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Pitfalls and common errors of anaesthetic monitoring devices. Part 2: Non-invasive blood pressure monitoring

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Electronic monitoring devices have an important role to play in safe anaesthesia. However, in order for the data they produce to be used appropriately, they need to be interpreted. The first part of the interpretation requires the anaesthetist to determine whether or not the numbers the monitor produces are likely to be realistic or not. Only after this is done should decisions about the ongoing management of the patient be made.

As we saw in the first article in this series (McMillan, 2016), electronic monitors are prone to failure. In fact, each piece of monitoring equipment has its own inherent flaws. Understanding how an individual monitoring device gets the numbers it displays is important so that you can understand and learn to recognise common errors and how to manage them.

Blood pressure monitoring

Hypotension is a common problem encountered while anaesthetising small animal patients. Most anaesthetic agents cause some degree of disturbance to the cardiovascular system, which means blood pressure alterations are commonly encountered. A recent study reported that significant hypotension (hypotension that required an intervention to be performed to counter it) occurred in 1 in 9 anaesthetised small animal patients (McMillan & Darcy, 2016). Hypotension can have serious sequelae such as hypo-perfusion, which can lead to organ damage, and therefore maintaining blood pressures within safe boundaries is an important part of an anaesthetist's role. Managing blood pressure relies on us being able to assess and measure blood pressure accurately.

Non-invasive methods of blood pressure monitoring are simple and affordable ways of monitoring blood pressure. The two non-invasive blood pressure monitoring methods commonly used in veterinary medicine are Doppler flowmetry and oscillometry. Both techniques rely on an inflatable cuff occluding blood flow through a vessel running to an extremity and then detecting the return of blood flow as the cuff is deflated. The pressure within the cuff can be measured and used to estimate blood pressure.

Doppler flowmetry

Mechanism of measurement

Return of blood flow when utilising Doppler flowmetry is detected via a Doppler ultrasound probe. Changes in blood velocity cause changes in the pitch of reflected ultrasound (the Doppler effect) which can be detected and turned into an audible (or visible) signal. The Doppler probe should be placed over an artery below the cuff and can be used as a method of continuous pulse monitoring. The cuff is attached to a hand-held sphygmomanometer which can manually inflate and deflate the cuff. The equipment required for Doppler flowmetry blood pressure is shown in **Figure 1**.

Theoretically, Doppler flowmetry detects the pressure at which blood flow returns to the artery beneath it during cuff deflation, a point which should correspond to systolic blood pressure.

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Figure 1. The equipment required for non-invasive blood pressure measurement using the Doppler flowmeter technique. (A) Sphygmomanometer with (B) a selection of occlusive cuffs. (C) A Doppler flowmeter. (D) Ultrasound coupling gel

Limitations of Doppler flowmetry

The point at which a Doppler flowmeter is able to detect flow may not in fact correspond to systolic pressure. How closely a Doppler is able to measure systolic pressure probably depends on a number of factors. First and foremost, the size of the vessel and the amount of flow passing through it will affect the reading. Flow is likely to be detected later and at lower pressures in small arteries with lower flow. This has been borne out by many studies in cats that suggest Doppler blood pressure regularly under-reads systolic pressure. It has been recommended that simple correction factors could improve the accuracy of systolic blood pressure obtained through Doppler flowmetry (Grandy et al., 1992), but other sources suggest that Doppler flowmetry may in fact be giving a value closer to mean pressures (Caulkett, Cantwell, & Houston, 1998). This problem may be compounded during anaesthesia if alpha-2 agonists, such as medetomidine or dexmedetomidine, are administered due to reduced cardiac output and vasoconstriction reducing flow in the vessel being monitored.

In reality, it is difficult to say what the pressure achieved through Doppler flowmetry corresponds to in an individual patient. The relationship between systolic pressure and Doppler pressure may even change throughout anaesthesia as circulating blood volume, cardiac function and vasomotor tone change; however, it generally appears to at least correlate well with systolic pressure (Caulkett et al., 1998). As a consequence, Doppler flowmetry should be used as a guide to what blood pressure is doing (i.e. be used for trends) rather than giving an exact blood pressure. One recent study concluded that the use of Doppler flowmetry in cats could be “misleading” and should be “interpreted with caution” (da Cunha et al., 2014). Clinically, therefore, trends rather than absolute values should be monitored.

Secondly, there is an element of inter-user variability, with experienced users usually having a better “ear” for detecting the change in pitch associated with returning pulses. Thirdly, changes in environmental noise may affect the ability of the user to detect the audible signal.

Poor coupling (contact between the ultrasound probe and the patient) can also cause problems. Doppler ultrasound probes rely on good contact in order to transmit and receive their signal. Clipping the area directly over the artery, applying spirit and ultrasound gel can improve contact. Gel can dry (especially when hot-air warming blankets are utilised) and be displaced throughout a long anaesthetic, so plenty of gel should be applied in the initial probe placement. The use of headphones can improve the ability of the user to hear the pulse as it returns.

For the best results the cuff should be inflated rapidly to a pressure 20–30 mmHg above the point where the audible pulse disappears. The cuff should be deflated in a slow and steady fashion, the rate of which depends on the heart rate. The faster the rate, the quicker you can afford to be with deflation.

Finally, movement of the probe during measurement and between measurements can affect accuracy, consistency of measurements and usability. Tape can be used to hold the probe in place and this reduces movement and ensures consistent probe placement.

Electromagnetic interference

Any strong electromagnetic field can interfere with Doppler flowmetry. One of the biggest problems can be caused by the use of electric heat blankets such as the Hot Dog™. Electrical interference generally is audible as pulsatile crackling or constant background hissing. Intermittently turning off the heating blanket may allow interference-free readings to be made, but does impair the use of the Doppler as a continuous pulse monitor.

Battery failure

Doppler flowmeter devices generally run off a battery, which can cause problems if the battery runs out during an anaesthetic as the quality of the signal reduces before the unit finally fails. It is therefore vitally important to maintain Doppler flowmeter batteries as per the manufacturer’s instructions, ensuring that they are charged appropriately prior to any anaesthetic.

Damaged piezoelectric crystal array and wiring

Ultrasound is transmitted and received from an array of piezoelectric crystals in the Doppler probe. These crystals produce ultrasound when an electric current is applied to them and produce an electric current when ultrasound returns. These can be arranged in a linear or circular array (see **Figure 2**). Doppler flowmeter probes can be easily damaged and this can impair the signal produced. Probes should be stored carefully and be protected from damage; for example, they can be wrapped in foam or bubble wrap when being stored at the end of the day. Wiring can also be damaged, especially in units where the probe can be removed from the rest of the Doppler unit. Removal of the wires should be kept to a minimum to avoid excessive wear and tear.

Figure 2. Doppler flowmeter ultrasound probes with a circular (above) and linear (below) piezoelectric crystal array

Oscillometric blood pressure monitoring

Mechanism of measurement

A microprocessor in the monitor controls and measures inflation and deflation of the cuff. As flow returns in the artery beneath the cuff, turbulence in the vessel causes pressure oscillations to occur, and this small change in pressure can be detected by a pressure transducer. The point at which oscillations return is considered to be systolic pressure; the point at which oscillations are at their maximum is considered systolic pressure and the point where oscillation intensity starts to diminish is considered diastolic pressure. Each of these pressures are then displayed by the monitor (**Figure 3**).

Limitations of oscillometers

In general, oscillometers tend to under-read systolic pressure and over-read diastolic pressures. Mean pressures tend to be the most reliable as they are taken from the point where the pressure oscillations are at their largest.

Oscillometers rely on strong, regular pulsations and therefore they can often struggle to obtain readings from animals that have an arrhythmia. Again, when alpha-2 agonists are used, profound sinus arrhythmia and even second-degree atrioventricular blocks are common, so oscillometry can consequently become less accurate and reliable. The quantity and quality of flow occurring in the occluded artery also affect the ability of an oscillometer to detect flow.

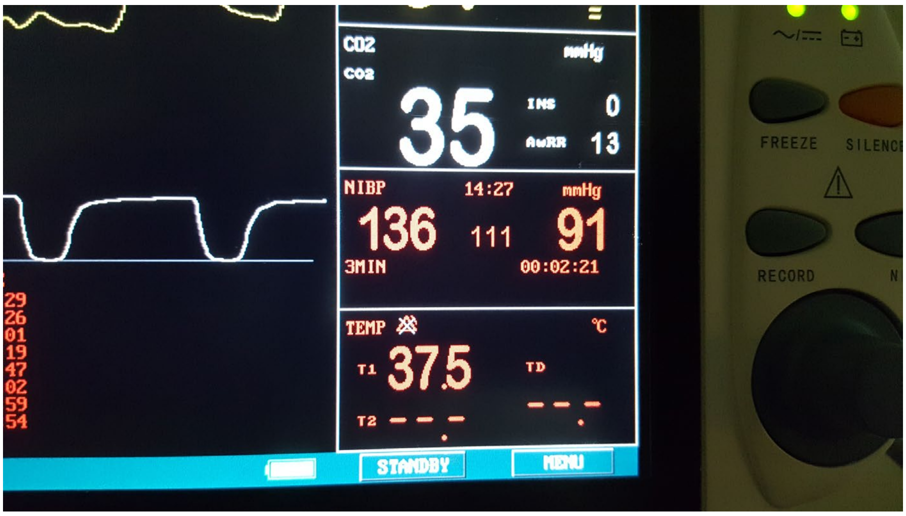

Figure 3. The output from an oscillometric non-invasive blood pressure monitoring device. The centre panel shows systolic (136 mmHg), mean (111 mmHg) and diastolic (91 mmHg) pressures

The size of the patient and its current haemodynamic status (circulating blood volume, cardiac function and vasomotor tone) will all affect the ability of an oscillometer to obtain accurate readings. Smaller patients and patients that are either hyper- or hypotensive are likely to pose the biggest challenge to accurate measurement.

Many oscillometers, those designed for human not veterinary use, use normal human blood pressures to determine cuff inflation. They often have settings for neonatal, paediatric and adult patients, which alters the pressure that the cuff initially inflates to. Patient type can often be manually selected, but may be chosen automatically depending on the cuff selected. As human neonates have much lower blood pressures than adult veterinary patients of similar size, oscillometers in neonatal mode may struggle to obtain readings from an adult veterinary patient as they will initially inflate to a pressure that will not occlude flow. This often causes monitors to "time out".

Veterinary monitors are now more widely available and technology is becoming more sophisticated, but even so-called "high-definition" oscillometers have been shown to have mixed accuracy and precision. However, many newer oscillometers seem to cope with the range of sizes and heart rates of veterinary patients better than some models originally designed for use on humans.

General limitations of non-invasive blood pressure monitoring

There are also a number of more generic limitations for non-invasive blood pressure monitoring that pertain to both Doppler flowmetry and oscillometry.

Cuff size

Selecting the appropriate cuff size is important for accurate non-invasive blood pressure monitoring. Ideally the width of the cuff should be 40% of the circumference of the limb it is being placed on. In reality, the limited number of cuff sizes available means that many animals fall between two sizes, which can lead to erroneous measurement. If a cuff is too narrow this tends to over-read blood pressures (giving blood pressures that are greater than reality) as the cuff is not wide enough to properly

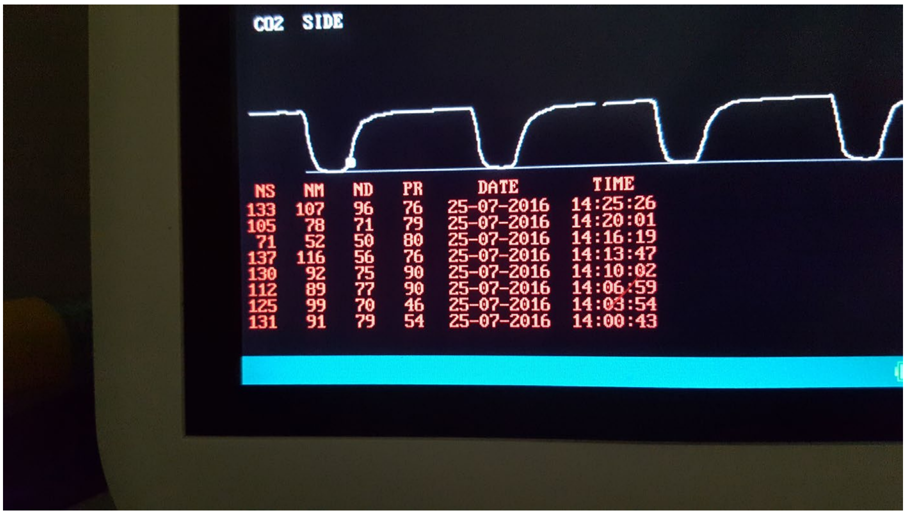

Figure 4. Historical oscillometric blood pressure outputs showing columns for (from left to right): Systolic (NS), mean (NM) and diastolic (ND) pressures (mmHg), pulse rate, date and time. Comparing the pulse rate obtained by the oscillometer to that obtained through manual pulse palpation or via another piece of monitoring equipment such as a pulse oximeter

occlude the artery, whereas too wide a cuff reduces flow through the artery more due to increasing resistance so tends towards under-reading (giving blood pressures that are lower than reality). The error tends to be greater with too small a cuff than too large. As a general rule of thumb, if the two Velcro sections of the cuff meet nicely then the cuff is likely to be an appropriate size!

Interval between readings

It is important to recognise that non-invasive blood pressure monitoring does not give you beat-to-beat changes in blood pressure, but rather gives you snap-shots taken at regular intervals. As blood pressure can swing rapidly, especially in a crisis, non-invasive blood pressure monitors may be less reliable in sick or otherwise unstable patients. The additional audible pulse monitoring afforded by the use of a Doppler flowmetry does, however, allow beat-by-beat qualitative assessment of cardiovascular function, in terms of pitch and duration of the audible signal, so it has a certain advantage in some patients despite only giving an estimate of systolic pressure.

In addition, the timing between measurements using both techniques is important. If the interval is too short, blood flow through the artery can be impaired, which leads to lowered blood pressures on subsequent measurements. Most oscillometers have an automated cycle time that limits how regularly they cycle and try to take measurements. Cycling should be set to 2.5–3 min to avoid this.

Cuff position

The position that the cuff is placed is also important. Most cuffs have an arrow to mark the point of the cuff that should overly the artery; correct positioning improves the ability of the monitor to detect pressure oscillations.

Theoretically, cuffs should be placed over relatively non-compressible appendages with a circular cross-sectional area; however, one study has suggested that the best position for one make of oscillometer is just above the hock (a readily compressible region) (Garofalo et al., 2012).

The level of the appendage (limb or tail) and cuff in regards to the level of the right atrium of the heart is also important. A distance of 10 cm above the right atrium will underestimate blood pressure by 7.36 mmHg, and 10 cm below the right atrium will overestimate by the same amount. In reality this rarely makes much difference in small animals in most normal circumstances.

How can we assess the accuracy of an oscillometer reading?

This can be difficult. Some models like the HDO (high-definition oscillometer) can give an oscillometric diagram when plugged into a laptop with the appropriate software installed. The oscillometric diagram graphically demonstrates where the machine got its pressure readings from and can be used to assess how realistic the readings are likely to be.

In most models, assessing whether the pulse rate given by the oscillometer (**Figure 4**) is close to the pulse rate as obtained through manual palpation or from other monitoring equipment can give an idea of whether the reading is likely to be accurate.

What to do when an abnormal reading is obtained?

When any abnormal reading from a piece of anaesthetic monitoring is obtained, the patient should be assessed. Pulses should be checked and all monitoring should be compared and cross-referenced. After assessment the anaesthetist can decide whether the reading is likely to be true and whether they wish to intervene to counter the hypotension (e.g. by reducing the vaporiser setting or administering a bolus of fluids). Taking another measurement while assessing the patient is another valid option, but taking another reading without assessing the patient is not to be recommended as it can cause delays in intervention.

Conclusion

Monitoring with electronic devices is fraught with problems. Knowledge of the mechanisms of measurement and the likely errors and pitfalls can assist the anaesthetist's decision-making during an anaesthetic and help ensure the patient is kept safe.

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Multiple Choice Questions

1. Doppler blood pressure readings in cats are indicative of systolic blood pressure:

(a) True

(b) False

2. In the McMillan & Darcy, 2016 study how many patients showed significant hypotension?

(a) 1 in 9

(b) 1 in 37

(c) 1 in 54

(d) 1 in 106

3. Which of the following drugs commonly used in anaesthetic premedication may reduce cardiac output and cause vasoconstriction which will affect the accuracy of the Doppler reading?

(a) Methadone

(b) Acepromazine

(c) Medetomidine

(d) Buprenorphine

4. The width of the blood pressure cuff should be what percentage of the limb circumference?

(a) 10%

(b) 20%

(c) 40%

(d) 50%

5. A blood pressure cuff that is too narrow will over-read the patient's blood pressure:

(a) True

(b) False

6. It is recommended that the automated cycle time on an oscillometric blood pressure machine is:

(a) Every 1 minute

(b) Every 3-3.5 minutes

(c) Every 5 minutes

(d) Every 10 minutes

7. Placing the cuff on the limb significantly (i.e. 10cm) below the heart will cause overestimation of the blood pressure:

(a) True

(b) False

8. Which of the following would not cause the oscillometric blood pressure monitor to become less accurate and reliable?

(a) Sinus rhythm

(b) Second degree AV bloock

(c) Alpha-2 agonists

(d) Severe sinus arrhythmias

9. The cuff pressure that the cuff should be inflated to above the point at which an audible pulse returns; using a sphygmomanometer for Doppler pressure is:

(a) 10-15mmHg

(b) 20-30mmHg

(c) 35-40mmHg

(d) 50mmHg

10. If an abnormal blood pressure reading is detected, which of the following is the least appropriate action?

(a) Take another reading immediately

(b) Assess the patient

(c) Evaluate the pulses

(d) Check other monitoring and cross reference

For the answers to the MCQs, please go to: http://www.bvna.org.uk/publications/veterinary-nursing-journal