 Anaesthetic monitoring equipment for small animals

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A WIDE variety of monitoring equipment is now available for use in anaesthetised small animal patients. However, the information produced is only of value if it can be correctly interpreted and acted upon, underlining the importance of the continued presence of a suitably trained person throughout the anaesthetic period. This article discusses the types of monitoring systems available, and gives guidance on how they may be employed effectively and how the resulting information can best be used to manage patients safely.

THE CASE FOR ANAESTHETIC MONITORING

In 1990, Clarke and Hall carried out a survey of anaesthetic mortality in small animal practice. Their findings suggested that approximately 1 in 679 healthy dogs and cats died as a result of anaesthesia, while the figure increased to 1 in 31 for sick patients. More recently, the preliminary results of a Confidential Enquiry into Perioperative Small Animal Fatalities (CEPSAF) indicated that the risk of anaesthetic death was 1 in 1849 for healthy dogs, 1 in 895 for healthy cats, 1 in 75 for sick dogs and 1 in 71 for sick cats (Brodbelt and others 2005). Thus, anaesthetic-related deaths appear to have decreased somewhat in veterinary practice over the past 15 years. In comparison, although it is difficult to establish exact equivalent figures, mortality associated with anaesthesia in humans appears to be approximately 1 in 10,000 to 1 in 100,000.

There is little doubt that the lower mortality figures in humans are due in part to the administration of anaesthesia primarily by specialist anaesthetists, but it is highly likely that access to electronic monitoring equipment plays a role. Indeed, minimum standards of monitoring are now well established for human anaesthesia (see box on the right), whereas the majority of patients anaesthetised in veterinary practice are not afforded this luxury. This is not to say that the provision of electronic monitoring equipment, in itself, will necessarily improve the standards of anaesthesia in veterinary patients; a thorough understanding of the equipment in use, and the ability to interpret the results produced, are absolutely fundamental to achieve any benefit. However, such equipment certainly provides an ‘early warning’, and helps alert the anaesthetist to the development of potentially critical situations, which may then be averted. The statement ‘There are no safe anaesthetic agents; there are no safe anaesthetic procedures; there are only safe anaesthetists’ (Robert Smith) is particularly pertinent in this regard.

Although a wide range of equipment is available for monitoring anaesthetised patients, it can only be as accurate as the person who assesses the information it provides. Unfortunately, expensive electronic equipment is often purchased with little understanding of the underlying function, and this commonly leads to errors in interpretation. Thus, the most important consideration in monitoring should be the continued presence of a suitably trained person. This should ensure that the information provided will maximise the safety of anaesthesia and minimise any compromise to organ function – so increasing the potential for an uneventful recovery.

Minimum requirements for induction and maintenance of anaesthesia in humans

- Anaesthetist with appropriate experience
- Pulse oximeter
- Non-invasive blood pressure monitor
- Electrocardiograph
- Capnograph
- Vapour analysis (required during the maintenance phase)
- Nerve stimulator if a muscle relaxant is being used
- Means of measuring the patient’s temperature

From Anon (2000)
The target site of action for all anaesthetic agents is the central nervous system (CNS), which becomes increasingly depressed with progressive ‘deepening’ of anaesthesia. While monitoring systems are available for directly assessing the degree of CNS depression, these are relatively complex and expensive, and are unlikely to be used in veterinary practice for many years. Instead, during anaesthesia, emphasis is placed mainly on electronic monitoring of the ‘indirect’ effects of the CNS depression on cardiopulmonary function. That is to say, with progressive deepening of anaesthesia, as the CNS becomes more depressed, increasing cardiopulmonary depression will also be evident. Monitoring the cardiovascular and respiratory systems therefore provides ‘a handle’ on the depth of anaesthesia, and gives some information on tissue perfusion and oxygenation.

**MONITORING CARDIOVASCULAR FUNCTION**

**OESOPHAGEAL STETHOSCOPE**

An oesophageal stethoscope consists of a blind-ending plastic tube with a number of side openings at the distal end, which are covered with a thin plastic membrane. The device is placed into the oesophagus until it overlies the heart, and the cardiac and respiratory sounds can then be detected by attaching the proximal end to an ordinary stethoscope from which the bell part has been removed. Unfortunately, unless the anaesthetist is willing to wear stethoscope earpieces throughout the period of anaesthesia, this device provides non-continuous information. However, oesophageal stethoscopes can also be attached to electronic monitors that amplify the cardiac sounds, thus permitting a continuous audible signal and freeing the anaesthetist to move around the theatre.

There is evidence from human studies that the intensity of the heart sounds shows some correlation to systemic blood pressure (Sakamoto and others 1965), although this has been more difficult to prove in veterinary patients.

Oesophageal stethoscopes are available in small, medium and large sizes, and are cheap and reliable monitors.

**ELECTROCARDIOGRAPHY**

Electrocardiography is relatively standard for monitoring anaesthetised patients, but actually gives limited information. The machine displays the electrical activity of the heart, but there is no correlation between this and the cardiac output. For example, the condition termed electromechanical dissociation (EMD) produces near-normal electrical activity of the heart but no contraction; under these circumstances, electrocardiography provides a false sense of security, as it implies that cardiac activity is normal. If an oesophageal stethoscope is in place, however, or if a pulse is being palpated, it should be obvious that there is no output from the heart (heart sounds are absent during EMD).

Alterations in cardiac rate and rhythm are common during anaesthesia, with an incidence of 50 to 80 per cent in humans undergoing surgery (Bertrand and others 1971). Bradycardia, tachycardia and ventricular premature complexes (VPCs) are most frequently encountered. While abnormalities of heart rate are readily detectable in the absence of monitoring equipment, VPCs and other arrhythmias are difficult to assess without electrocardiography. For the purposes of anaesthetic monitoring, precise placement of the electrocardiographic leads is not necessary, and a basic three-lead system (leads I, II and III) is sufficient.

Although abnormalities of heart rate or rhythm may be caused by a number of factors (see box below), their development during anaesthesia is usually due to an inadequate depth of anaesthesia or quality of analgesia, or the development of hypercapnia or hypoxaemia. These factors should therefore be ruled out before more direct pharmacological intervention is undertaken. Agents such as halothane sensitise the myocardium to catecholamines, and it is relatively common to observe VPCs during the maintenance of anaesthesia. When this occurs, the temptation is to reduce the quantity of vapour being inspired by the patient but, in many circumstances, it may be more appropriate to increase the vaporiser dial setting, as the arrhythmia is often due to inadequate anaesthesia.

**Common causes of anaesthetic-related arrhythmias**
- Inadequate anaesthesia/analgesia
- Hypoxaemia
- Hypercapnia
- Hypotension
- Hypo/hyperthermia
- Electrolyte abnormalities

Small, medium and large oesophageal stethoscopes

ECG showing ventricular premature complexes. Picture, Dr J. Dukes McEwan
Electrocardiography can also be a useful guide to certain electrolyte abnormalities, particularly alterations in extracellular potassium concentration; reasonably characteristic changes are seen, especially in the case of hyperkalaemia (as illustrated above). In humans, electrocardiography is also widely used to detect myocardial hypoxia during anaesthesia (which is common due to the high incidence of coronary arterial disease); elevation or depression of the S-T segment of the electrocardiogram (ECG) is suggestive of inadequate myocardial perfusion or oxygenation. However, S-T segment changes appear to occur commonly in anaesthetised animals, and do not seem to reliably indicate myocardial hypoxia.

**R WAVE MONITORS**

These electronic monitors detect (but do not display) electrical activity of the heart, and ‘bleep’ in response to the presence of the R wave on the ECG. These devices suffer from the same disadvantage as electrocardiographs in that they fail to detect EMD. In addition, they may give a signal during periods of electrical interference (eg, during the use of diathermy), which may be misinterpreted as indicating an arrhythmia.

**MONITORS OF ARTERIAL BLOOD PRESSURE**

Arterial blood pressure is the product of cardiac output and total peripheral resistance (systemic vascular resistance):

\[
\text{Arterial blood pressure} = \text{Cardiac output} \times \frac{\text{Total peripheral resistance}}{\text{Cardiac output}} \times \text{Total peripheral resistance}
\]

Consequently, arterial pressure is often monitored during general anaesthesia to provide information on cardiac output, which is a major determinant of tissue perfusion. However, arterial pressure is also dependent on the degree of vascular tone. Therefore, it is possible for a patient with normal or high arterial blood pressure to have low cardiac output but high peripheral resistance. Under these circumstances, tissue blood flow may well be impaired despite reasonable blood pressure. Thus, the results of arterial blood pressure monitoring, while potentially providing information on cardiac output and organ perfusion, cannot be viewed in isolation. A rough evaluation of vascular tone may be made by assessing mucous membrane colour and capillary refill time. In the absence of anaemia, pale mucous membranes generally suggest peripheral vasoconstriction.

Although monitoring systems for direct measurement of cardiac output are now more widely available, these are both expensive and invasive, and it is likely that arterial blood pressure monitoring – despite the limitations outlined above – will continue to be the standard method of assessing the adequacy of cardiac output and blood flow for many years to come.

General opinion suggests that, during general anaesthesia, systolic arterial pressure should be maintained above 80 to 90 mmHg, and mean pressure above 60 to 70 mmHg, in order to ensure sufficient perfusion pressure for the brain and heart. Diastolic pressures of less than 40 mmHg are associated with impaired coronary artery perfusion in humans (most myocardial perfusion occurs during diastole), but no comparative studies have been performed in animals; as there is a lower incidence of coronary artery disease in veterinary patients, lower diastolic pressures may be acceptable.

Intraoperative hypotension may impair organ perfusion and increase perioperative morbidity, thus measurement and support of arterial blood pressure is important. Arterial blood pressure can be measured by:

- Direct (invasive) monitoring;
- Indirect (non-invasive) monitoring.

**Direct monitoring**

Direct arterial blood pressure monitoring gives more accurate and continuous information compared with indirect methods. It is performed by cannulation of an artery and connection of the cannula to a device that gives a reading of arterial blood pressure. The cannula is commonly connected to a transducer, which converts the pressure signal from the artery into an electrical signal, and then to an electronic monitor, which provides a display of the arterial blood pressure trace, as well as values for systolic, mean and diastolic pressure. Alternatively, the cannula can be connected to an aneroid manometer to give mean arterial blood pressure values.

Technical skill is required for successful cannulation of a peripheral artery, especially in smaller patients. However, because this method of blood pressure measurement gives beat-to-beat information, it is preferable to non-invasive techniques if large swings in blood pressure are anticipated during surgery, or if the operation has the potential to induce excessive haemorrhage. Direct blood pressure measurement carries a small risk of ischaemic damage to the area supplied by the cannulated artery, but this is less common in veterinary patients than in humans due to the lower incidence of peripheral vascular disease in animals. Haematoma formation must be prevented when the arterial cannula is removed by applying firm pressure to the area for five minutes.

Cannula placed in the dorsal pedal artery
Indirect monitoring

Indirect arterial blood pressure monitoring is less technically demanding than direct methods and is associated with lower morbidity because arterial cannulation is not required. However, the technique is also less accurate and does not give continuous readings. In addition, the presence of cardiac arrhythmias may provoke dubious results from certain indirect blood pressure monitors, and this can be problematic even if the patient is exhibiting a normal rhythm variation (eg, sinus arrhythmia).

There are two indirect methods for arterial blood pressure monitoring:
- Doppler ultrasonic flow;
- Oscillometry;

**Doppler Ultrasonic Flow Method**

The Doppler ultrasonic flow method involves positioning a small probe, which emits an ultrasonic beam, over a peripheral artery (usually on the tail or paw) and applying ultrasound coupling gel between the probe and the skin. As blood flows along the vessel under the probe, a ‘whooshing’ noise is emitted by the monitor. If an inflatable cuff, connected to an aneroid manometer, is placed further up the appendage and sufficiently inflated, it will occlude the artery and the noise will disappear. If the cuff is then slowly deflated, the sound will recur at systolic arterial pressure, which can be read off the manometer.

In dogs, good correlation has been observed between measured Doppler systolic arterial pressure and that provided by direct femoral arterial cannulation (Weiser and others 1977) but, in cats, the system tends to under-read the true systolic pressure and it has been suggested that a
correction factor of approximately 14 mmHg has to be added to the observed reading (Grandy and others 1992). However, Caulkett and others (1998) demonstrated greater correlation in cats between directly measured mean arterial pressure and that measured by the Doppler system. Thus, although this technique is used to assess systolic arterial pressure, due to inherent inaccuracies in the system the value obtained in cats probably correlates more closely to mean arterial pressure. Doppler monitoring provides only a vague (and inconsistent) indication of diastolic pressure in all species.

The Doppler flow probe can also be used as a pulse monitor to provide an audible beat-to-beat signal.

**Oscillometric method**
The oscillometric method involves connecting a cuff system to an electronic monitor. The cuff is placed over a peripheral artery and the machine automatically inflates the cuff to occlude the artery before slowly releasing the pressure. As the cuff deflates, the machine detects oscillations in the artery as the blood begins to flow back through; these oscillations begin at systolic pressure, reach a maximum at mean arterial pressure, and gradually disappear at diastolic pressure. Thus, unlike the Doppler system, the oscillometric method gives readings at all three blood pressure points. It can also be set to cycle automatically, thereby giving regular readings, whereas the Doppler technique has to be performed manually each time. With the oscillometric method, the mean reading is the most reliable, followed by the systolic measurement; the diastolic reading should only be considered moderately accurate. Cuffs are commonly placed over the dorsal pedal artery at the metatarsus, over the radial artery just above the carpus, or over the coccygeal artery in the ventral tail.

**Urine output**
Urine production depends on adequate renal perfusion. As blood flow to the kidneys declines and subsequently ceases at a mean arterial blood pressure of less than 60 mmHg approximately, urine output can give an indirect indication of the adequacy of arterial blood pressure.

Normal urine output is 1 to 2 ml/kg/hour, with values of less than 0.5 ml/kg/hour representing oliguria. Therefore, if urine output is measured and proves to be greater than 1 ml/kg/hour, this suggests that mean arterial blood pressure is greater than 60 mmHg. Unfortunately, many anaesthetic drugs influence urine production, and the

**Doppler and oscillometric monitoring compared**
Older oscillometric machines were extremely unreliable in small dogs and cats, often failing to display any blood pressure reading whatsoever. However, newer machines have, to some extent, overcome this problem (Pedersen and others 2002, Sawyer and others 2004). Since oscillometric devices generally record the pulse rate as well as the arterial blood pressure, it is always worth checking that the displayed value is equivalent to a manually recorded pulse rate before placing any reliance on the blood pressure reading. Similarly, inaccurate oscillometric arterial blood pressure results commonly occur if cardiac arrhythmias are present – even in the case of normal variants such as sinus arrhythmia. In these cases, Doppler or direct arterial blood pressure monitoring will provide more accurate results.

With both Doppler and oscillometric methods of blood pressure measurement, the size of the occluding cuff, and its position relative to the heart, are critical in obtaining accurate results. The width of the cuff should be approximately 40 to 60 per cent of the circumference of the area it is placed around; cuffs that are too small will result in an over-reading of the blood pressure, and vice versa. In addition, the occluding cuff should be positioned level with the heart; arterial pressure will be erroneously high if the cuff is below the heart, and erroneously low if above it. Applying cuffs too tightly around the appendage will result in an under-reading of the blood pressure, while applying them too loosely will cause an over-reading.

While direct arterial blood pressure monitoring gives reliable results on a beat-to-beat basis, indirect techniques are considered more useful for following trends in pressure rather than for providing absolute values. Despite being less accurate, indirect techniques are particularly convenient because of their ease of use and limited dependence on the technical skills of the anaesthetist. Of the two types available, the Doppler system is the more reliable in the presence of cardiac arrhythmias or low arterial pressure.

As well as providing some information on tissue perfusion, monitoring of trends in arterial blood pressure can give a useful indication of altering anaesthetic depth. In the absence of marked surgical blood loss, a gradual decline in arterial blood pressure suggests deepening of anaesthesia, and vice versa.
stress response associated with both anaesthesia and surgery increases the release of antidiuretic hormone, which may acutely decrease urine output. Thus, many normal patients may exhibit reduced urine flow during anaesthesia, even in the face of adequate blood pressure and renal perfusion.

Monitoring urine production is recommended in patients with renal disease or conditions predisposing to renal shutdown (e.g., sepsis, major trauma), to ensure appropriate treatment can be undertaken rapidly if urine output falls. It is important that the bladder is drained of urine at the start of the procedure before an assessment of urine production is made. As monitoring of urine output relies on catheterisation of the bladder, an aseptic technique is essential.

**CENTRAL VENOUS PRESSURE**

Central venous pressure (CVP) is a useful indicator of circulating volume and the ability of the right side of the heart to pump the returning blood. Impaired right ventricular function and circulating volume expansion will cause CVP to increase, while decreased circulating plasma volume (hypovolaemia) will reduce it. Thus, monitoring CVP is also helpful for assessing the adequacy of fluid therapy.

CVP measurement requires jugular catheterisation, the tip of the catheter being positioned to lie within the intrathoracic vena cava (although shorter jugular cannulas also appear to give reasonably accurate results). The catheter is then connected to an extension set, which terminates at a three-way tap. A bag of intravenous fluids is connected to a second port of the tap, and an open-ended piece of drip tubing is attached to the remaining port to act as a manometer. A centimetre scale is placed alongside the manometer tube, with the zero point on the scale positioned level with the right atrium (the sternal manubrium in lateral recumbency or the point of the shoulder in dorsal recumbency). The intravenous fluids are turned on to fill the jugular extension line, and the three-way tap is adjusted so the intravenous fluids fill the open-ended manometer tube. The tap is turned again to connect the manometer tube with the jugular line, and the fluid meniscus will fall down the manometer tubing until it equilibrates with the CVP, which can be read off the adjacent scale. Alternatively, the central venous line can be connected directly to a pressure transducer, and the CVP trace and numerical value can be displayed on a monitor in a similar fashion to that employed for direct arterial blood pressure measurement. It is important to appreciate that CVP measurement and arterial blood pressure measurement provide information on different aspects of cardiovascular function – they are in no way interchangeable.

Trends in CVP are more reliable than single values, but low readings usually imply the need for plasma volume replacement. Normal values in small animals are in the range of 0 to 10 cmH$_2$O (most commonly 3 to 7 cmH$_2$O), while severely hypovolaemic patients often have a CVP of <0 cmH$_2$O.

CVP monitoring is particularly important when undertaking aggressive fluid therapy in animals with cardiac or renal disease, as these patients are intolerant of over-infusion, commonly developing pulmonary oedema. Care must be taken and the fluid administration rate reduced if CVP increases more than 6 cmH$_2$O from the baseline or exceeds 10 cmH$_2$O.

**MONITORING RESPIRATORY FUNCTION**

**RESPIRATORY RATE MONITORS/ APNOEA ALARMS**

Respiratory rate monitors and apnoea alarms incorporate a thermistor probe, which is positioned in the patient’s airway between the endotracheal tube and breathing attachment. A thermistor is simply a fine wire that experiences changes in electrical resistance in response to alterations in temperature; as expired air is warmer than inspired air, the resistance across the thermistor will alter as the patient exhales. This variation in resistance can be detected by an
attached monitor, which can be programmed to bleep each time the patient takes a breath. In addition to providing a numerical display of the respiratory rate, most of these monitors can also be set to emit an alarm if there is no air movement for a pre-assigned period.

Although fairly widely used in veterinary practice, respiratory rate monitors/apnoea alarms are relatively expensive for the amount of information they provide, as exactly the same endpoint can be achieved by observing the movement of the reservoir bag on the anaesthetic breathing system.

**PULSE OXIMETRY**

Ninety-eight per cent of oxygen transported by the blood is bound to haemoglobin, and only a small proportion is carried dissolved in the plasma. Thus, measuring the amount of haemoglobin that is saturated with oxygen will give an idea of how well oxygenated the patient is. Deoxygenated and oxygenated haemoglobin absorb different wavelengths of light and, very simplistically, this is the basis of pulse oximetry.

There are two types of pulse oximeter probe – transmittance probes and reflectance probes. Transmittance probes consist of, on one side, red and infrared (660 nm and 940 nm, respectively) light-emitting diodes, which flash on and off several hundred times a second and, on the other side, a photodetector to determine the amount of each wavelength of light that passes through the tissue bed (usually the tongue, ear, toe or skin flap). Reflectance probes have the light-emitting diodes and photodetector placed adjacent to each other, and the light is reflected off a tissue rather than transmitted through it; these probes are commonly placed in the rectum in very small patients, but may also be wrapped around digits.

With both types of probe, the light is absorbed not only by the haemoglobin in the arterial blood, but also by haemoglobin in capillary and venous blood, and by the tissue itself. The pulse oximeter is, however, able to ignore absorption from these other sources, and concentrate only on the arterial haemoglobin. It does this by assessing only pulsatile absorption (arterial blood), and ignoring static, non-pulsatile absorption (tissue, venous blood, and so on). By comparing the amount of the two wavelengths of light that has been absorbed across the tissue, the pulse oximeter can indicate the percentage of haemoglobin saturation. As pulse oximetry depends on pulsatile blood flow, it not only gives an indication of oxygenation but also that cardiac output is reaching the peripheral tissues. Thus, it can be considered as a monitor of both respiratory and cardiovascular systems.

In general, arterial haemoglobin saturation should be >95 per cent in anaesthetised patients breathing an oxygen-enriched gas although, provided haemoglobin saturation is >90 per cent, there is no immediate cause for concern. Values of between 90 and 95 per cent in anaesthetised patients may indicate an underlying problem that should be identified but, most commonly, there is a fault with the probe, and adjusting its position will usually result in a return to more normal values. Saturation of <90 per cent should be investigated immediately. Animals premedicated with alpha-2 adrenoceptor agonists (eg, xylazine, medetomidine, romifidine) develop intense peripheral vasoconstriction and, in these cases, pulse oximeters may be unable to detect a signal.
The pulse oximeter probe must be placed at a suitable site to provide a reliable reading. The best site is a non-pigmented, relatively hairless part of the body. The tongue is usually the most appropriate, but the pinna, webbing between the digits, vulva or scrotum are often suitable alternatives if they are not heavily pigmented. Failure to obtain an accurate reading may be due to:

- Pigment or fur at the site;
- Lack of perfusion (e.g., vasoconstriction associated with alpha-2 adrenoceptor agonist administration or hypothermia);
- Ambient lighting overwhelming the light from the light-emitting diodes;
- Movement obscuring the signal;
- Haemoglobin abnormalities (e.g., methaemoglobinaemia and carboxyhaemoglobinaemia);
- Inappropriate size or shape of probes.

The pulse oximeter provides a measure of haemoglobin saturation and pulse rate and, in some cases, will generate a plethysmographic trace (a graph of pulse volume against time), which displays consecutive pulse waveforms.

**CAPNOGRAPHY**

The ‘gold standard’ method for assessing the adequacy of ventilation is measuring the partial pressure of carbon dioxide (PaCO₂) in the arterial blood by blood gas analysis. However, this technique is invasive, technically demanding and the equipment required is expensive. An alternative, non-invasive technique is capnography. In patients with normal lungs, the carbon dioxide concentration in the pulmonary capillaries will have equilibrated with that in the alveoli by the end of expiration. Therefore, if a sample of the end-tidal expired gas can be obtained and its carbon dioxide concentration measured, it will allow the carbon dioxide concentration of the arterial blood to be evaluated with a reasonable degree of accuracy, and so provide a non-invasive tool for assessing ventilatory adequacy.

Capnography relies on the absorption of infrared light by carbon dioxide molecules in the patient’s respired gases. A capnograph incorporates a compact probe, which sits between the endotracheal tube and patient breathing system, and an analyser. The presence of the probe increases the dead space in the breathing system, which may be significant in very small patients, although low dead space adaptors have recently become available. There are two types of analysers: mainstream analysers, which measure carbon dioxide directly at the site of the probe; and sidestream analysers, which continually divert a small sample of gas from the airway to the main body of the machine. While mainstream analysers have a more rapid response rate, they tend to be bulkier than sidestream versions.

Capnographs generate a graphical display of carbon dioxide concentration against time during the patient’s respiratory cycle, as well as a numerical value for the end-tidal carbon dioxide (ETCO₂), which allows assessment of the adequacy of ventilation. Normal ETCO₂ in dogs ranges from 4.7 to 6.0 kPa (35 to 45 mmHg); values are usually slightly lower in cats. A measurement of >6.0 kPa is generally indicative of hypoventilation, while a measurement of <4.7 kPa indicates hyperventilation. This, in turn, can provide some indirect information on the depth of anaesthesia (i.e., as the depth of anaesthesia increases, an animal’s ETCO₂ will usually increase).

In any patient, the ETCO₂ value obtained reflects the effects of three processes:

- Tissue metabolism (carbon dioxide production);
- Perfusion (blood flow carrying carbon dioxide from tissues via the heart to the pulmonary capillaries);
- Ventilation (carrying carbon dioxide from the alveoli in exhaled breath).

A change in the ETCO₂ value suggests an alteration in one or more of these three processes. Therefore, although capnography is primarily a monitor of ventilation, it also indicates that the patient has a cardiac output.

While the ETCO₂ value provides information about the degree of respiratory depression present, the capnographic trace (capnogram) is also of interest. Characteristic alterations indicate certain events:

- If the capnogram does not return to baseline between each expiration, this implies rebreathing, which may be...
due to a failure of the unidirectional flow valves in a circular breathing system, exhaustion of soda lime, inadequate fresh gas flow in a non-rebreathing system or excessive apparatus dead space;

- Pulmonary embolisation may be suspected if the ETCO₂ falls over consecutive expirations due to a reduction in pulmonary artery perfusion;

- In cases of chronic obstructive airway disease or acute-onset bronchospasm, a characteristic waveform with a slow upstroke is produced;

- Patients undergoing intermittent positive pressure ventilation may ‘buck’ the ventilator and this will be evident as dips or clefts along the alveolar plateau;

- A normal variation on the usual capnogram is that of cardiogenic oscillations, which appear as a number of ‘bumps’ on the downward slope of the trace. These oscillations are usually observed with slow respiratory rates, and are thought to be due to the heart beating against the lungs during the prolonged expiratory phase, which causes small amounts of carbon dioxide to be expelled.

Capnometers are similar to capnographs, but only display a numerical value for ETCO₂. Although these devices can be useful, the absence of a graphical display of carbon dioxide concentration limits the information that can be interpreted by the anaesthetist.

**OTHER FORMS OF MONITORING**

**TEMPERATURE MONITORING**
Hypothermia is perhaps the most ubiquitous complication of general anaesthesia, and has numerous detrimental effects on the patient. It is the most common cause of delayed recovery of consciousness; therefore, temperature monitoring is usually performed in the perianesthetic period. Although rectal thermometers (eg, digital or mercury) are accurate in the awake patient, under anaesthesia the rectum tends to balloon, reducing the validity of results obtained from this site. Small thermistor probes that can be placed into the oesophagus are more useful, as the temperature at this site closely approximates to the core temperature.

**MULTI-GAS ANALYSIS**
Machines that measure and display inspired and expired anaesthetic vapour concentrations, as well as oxygen and nitrous oxide, are available. These are particularly useful when using rebreathing anaesthetic systems at low gas flows where there is usually a marked discrepancy between the vaporiser setting and the concentration of agent inhaled by the patient. Due to their cost, these machines are not commonly available outside large veterinary referral institutions.

**PERIPHERAL NERVE STIMULATION**
In patients that receive neuromuscular blocking agents (muscle relaxants) as part of their anaesthetic regimen, one of the problems encountered is the assessment of the degree of neuromuscular blockade produced, both intraoperatively and, perhaps more importantly, at the end of anaesthesia prior to tracheal extubation. It is common practice, therefore, to use a nerve stimulator to help quantify the intensity of relaxation. This is a hand-held device that delivers a small electrical current through a pair of electrodes that are attached to the skin over a peripheral nerve (commonly the ulnar nerve on the medial aspect of the elbow, the peroneal nerve at the lateral cranial tibia, or the facial nerve on the lateral aspect of the head). The response of the muscle groups innervated by these nerves is observed when the nerve stimulator is activated.

The most common form of stimulation in use is train-of-four (TOF), where four electrical pulses are applied to the nerve over a two-second period (ie, 0.5 second between twitches). In the absence of neuromuscular blocking agents, four distinct muscle twitches – each of identical strength – will occur. If a non-depolarising relaxant is subsequently administered, the fourth twitch in the TOF will become weaker and eventually disappear, followed by the third twitch, then the second, and eventually the first, if sufficient relaxant is given. This phenomenon of a gradually decreasing muscle response to nerve stimulation, with the onset of non-depolarising induced relaxation, is known as fade.

Peripheral nerve stimulation serves two useful purposes. First, it has been shown that ideal muscle relaxation for abdominal surgery is achieved when only one or two
Peripheral nerve stimulator with various stimulation pattern options. Hypodermic needles are commonly placed subcutaneously over the peripheral nerve, and the stimulating leads applied to these

twitches remain in the TOF. This allows the anaesthetist to titrate the dose of a neuromuscular-blocking drug to achieve suitable surgical conditions. Secondly, at the end of surgery, it permits an assessment of residual neuromuscular blockade. The TOF should have recovered to four equal-strength twitches before the animal is allowed to awaken and the trachea extubated.

Suxamethonium-induced relaxation exhibits a slightly different TOF pattern to the non-depolarising type described above, in that twitch strength decreases but fade is not observed (ie, all four twitches become weaker, but remain equal to each other). Peripheral nerve stimulation is less commonly employed in the monitoring of suxamethonium neuromuscular blockade due to its short duration and the drug is now seldom used in veterinary anaesthesia.

**SUMMARY**

The use of electronic monitoring equipment during anaesthesia supplies some information that would not otherwise be available. It assists the anaesthetist by providing an ‘early warning’ of impending complications and may help to avoid these. However, a thorough understanding of the data presented is essential to gain maximum benefit from such equipment.

**References**


Further reading


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In Practice 2005 27: 512-521
doi: 10.1136/inpract.27.10.512

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