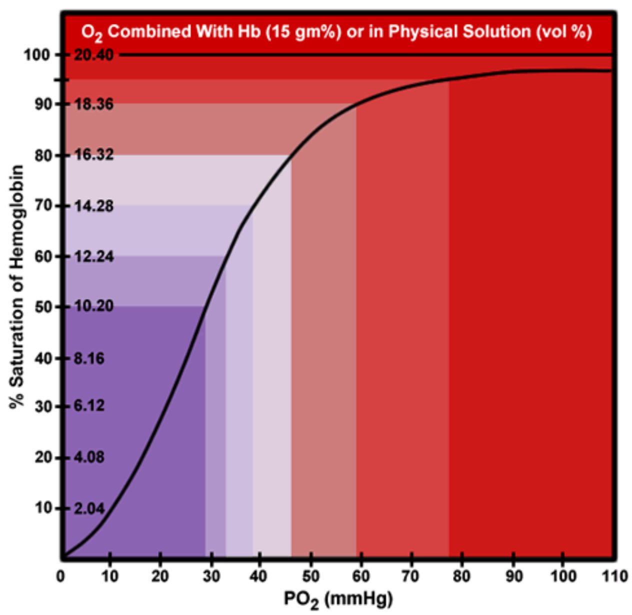
Objective methods

- Objective methods include using blood gas analysis for PaO2 (partial pressure of oxygen in the arterial blood) and pulse oximetry.

Pulse oximetry

- Provides a non-invasive, continuous detection of pulsatile arterial blood in the tissue bed, calculates the percentage of oxyhemoglobin present in the arterial blood, and provides the pulse rate of the monitored patient.
- Rapidly has become **standard** care in anesthetized human patients and has gained **widespread popularity** in veterinary anesthesia.
- Methemoglobin and carboxyhemoglobin do not contribute to functional oxygen transport, and one should be aware of the impact of these abnormal hemoglobin species in pulse oximetry.
- Abnormal accumulation of methemoglobin species tends to push the oximeter reading toward 85 %, underestimating measurements when SaO_2 is above 85 % and overestimating it when below 85%.
- Carboxyhemoglobin has light absorption characteristics similar to oxyhemoglobin, and this would contribute to the increase the apparent oxyheoglobin readings in the presence of carboxyhemoglobin.
- Affected by motion artifact (e.g, shivering), ambient light, poor peripheral blood flow from hypotension and vasoconstriction, electrical noise from electrocautery, and increased carboxyhemoglobin and methemoglobin levels.
- The percentage of hemoglobin saturation with oxygen at different partial pressure of oxygen in the blood is described by the oxyhemoglobin dissociation curve as shown in figure 1 below.

Figure 1. The oxyhemoglobin dissociation curve.



- Normal pulse oximeter readings in anesthetized animals should be 99-100%.
- Hemoglobin oxygen saturation (SpO_2) of 90% corresponds to P_aO_2 of 60 mmHg which provides definition of hypoxemia if lower than this value.
- In the clinical setting, P_aO_2 (as measured by the blood gas analysis) can be estimated using pulse oximetry.
- The sites for probe placement include the tongue, ear lip folds, toe pads, axillary or inguinal skin fold, or prepuce/vulva.

Blood gas analysis

- The partial pressure of the oxygen can be measured with a blood sample.
- Remains the ‘gold standard’ for assessment of oxygenation because of its ability to directly determine the tension of the respiratory gases.
- Requires invasive access of blood, does not provide continuous monitoring and is costly
- Normal PaO_2 in the anesthetized animal that is breathing 100% oxygen should be greater than 200 mmHg (it can be as high as 600 mmHg).

Ventilation monitoring

- To ensure adequate ventilation, the ventilatory function of the anesthetized patient needs to be monitored.

Subjective methods

- May be done by observing chest wall movement or rebreathing bag excursion when the patient is connected to an anesthesia machine.
- Auscultation of breathing sound via an esophageal stethoscope or an audible respiratory monitor provides only respiratory rate, and the absence or presence of respiration.

Objective methods

- Requires respirometry, blood gas analysis, or capnography/capnometry.
- A respirometer (or respirometry) is an instrument that measures the amount of volume of expired gases.
- The device is usually placed between the expiratory limb of an anesthetic machine and the anesthetic breathing hose.
- Alternatively, a respirometer connected to a face mask may be used to assess ventilation efficiency in a non-intubated anesthetized patient, although the accuracy is reduced due to air leaks around the mask.
- Respirometry assesses tidal volume and minute volume in the anesthetized patient.
- Minute volume (V_E) is the product of respiratory rate (RR) per minute and tidal volume (V_T) of the patient ($V_E = V_T \times RR/min$).
- Respiratory rate and/or tidal volume reduction result in minute volume reduction and reflect the patient’s depressed ventilatory function.
- $PaCO_2$, in the patient’s blood can be determined to assess and monitor the anesthetized patient’s ventilation, using a sample collected from the femoral artery or other peripheral artery. Normal values in the anesthetized patient are between 35 mmHg to 45 mmHg.
- $PaCO_2$ measurement requires an expensive blood gas analyzer and arterial blood samples may be difficult to collect particularly in small patients. Measuring endtidal CO_2 using capnography is a useful alternative to estimate $PaCO_2$ without the need for invasive collection of blood samples.

Capnography/Capnometry

- The measurement and numerical (or graphical) display of CO_2 concentration, in the expired air, during the respiratory cycle (inspiration and expiration).
- A capnograph displays a graphic shape (capnogram) of exhaled CO_2 gas, end-tidal CO_2 concentration and also indicates the respiratory rate of a patient.
- A capnometer, on the other hand, presents only the end-tidal CO_2 concentration and respiratory rate without a graphic shape.
- A capnometer lacks the capnogram, and therefore, cannot provide a qualitative analysis and precise diagnosis for the morphologic changes of exhaled CO_2.
- Normally end-tidal CO_2 reflects the partial pressure of CO_2 in the alveoli.
- End-tidal CO_2 concentrations between 35 and 45 mmHg are considered normal in anesthetized animals.
- The measurement of end-tidal CO_2 is useful for determining optimal minute ventilation, hypoventilation, and airway disconnection or airway obstruction.
- This technique is finding increased use in veterinary anesthesia as it is becoming relatively inexpensive.
- It provides continuous method to document ventilation adequacy and limits the need for invasive procedures such as arterial blood gas analysis.
- There are four distinct phases of the capnogram (see figure 2 below).
  - Phase I: inspiratory baseline, which represents fresh gas flow, anesthetic plus oxygen, past the CO_2 sensor during inspiration. The baseline should have a value of zero otherwise the patient is rebreathing CO_2.
  - Phase II: expiratory upstroke, which represents the arrival of CO_2 at the sensor just as exhalation begins. Usually very steep.
  - Phase III: expiratory plateau, which represents exhaled CO_2. The peak of this exhaled CO_2 is called the end-tidal CO_2.
  - Phase IV: inspiratory downstroke, which is the beginning of the inhalation and the CO_2 graphic curve falls steeply to zero.

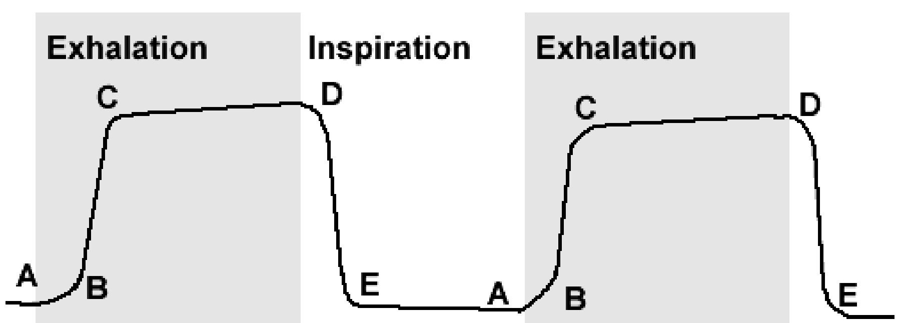


Figure 2. Four distinct phases of capnogram

A-B: exhalation of CO_2 free gas contained in dead space at the beginning of exhalation. **Phase I**
B-C: respiratory upstroke, representing the emptying of connecting airways & the beginning of emptying of alveoli. **Phase II**
C-D: Expiratory (or alveolar) plateau, representing of emptying of alveoli - due to uneven emptying of alveoli, the slope continues to rise gradually during the expiratory pause. **Phase III**
D: End-tidal CO_2 level - the best approximation of alveolar CO_2 level
D-E: Inspiratory downstroke, as the patient begins to inhale fresh gas. **Phase IV**
E-A: Inspiratory pause, where CO_2 remains at 0

- Any deviations from the above normal shape of capnogram should be investigated.

Figure 3. The capnogram below shows a rebreathing of CO_2 due to a possibility of incompetent expiratory valve or exhaustion of soda lime.

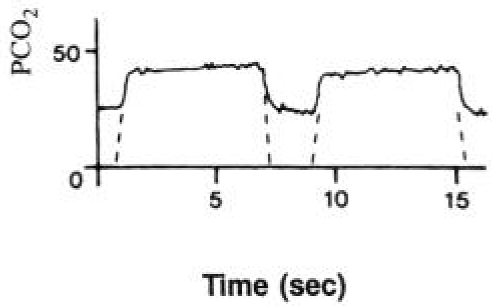
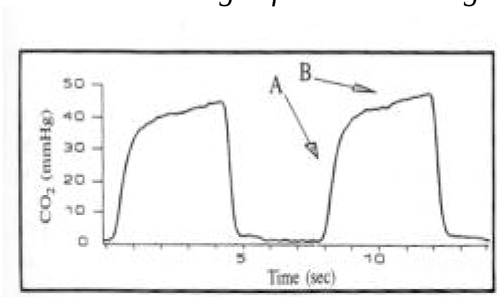


Figure 4. This capnogram below shows a kinked endotracheal tube. Note the prolonged expiratory upstroke (A) and a slanted expiratory plateau (B) due to the slower gas flow rate during these two phases.



- Increases in end-tidal CO_2 concentrations may be due to impaired alveolar ventilation (anesthetic induced respiratory depression), increased metabolism (malignant hyperthermia or sepsis), or the addition of CO_2 to the circulatory system as a result of rebreathing CO_2.
- Rebreathing CO_2 can be due to soda lime exhaustion, incompetent expiratory valve on the anesthetic machine allowing exhaled CO_2 to be re-inhaled (even with normal function of soda lime), or intravenous bicarbonate injection.
- Decreased or abolished end tidal CO_2 concentrations may be due to hyperventilation, low cardiac output (low blood volume delivery to the lungs), respiratory arrest (no alveolar ventilation), or cardiac arrest (no circulation).
- Capnogram monitoring in anesthetized patients, also provides vital information regarding the patient's airway patency.
- A depressed or absent capnogram may be due to a dislodged endotracheal tube, misplaced endotracheal tube (i.e., esophageal intubation), obstructed endotracheal tube or airway, a leak around endotracheal tube cuff or, disconnection of the endotracheal tube from the anesthetic machine.

Urine Output monitoring

- Measure urine output in patients with renal insufficiency and patients susceptible to decreased cardiac output and blood pressure. Use a closed collection system (sterile urinary catheterization required).
- The primary purpose of monitoring includes avoiding excessive distension of the bladder, as an indicator of renal perfusion, adequacy of blood and fluid therapy.
- Urine output should be maintained at 1-2 ml/kg/hour.
- If urine output is inadequate, ensure that the collection system is functioning properly.
- Oliguria may be treated with one, or in combination of the following agents;
    - fluids (e.g. lactate Linger solution) at 15-40 ml/kg/hr
    - furosemide at 2-5 mg/kg IV or 1 mg/kg/hr
    - mannitol or dextrose at 0.25-0.5 g/kg IV over 5-15 minutes
    - dopamine at 1-5 mcg/kg/min IV

Temperature monitoring

- Patient body temperature should also be monitored during general anesthesia to avoid accidental hypothermia or detect malignant hyperthermia.
- Small patients lose body heat very rapidly when anesthetized and precautions should be taken to avoid this.
- Body temperature should always be monitored during prolonged surgery of the body cavities. Electronic thermistor probe is commonly placed either in rectum or esophagus for continuous temperature monitoring.
- Low body temperature decreases body metabolic rate and impairs the pharmakokinetic profile of drugs on board during anesthesia potentially prolonging recovery.
- The temperature should be checked at the end of anesthesia to see whether external heating is required.
- The animal in low body temperature will increase muscle contraction to raise body temperature at the time of recovery, a process increasing oxygen demand at the worst time when the tissues need to preserve it most.

ANESTHETIC RECORD KEEPING

- In order to achieve the best out of monitoring equipment it is advisable to maintain a written record of every anesthetic procedure.
- Minimal data to be entered into an anesthesia record are patient identification, operative procedure, significant preoperative findings in patient's record, amount and route of anesthetic agents and other drugs, monitoring of heart rate and breathing rate, and complications.
- Anesthetic records are useful for four main reasons.
    - Trends in patient variables to be noticed, at an early stage.
    - An archive of anesthetic records will be useful to compare similar cases and establish statistical analysis
    - Record keeping will aid the inexperienced personnel concentrate and improve their standard of patient monitoring.
    - In cases where the anesthetic management of a case needs to be defended, an anesthetic record is of enormous worth both as a reminder of the details of the individual cases and as evidence of the general standard of care given by the veterinary practice. To be admissible anesthetic record must be contemporaneous i.e. it must have been made at the same time that the anesthetic was given.
- Monitored variables such as heart rate and breathing rate are recorded at regular intervals with minimum of 10 minutes apart, although 5 minute interval recording is a common practice during anesthesia in most veterinary teaching hospitals including Boren Veterinary Medical Teaching Hospital at OSU.

Further readings

- The American College of Veterinary Anesthesiologists guidelines of anesthetic monitoring JAVMA 206 (7) 936-937, 1995
- Hall L, Clarke K, and Trim C. Veterinary Anesthesia Saunders 2002
- Thurmon J, Benson J, and Tranquilli W Veterinary Anesthesia Williams and Wilkinson 1996
- Seymour C and Gleed R (eds) BSAVA Manual of Small Animal Anesthesia and Analgesia 1999