How Do I Know that My Patient is Alive? Mini Series

Session 3: Blood Pressure and Basic Electrocardiography for the Anaesthetist

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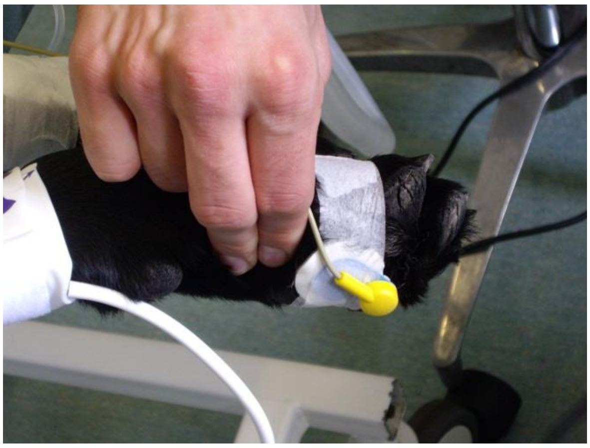


CARDIOVASCULAR MONITORING

The most basic monitoring of the cardiovascular system entails an assessment of mucous membrane colour, capillary refill time, and pulse quality.

Mucous membrane colour and capillary refill time (CRT)

Assuming normal haemoglobin levels, assessment of these two variables gives some idea of peripheral perfusion. Information can be derived from mucous membrane colour as detailed in Table 1.

Mucous membrane colour	**Significance**
pink	normal
pale	vasoconstriction
congested	vasodilation
cyanotic	> 5 g deoxygenated Hb per 100 ml blood
grey	circulatory failure

Table 1 - Relationship between mucous membrane colour and circulatory status

There is no correlation between mucous membrane colour and arterial blood pressure.

Normal CRT is less than 2 seconds but can be misleading as capillaries can refill from distended veins as well as arteries; it is perfectly possible to obtain a normal CRT in a freshly dead animal.

Palpation of peripheral pulses

Pulses can be palpated at a variety of areas in dogs, cats and horses, with the most common sites detailed below:

- Dog – femoral, lingual, brachial, radial, cranial tibial, coccygeal, auricular
- Cat – femoral ,brachial, cranial tibial, coccygeal
- Horse – facial, transverse facial, median, lateral metatarsal, coccygeal, auricular

It is important to palpate *peripheral arteries* rather than central ones, as the former are much more sensitive to changes in cardiovascular function. For example, marked decreases in arterial blood pressure may result in minimal palpable changes in femoral pulse quality, but obvious changes (and perhaps even disappearance) are likely to be observed in peripheral arteries. It is important to recognise exactly what pulse palpation tells you: the pulse pressure (pulse strength) is merely the difference between systolic and diastolic pressure - an animal with an arterial blood pressure of 120/80mmHg will have similar pulse strength to one with arterial pressure of 80/40mmHg, i.e. the pulse quality reflects stroke volume, not blood pressure.

Similarly, hypovolaemia results in a weak, easily compressible pulse but arterial blood pressure may be normal. However, peripheral pulse palpation can give a subjective indication of stroke volume if the clinician is familiar with this technique.

Although pulse quality doesn't generally directly reflect arterial pressure, a common rule of thumb is that the cranial tibial (dorsal pedal) pulse will become impalpable once the mean arterial pressure drops below about 60mmHg (the minimal blood pressure usually taken as acceptable in dogs and cats). However, this pulse may also disappear in the face of vasoconstriction (e.g. following alpha-2 agonist drugs) even with acceptable/high arterial pressures. The take-home message here is that, if the cranial tibial pulse is palpable, mean arterial blood pressure is likely to be at least 60mmHg; if it is not palpable, this may be because either blood pressure is low or there is high vascular tone (vasoconstriction).

Oesophageal stethoscope

The 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. It is placed down the oesophagus until it overlies the heart, and the cardiac and respiratory sounds can then be detected by attaching the proximal end of the device 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, freeing the anaesthetist to move around the theatre, and permitting a continuous audible signal.

There is evidence from human studies that the intensity of the heart sounds shows some correlation to systemic blood pressure, 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 (ECG)

The ECG is a relatively standard monitor for anaesthetised patients, but actually gives limited information. The machine displays the electrical activity of the heart, but there is no correlation between this and cardiac output. In fact, the condition termed pulseless electrical activity (PEA; previously known as electromechanical dissociation) produces near-normal electrical activity of the heart but no contraction, and, under these circumstances, the ECG will provide a false sense of security, since it will be suggesting 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 PEA).

Alterations in cardiac rate and rhythm are common during anaesthesia, with an incidence of 50-80% in human subjects undergoing surgery. Bradycardia, tachycardia and ventricular premature complexes (VPCs) are most frequently encountered. While abnormalities of heart rate are easily detected 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 ECG leads is not necessary, and a basic three lead system will suffice.

Although abnormalities of heart rate or rhythm may be caused by a number of factors, their development during anaesthesia is most commonly due to inadequate anaesthetic “depth” / quality of analgesia, or development of hypercapnia or hypoxaemia. Thus, these conditions should be ruled out before more direct pharmacological intervention is undertaken. Older agents, such as halothane, sensitised the myocardium to catecholamines, and it was relatively common to observe VPCs during maintenance of anaesthesia with this drug; the more modern inhalants (isoflurane, sevoflurane, desflurane) do not cause myocardial sensitisation, so the cardiac rhythm is much more stable.

The ECG can also be a useful guide to certain electrolyte abnormalities, particularly alterations in extracellular potassium concentration, with reasonably characteristic changes being seen, particularly with hyperkalaemia. In addition, the ECG is widely used as a monitor for detection of myocardial hypoxia during anaesthesia in humans (which is a not uncommon situation due to the high incidence of coronary arterial disease in this species): elevation or depression of the S-T segment of the ECG trace is suggestive of inadequate myocardial perfusion or oxygenation. However, while much emphasis is placed on this in humans, S-T segment changes appear to occur commonly in anaesthetized animals, and do not appear to reliably indicate myocardial hypoxia.

Arterial blood pressure monitoring

The main function of the cardiovascular system is to provide a flow of blood to tissues, such that oxygen and nutrients are delivered and waste products produced by cellular metabolic processes are removed. Blood pressure is a fundamental cardiovascular parameter that describes the force driving tissue perfusion, where blood pressure is the pressure exerted by blood on the walls of the arteries and arterioles of the systemic circulation. It also determines the workload of the myocardium (afterload).Blood pressure is commonly measured in millimeters of mercury (mmHg). Systolic arterial blood pressure (SAP) is the pressure exerted on the arterial walls during left ventricular contraction. Diastolic arterial blood pressure (DAP) is the pressure exerted on the arterial walls during ventricular relaxation due to the Windkessel effect (elastic recoil of arteries and arterioles). Mean arterial blood pressure (MAP) – is the average pressure exerted over the cardiac cycle and therefore is a determinant of tissue perfusion. It can be estimated using the following calculation:

Mean pressure = Diastolic pressure + 1/3 (Systolic pressure – Diastolic pressure).

Arterial blood pressure (ABP) is dependent on a number of factors and can be described by the equation:

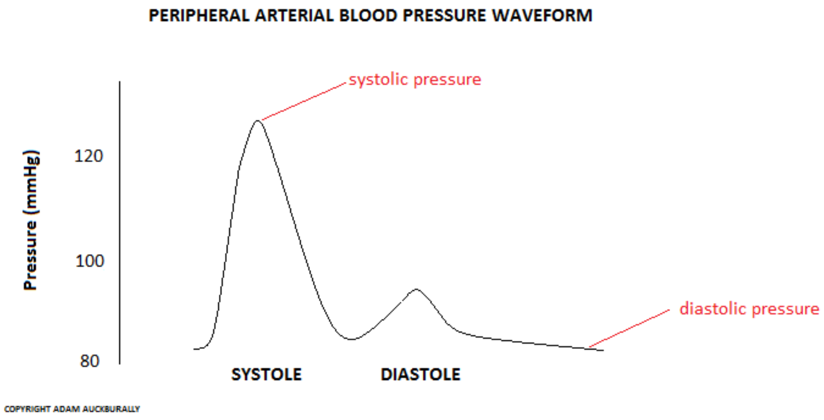
Arterial Blood Pressure = Cardiac Output x Total Peripheral Resistance
and
Cardiac Output = Heart rate x Stroke Volume
so....
Arterial Blood Pressure = Heart Rate x Stroke Volume x Total Peripheral Resistance

Consequently, arterial pressure is often monitored during general anaesthesia to provide information on cardiac output, which is a major determinant of tissue perfusion. However, it can be appreciated from the above equation that the arterial pressure is also dependent on the degree of vascular tone. Therefore, it is perfectly possible to have a patient with normal or high arterial blood pressure, which has low cardiac output but high peripheral resistance. Under these circumstances, tissue blood flow may well be impaired despite reasonable blood pressure. Thus, arterial blood pressure monitoring, while potentially providing information on cardiac output and organ perfusion, cannot be assessed 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 pressure monitoring - despite the limitations referred to above - will continue to be the standard method of assessing adequacy of cardiac output and blood flow, for many years to come.

ABP can be represented as a waveform over time (Figure 1); the maximum point being the systolic pressure and the minimum point the diastolic pressure. Integration of the area under the waveform over consecutive beats and then averaged, gives the average or mean arterial blood pressure (MAP).

Figure 1 – a typical peripheral arterial waveform



Hypotension is defined as an abnormally low blood pressure. General opinion would suggest that, during general anaesthesia in dogs and cats, systolic arterial pressure should be maintained above 80-90mmHg, and mean pressure above 60mmHg, in order to maintain sufficient perfusion pressure for the vital organs; the kidney, in particular, is particularly susceptible to hypoperfusion in small animals, and acute renal failure may result. Adequate pressure (mean >65-70mmHg) may also be important in optimising muscle perfusion in anaesthetised horses, and help reduce the incidence of post-anaesthetic myopathy. Diastolic pressures less than 40mmHg are associated with impaired coronary artery perfusion in humans (most myocardial perfusion occurs during diastole), but no comparative studies have been performed in animals, and since there is a lower incidence of coronary artery disease in veterinary patients, lower diastolic pressures may be acceptable. As intra-operative hypotension may impair organ perfusion and increase peri-operative morbidity, measurement and support of arterial blood pressure is important.

Common anaesthetic practice would be to treat blood pressure when the MAP is decreasing to below 60 -70 mmHg with an absolute minimum of 60 mmHg.
N.B. neonates generally have a lower MAP than an adult and so 40 – 60 mmHg would be an acceptable goal in these patients under general anaesthesia.

Arterial pressure can be measured in 2 ways:

1. Direct arterial blood pressure monitoring - gives more accurate and continuous information compared to indirect methods. This technique gives accurate beat-by-beat analysis and generates the waveform depicted in Figure 1. It is the gold standard for measurement of arterial blood pressure and also allows for sampling of arterial blood for blood-gas analysis. It is essential that the anaesthetist is familiar with the limitations and complications of direct arterial blood pressure measurement and its potential inaccuracies. It is performed by catheterisation of an artery, and connection of the catheter to a device which gives a reading of arterial pressure.

Commonly, the catheter is connected to a transducer - a device 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 pressure trace, as well as values for systolic, mean and diastolic pressure. Alternatively, the catheter can be connected to an aneroid manometer to give mean arterial blood pressure values.

Technical skill is required for successful catheterisation 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 when it is anticipated that there may be large swings in blood pressure during surgery, or where the operation carries the potential for excessive haemorrhage. Direct blood pressure measurement carries a small risk of ischaemic damage to the area supplied by the catheterised artery, but this appears much less common in veterinary patients than in humans, due to the lower incidence of peripheral vascular disease in animals. In addition, haematoma formation must be prevented when the arterial catheter is removed, by applying firm pressure to the area for a period of at least 5 minutes.

2. <u>Indirect arterial blood pressure monitoring</u> - is both less technically demanding, and associated with lower morbidity, than invasive measurement, since arterial catheterisation 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, such as sinus arrhythmia.

Two indirect methods are used in veterinary practice

- **Doppler ultrasonic flow method.** In this technique, a small probe, which emits an ultrasonic beam, is positioned over a peripheral artery (usually, tail or paw), and ultrasound coupling gel applied between the probe and skin. As blood flows along the vessel underneath the probe, a “whooshing” noise is emitted by the monitor. If an inflatable cuff, connected to an aneroid manometer, is placed further up the limb and sufficiently inflated, it will occlude the artery and the noise will disappear. If the cuff is now slowly deflated, the sound will reappear at systolic arterial pressure, which can be read off the manometer. In dogs, good correlation is observed between measured Doppler systolic arterial pressure and that provided by direct femoral arterial catheterisation, but in cats, the system tends to under-read the true systolic pressure, and it has been suggested that a correction factor of approximately 14mmHg has to be added to the observed reading More recently it has been demonstrated that there is greater correlation in cats, between directly measured <u>mean</u> arterial pressure and that measured by the Doppler system. Thus, although this technique is being used to assess systolic arterial pressure, due to inherent inaccuracies in the system, the value obtained in cats probably more closely correlates to the 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, providing an audible beat-to-beat signal.

- **Oscillometric method.** These machines comprise a cuff system coupled with 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, oscillations beginning at systolic pressure, reaching a maximum at mean pressure, and gradually disappearing at diastolic pressure. Thus, unlike the Doppler system, the oscillometric technique gives readings of all 3 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 technique, the mean reading is most reliable, followed by the systolic, while the diastolic should only be considered moderately accurate. Cuffs are commonly placed around the cranial tibial (dorsal pedal) artery at the metatarsal area, the radial artery just above the carpus, or the coccygeal artery in the ventral tail.

  Older oscillometric machines were extremely unreliable in small dogs and cats, often failing to display any blood pressure reading whatsoever. However, newer machines are available which, to some extent, have overcome this problem. Since oscillometric devices generally record the pulse rate as well as the arterial 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 pressure results commonly occur if cardiac arrhythmias are present – even normal variants such as sinus arrhthymia. If this is the case, Doppler or direct arterial blood pressure monitoring will provide more accurate results.

  With both the Doppler and oscillometric techniques of blood pressure measurement, the size and positioning of the occluding cuff used is critical in obtaining accurate results. The diameter of the cuff should be approximately 40% of the circumference of the area it is placed around: cuffs which 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 pressure monitoring gives reliable results on a beat-to-beat basis, indirect techniques should probably be considered more useful for following trends in pressure, rather than for absolute values. Despite being less accurate, however, indirect techniques are particularly convenient because of their ease of use and limited reliance on technical skills on the part of the anaesthetist.

Hypotension (or reduced cardiac output) may be recognised using other clinical signs but none are particularly specific:

- Hypocapnia – a reduction in pulmonary blood flow due to reduced right ventricular output, may lead to reduced end tidal values of carbon dioxide, but there are other causes of hypocapnia that should be considered.
- Mucous membrane pallor – due to peripheral vasoconstriction
- Reduced capillary refill time
- Surgical bleeding
- Urine output

Once hypotension has been recognised the cause needs to be identified. Referring back to the equation, it can be deduced that a fall in any of the factors on the right hand side of the equation (heart rate, stroke volume or TPR) will lead to a fall in ABP. Working through the equation logically can help to identify the cause of hypotension and therefore a suitable treatment.
Note that although what follows seems a very simplistic approach, multiple parts of the equation can be affected at the same time.

1. Reduction in heart rate – bradycardia is relatively common in anaesthetised small animals, especially with the now commonplace administration of opioid analgesics. Heart rate should be monitored, ideally using electrocardiography. Slow heart rates reduce cardiac output and therefore can lead to hypotension. However, bradycardia may also be a reflex response to an increase in blood pressure e.g. following the administration of alpha2 agonists. If bradycardia co-exists with hypotension, then treatment with an antimuscarinic may be warranted. Take into account other things that may be affecting heart rate e.g. depth of anaesthesia, alpha2 agonists, opioids, vagal stimulation (e.g. surgery of the eye, neck, thorax and abdomen) and change these if possible. Sinus bradycardia should be distinguished from other bradydysrhythmias and appropriate treatment instituted as necessary.

2. Reduction in stroke volume
   a. Dehydration and hypovolaemia – these two conditions do not necessarily occur together. An animal can lose much of its blood volume (hypovolaemia) without being dehydrated (interstitial fluid deficit). Circulating blood volume is preferentially protected although severe dehydration can lead to hypovolaemia and a reduction in preload.

b. Pre-existing cardiac disease can lead to reductions in contractility – the extent of the disease will determine the effect on cardiac output and blood pressure. A diagnosis prior to anaesthesia is important, ideally followed by echocardiography if the disease is thought to be significant and so careful preoperative assessment is essential. Regurgitant valves can reduce cardiac output if the regurgitant fraction is high.

c. Cardiac arrhythmias will have varying effects on blood pressure, and this may change when combined with general anaesthesia. If the arrhythmia is pathological and anaesthesia is elective, then a complete cardiac examination is warranted to determine the nature and extent of the problem. Cardiac arrhythmias can lead to reductions in contractility or reduce the time necessary for appropriate atrial filling i.e. reduce preload. If the underlying cause of the arrhythmia is myocardial disease then this can affect contractility further.

d. IPPV – positive pressure ventilation is not a benign procedure and the risks associated with it should be appreciated. One of the side effects of creating positive intrathoracic pressure is squashing of the vena cava and reducing preload. Additionally, positive pressure around the heart itself can prevent normal cardiac filling during diastole (tamponade) and reduce cardiac output. Careful attention should be paid to the amount of pressure used to inflate the lungs. IPPV can also lead to changes in vagal tone precipitating a bradydysrhythmia although this is uncommon.

e. Vasoconstriction – this leads to an increase in afterload and a reduction in stroke volume. Vasoconstriction can occur if there are high levels of circulating catecholamines e.g. light anaesthesia or noxious insults (inappropriate analgesia, hypercapnia, severe hypoxemia). Vasoconstriction may also be present following the administration of drugs e.g. alpha2 agonists. Here it must be emphasised that although anything causing vasoconstriction may lead to an increased ABP **number**, cardiac output will fall due to an increase in afterload i.e. it is more difficult for heart to pump blood out. Hence why it is important to assess ABP in conjunction with other clinical signs.

f. Acid-base and electrolyte derangements – acidaemia and hypocalcemia may lead to negative inotropy and reduced cardiac output. Hyperkalemia can lead to bradycardia and often co-exists with acidaemia.

3. Reduction in systemic vascular resistance

    a. Sepsis – e.g. secondary to a ruptured gastric ulcer. The release of toxins into the circulation leads to vasodilation, myocardial depression and a ‘relative’ hypovolaemia. Animals presenting with septic shock require aggressive fluid resuscitation and/or cardiovascular support. Gastrointestinal emergencies also lead to fluid and electrolyte shifts into the gastrointestinal tract which can affect circulating volume and blood pressure further.

    b. Drugs – all anaesthetic drugs have some effect on the cardiovascular system. Volatile anaesthetic agents tend to cause most of the problems through their effect on the myocardium and on systemic vascular resistance. Attempts should be made to lower the concentration by using appropriate analgesics and sedatives or tranquillisers. Other drugs may have an effect on blood pressure e.g. acepromazine is an α_1 antagonist and causes vasodilation.

Hypotension should not be treated aggressively in all cases. Animals which have ongoing blood loss e.g. splenic haemangiosarcoma rupture, should be conservatively resuscitated if possible. This is known as permissive or hypotensive resuscitation.

Hypotension occurring under anaesthesia should be treated using the following steps:

1. Confirm that blood pressure is actually low – check instrumentation
2. Assess depth of anaesthesia to determine if this is the cause and try to reduce the vaporiser setting if using inhalants
3. Administer appropriate fluid therapy - volume and type required will vary. Currently, the volume of fluid administered under general anaesthesia is controversial – see textbooks and recent literature for further information.
4. Administer appropriate vasoactive agents such as dopamine, ephedrine, epinephrine or phenylephrine. Each of these drugs have different sympathomimetic properties
5. Administer antimuscarinics if a vagally mediated bradycardia is contributing to hypotension

Summary

The measurement and monitoring of the cardiovascular system is extremely important in animals under general anaesthesia. The equipment necessary can be expensive but its regular use may help to detect problems early such that they can be dealt with before further deterioration occurs. However, anaesthetists need to be familiar with the many limitations and potential problems that can occur.