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RESEARCH PAPER

Comparison of arterial blood pressure measurements obtained invasively or oscillometrically using a Datex S/5 Compact monitor in anaesthetised adult horses

Tyfane T Yamaoka*, Derek Flaherty*, Patricia Pawson*, Marian Scott† & Adam Auckburally*

*Institute of Biodiversity, Animal Health and Comparative Medicine, School of Veterinary Medicine, University of Glasgow, Glasgow, UK

†School of Mathematics and Statistics, University of Glasgow, UK

Correspondence: Tyfane Tie Yamaoka, School of Veterinary Medicine, University of Glasgow, UK. Email: 2055971y@student.gla.ac.uk

Arterial blood pressure in anaesthetised horses

Abstract

Objective To assess agreement between non-invasive blood pressure (NIBP) oscillometrically-derived values from a multiparameter monitor (Datex Ohmeda S/5 Compact), with those obtained by invasive blood pressure (IBP) measurement, in anaesthetised horses undergoing elective surgery.

Study design Prospective clinical study.

Animal population Forty healthy adult horses.

Methods: Horses were anaesthetised with various anaesthetic protocols (based on clinical requirements). Depending on positioning, cannulation of the facial or lateral metatarsal artery was performed for IBP measurement. The cannula was connected via a transducer to the monitor. An appropriately sized NIBP cuff was placed around the tail base and connected to the same monitor. Systolic (SAP), mean (MAP) and diastolic (DAP) arterial blood pressures were continuously recorded from the invasive system, and at 3 minute intervals from the oscillometric system, throughout the surgical procedure using a Datex iCollect program. An appropriate arithmetic correction factor was applied to the oscillometric results where the cuff was not level with the heart. Assessment of the degree of agreement between invasive and non-invasive readings at each time-point was performed using a modified Bland-Altman analysis.

Results While in many horses there was relatively close correlation between the values obtained over time, there was substantial variability in individual animals which resulted in wide Bland-Altman limits of agreement. The oscillometric device over-reads by approximately 32, 23 and 22 mmHg, and under-reads by 26, 17 and 19 mmHg for SAP, MAP and DAP respectively, compared with the IBP values. However, using the mean difference and standard deviation, the device conforms to ACVIM standards.

Conclusions and clinical relevance Oscillometric blood pressure measurement using the Datex Ohmeda S/5 Compact multiparameter monitor conforms to ACVIM standards when the NIBP cuff is placed on the tail. However, due to the wide variability in measurements, we cannot recommend this technique to guide therapy in anaesthetised adult horses.

Keywords anaesthesia, blood pressure, Datex Ohmeda S/5 Compact, horses non-invasive blood pressure

Introduction

General anaesthesia in horses carries a perioperative mortality rate of between 0.12 and 1.8% in healthy individuals (Wagner & Brodbelt 1997; Mee et al. 1998a and 1998b; Johnston et al. 2002; Bidwell et al. 2007; Dugdale et al. 2016), which is significantly higher than that reported for most other species (Dyson et al. 1998, Johnston et al. 2002, Lagasse 2002; Brodbelt et al. 2008). Approximately one third of deaths are directly related to intraoperative cardiovascular issues such as cardiac arrest, or to post-operative cardiovascular collapse (Johnston et al. 2002). Fractures and myopathies are responsible for another one third, which may be associated with poor muscle perfusion during general anaesthesia (Johnston et al. 2002). Consequently, it is important that normal cardiovascular function is maintained as far as possible in anaesthetised horses. In the clinical setting, arterial blood pressure (ABP), in combination with a subjective assessment of mucous membrane colour, is used as an indicator of cardiovascular function (Trim 2005; Hubbell 2008). In anaesthetised dogs, hypotension has been defined as a mean arterial pressure (MAP) of less than 60-65 mmHg and prompts treatment (Ruffato et al. 2015). Furthermore, an increased incidence of myopathy has been shown in horses with MAP less than 60 - 70 mmHg (Grandy et al. 1987; Johnston et al. 2002; Trim 2005; Hubbell 2008). Thus, the recognition of hypotension is important, as this guides the requirement for supportive therapy.

The Association of Anaesthetists of Great Britain and Northern Ireland (2007) and the American Society of Anesthesiologists (2009) consider non-invasive monitoring of blood pressure mandatory during anaesthesia in humans, and it may be assumed that veterinary anaesthetists should be following similar guidelines. Invasive measurement of blood pressure is generally the technique of choice in anaesthetised horses, largely because of the ease in which peripheral arteries can be catheterised, and the necessity for frequent arterial blood gas analysis during anaesthesia. However, although rare, catheterisation of a peripheral artery may be associated with morbidity: notably infection, thromboembolism, haematoma formation and tissue necrosis (Wagner & Brodbelt 1997). In some circumstances (e.g. short procedures, difficult arterial catheterisation, an inexperienced anaesthetist), non-invasive blood pressure (NIBP) measurement may be preferable. In addition, due to the speed with which it can be applied, NIBP can potentially be used to provide some information on blood pressure whilst an arterial catheter is being placed. Although non-invasive measurement techniques are inherently safer, oscillometric measurement of arterial pressure in particular has been shown to agree poorly when compared with invasive measurement in the horse (Hatz et al. 2015, Tearney et al. 2015). However, the results from different monitors are not necessarily comparable, and there is no information on the accuracy of NIBP measurement using Datex technology in anaesthetised adult horses. Therefore, the aim of this study was to assess the agreement between oscillometrically-derived arterial blood pressure values from a commonly used multiparameter monitor (Datex Ohmeda S/5 Compact), with those obtained by invasive blood pressure measurement, in anaesthetised horses in a clinical setting.

Material and methods

This clinical study was approved by the Ethics Committee of the School of Veterinary Medicine, University of Glasgow, UK.

Forty client-owned adult horses of various breeds, ranging in body weight from 232 to 764 kg (mean 525 ± standard deviation (SD) 113kg), were included in this study. Horses were considered healthy based on complete physical examination, and classified as American Society of Anesthesiologists physical status 1 or 2. There were no exclusion criteria based on gender, breed or body weight. All horses were scheduled for elective procedures requiring general anaesthesia, using appropriate protocols selected by the individual anaesthetist. Food, but not water, was withheld for 12 hours prior to general anaesthesia.

All horses were administered acepromazine (Calmivet, Vetoquinol, France) intramuscularly (IM), approximately 40 minutes prior to general anaesthesia. Once mild sedation was achieved, a 14-gauge intravenous (IV) cannula (Mila International Inc., KY, USA), was placed into a jugular vein after subcutaneous infiltration with lidocaine (Lignol 2%; Dechra Veterinary Products, UK). Further premedication was administered IV and consisted of a combination of an $\pm_2$-adrenergic agonist and an opioid (Table 1). General anaesthesia was induced with diazepam (Hameln Pharmaceuticals, UK), combined with ketamine (Narketan; Vetoquinol UK Ltd, UK) IV, or IV infusion of guaifenesin (Myorelax; Dechra Veterinary Products, UK) until ataxic, followed by an IV bolus of thiopental (Ilium thiopentone; Troy Laboratories Australia Pty Ltd, Australia) (Table 1).

Once the horse attained lateral recumbency, orotracheal or nasotracheal intubation was performed. Horses were hoisted with straps onto a padded surgical table, attached to a large animal anaesthetic machine using a circle breathing system and were positioned in either dorsal or lateral recumbency, depending on the procedure, and this positioning was recorded. Maintenance of anaesthesia (Table 1) was achieved with an inhalational agent vaporised in either oxygen or an oxygen and air mixture to achieve a fraction of inspired oxygen (FIO_2) ranging from 0.5 to 0.95, or by a total intravenous anaesthetic (TIVA) technique. Initially, all horses were allowed to breathe spontaneously, but mechanical ventilation was used when the partial pressure of carbon dioxide ($PaCO_2$) was above 70 mmHg. Compound sodium lactate (Vetivex II, Dechra Veterinary Products, UK) was administered at 5 mL kg^{-1} $hour^{-1}$ to all horses throughout anaesthesia.

Some horses were administered medetomidine (Sedator; Dechra Veterinary Products, UK) as part of their premedication followed by an IV infusion during the maintenance phase of anaesthesia. Others were administered a ketamine infusion during the maintenance phase (Table 1). If horses demonstrated signs of inadequate anaesthesia, either an IV ketamine or thiopental bolus was administered. Romifidine (Sedivet; Boehringer Ingelheim Ltd, UK), morphine (morphine sulphate; Martindale Pharmaceutical Ltd, UK) or butorphanol (Dolorex; MSD Animal Health, UK), were administered during anaesthesia as necessary for the particular procedure. An infusion of dobutamine (dobutamine hydrochloride; Hameln Pharmaceuticals) was administered intraoperatively, as required, to maintain MAP above 65 mmHg. Two horses required additional muscle relaxation for ophthalmic procedures and this was achieved with IV atracurium (atracurium besilate; Hameln Pharmaceuticals Ltd) and reversed with edrophonium (edrophonium; Alliance Pharmaceuticals, UK) if needed (Table 1).

A Datex Ohmeda S/5 Compact monitor (Datex Ohmeda Division; Helsinki, Finland), was used to display the electrocardiogram (ECG), arterial haemoglobin saturation with oxygen (SpO_2), end-tidal carbon dioxide ($PE´CO_2$), fractional inspired oxygen (FIO_2), anaesthetic agent vapour and non-invasive (NIBP) and invasive (IBP) blood pressures. Data was automatically recorded using the Datex iCollect program (GE Healthcare Clinical System (UK) Ltd.) throughout the duration of the procedure.

Invasive Blood Pressure Measurement

A 20 gauge, 32 mm cannula (Biovalve; Vygon, UK) was placed aseptically in the right or left, facial, transverse facial, or lateral metatarsal artery, depending on patient position and surgical procedure taking place. The arterial cannula was inserted by an experienced anaesthetist to ensure prompt placement, and was connected to a disposable electronic transducer (Edwards Lifesciences LLC; CA, USA), via saline filled non-compliant tubing and a 3-way stopcock. Both the transducer and monitor were calibrated against a mercury manometer, and the transducer zeroed to atmospheric pressure and positioned at the level of the right atrium, using the point of the shoulder for horses in dorsal recumbency, and the xiphoid process of the sternum for horses in lateral recumbency.

Non-invasive Blood Pressure Measurement (NIBP)

The tail circumference was measured and a NIBP cuff with a width of approximately 40% of this measurement was chosen and placed around the base of the tail. Systolic (SAP), diastolic (DAP) and mean (MAP) arterial pressures were obtained by oscillometry. NIBP measurements were taken at 3 minute intervals throughout the surgical procedure. If the oscillometric device failed to read, the monitor was left to measure blood pressure again at the next scheduled time-point. The distance between the cuff and the right atrium was measured and a conversion factor of +/- 7.5 mmHg for every 10 cm difference in height was applied (Gay et al. 1977). This arithmetic correction factor was applied to the oscillometric results where the cuff was not level with the heart.

IBP and NIBP paired measurements collection

The Datex iCollect program was set to start recording data immediately following positioning of the horse on the surgical table. Recording continued throughout the entire procedure with the first pair of readings collected once arterial catheterization was achieved and connected to the monitor. In this study, the NIBP was set to cycle every 3 minutes and IBP recording was continuous, which facilitated exact retrospective matching of paired readings.

Statistical analysis

An estimated calculated sample size of 34 horses was required to detect a 10 mmHg difference between the 2 measurement methods (based upon American College of Veterinary Internal Medicine (ACVIM) standards (Brown et al. 2007)), with a power of 0.8 (1 - ^{2} error) and ± error of 5%. In order to compare our data with guidelines from the American Association of Medical Instrumentation (AAMI) and the ACVIM, we calculated the mean difference and standard deviation between paired measurements. The 95% limits of agreement (LOA) between SAP, MAP and DAP values obtained by non-invasive and invasive blood pressure measurement were assessed using a modified Bland-Altman analysis for repeated measurements (Bland & Altman 2007). The limits of agreement between the two methods were calculated as the mean difference +/- 2 standard deviations of the differences, where the standard deviation is calculated to take account of the repeated nature of the observations. This provides a range within which any individual difference between IBP and NIBP is highly likely (95%) to lie.

All statistical analysis, including power analysis, was performed using Minitab, Version 16.

Results

A total of 350 pairs of readings were obtained from 39 horses. One horse was excluded from the study as this horse had a tail bandage in place, which appeared to interfere with oscillometric measurements. The oscillometric method failed to provide blood pressure readings in 30 of the 350 pairs: a failure rate of 8.6%.

Twenty-one horses were positioned in dorsal recumbency (including the excluded horse), 10 were positioned in left lateral and 9 were in right lateral recumbency. Tail diameter ranged from 15.0 to 32.5 cm and the mean ratio between the cuff width and tail circumference was 41.2%. Arterial cannula placement varied depending on how the horse was positioned. For horses positioned in dorsal recumbency, 18 had the facial artery catheterized and 3 the metatarsal artery. For horses in left lateral recumbency, 8 had the transverse facial artery catheterized and 2 the metatarsal artery. For horses in right lateral recumbency, 7 had the transverse facial artery catheterized and 2 the metatarsal artery. Mechanical ventilation was necessary in 26 horses, and 27 required dobutamine to maintain a MAP above 65 mmHg as determined from IBP.

Values for the mean difference and standard deviation between paired readings are reported in Table 2. Based on the confidence interval for the mean difference in MAP values between the two techniques, there was no indication of systemic offset (bias). From the LOA, the oscillometric device may over-read by approximately 32, 23 and 22 mmHg, and under-read by 26, 17 and 19 mmHg for SAP, MAP and DAP respectively, compared with the IBP values. This large variability is shown in Figure 1.

Discussion

In this study, ABP was measured invasively via an arterial catheter, and non-invasively using oscillometric technology within a Datex Ohmeda S/5 multiparameter monitor. Measurements of ABP are used to make therapeutic decisions, and therefore the anaesthetist must be confident that any non-invasive measurement is accurate. Several organisations have produced specific protocols for assessing the precision of these devices. The European Society of Hypertension (ESH) International Protocol for the validation of non-invasive techniques in adult humans, grades monitors as being very inaccurate where differences in blood pressure measurements are greater than 15 mmHg between the device being assessed and values obtained via the Korotkoff method (O'Brien et al. 2002). The ESH specifically advises against comparison with invasive measurement of arterial blood pressure due to beat-by-beat variation, and suggests that readings from the two methods are very rarely (if ever) identical (O'Brien et al. 2002). The Korotkoff method is not described in equids and, therefore, the ESH protocol cannot easily be extrapolated to anaesthetised horses. In addition, since intra-arterial measurement of blood pressure is considered the 'gold standard' in horses, it seems logical to compare any alternative technique against this, despite the limitations suggested by the ESH. Indeed, most other validation studies in veterinary patients compare the device under investigation with invasive arterial pressure measurement (Binns et al. 1995; Branson 1997; Wagner & Brodbelt 1997; Giguere et al. 2005; Deflandre and Hellebrekers 2008; Aarnes et al. 2013; Hatz et al. 2015). The American Association for the Advancement of Medical Instrumentation (AAMI) has standards for performance of automated NIBP devices used in humans; they recommend a mean difference between the 'gold standard' (Korotkoff method or intra-arterial blood pressure measurement) and a new device of ± 5 mmHg or less, with a standard deviation of 8 mmHg or less, as acceptable (White et al. 1993). The Datex oscillometric device evaluated in this study did not conform to the strict AAMI criteria. In veterinary patients, a consensus statement regarding validation of blood pressure measurement devices used in conscious dogs and cats with systemic hypertension, based on the AAMI, was developed by the American College of Veterinary Internal Medicine (ACVIM). Using these ACVIM standards, when validating a new system, the mean difference should be 10 mmHg or less with a standard deviation of 15 mmHg or less (Brown et al. 2007). Although the ACVIM standards are reported for the validation of NIBP monitors in the dog and cat, they are in fact based loosely on the AAMI guidelines and may be applicable to other animal species. Our data do conform to these ACVIM standards.

In this study, we also used the Bland Altman for repeated measurements analysis which takes into account repeated measurements over time and the variability in the measurements for each individual. It is assumed that the difference between the two methods is relatively similar over the time period and that observations in the same animal by the same method are not independent. Bland & Altman (2007) recommend that this modified analysis is applied when the quantity being measured is unstable, such as blood pressure. Some horses demonstrated very large standard deviations between the NIBP and IBP values, but they were not omitted from subsequent analysis. The effect of these horses on the overall limits of agreement (LOA) are relatively small since their variation is the smaller part of the overall 'between horse' variation used to determine the LOA. There appears to be no published guidance for validation of NIBP monitors using Bland Altman analysis and LOA. From a clinical point of view, the wide LOA would suggest that the monitor we tested is unreliable despite conforming to the ACVIM standards described above. However, since the LOA are simply a calculation based upon the mean difference and standard deviation, they should also be acceptable. Nevertheless, if the oscillometric device over-reads by approximately 32, 23 and 22 mmHg, and under-reads by 26, 17 and 19 mmHg for SAP, MAP and DAP respectively, compared with IBP measurements, we would have reservations using this information to guide therapeutic interventions.

The size of the NIBP cuff is important: if the cuff width is too narrow in relation to the circumference of the limb or tail, the blood pressure will be overestimated; if too wide then blood pressure will be under-estimated (Riebold & Evans 1985). When using the tail for NIBP cuff placement in horses, Muir et al. (1983) found the ideal cuff size to be 35% of the circumference, while Bailey et al. (1994) proposed 40% to be most appropriate, and Geddes et al. (1977) suggested that 25% was optimal. Based upon the aforementioned studies, it seems that a wide range of cuff sizes are acceptable. However, to standardize the technique in this study, a cuff width of approximately 40% of the tail circumference was selected.

In terms of cuff positioning, Taylor (1981) suggested a blood pressure cuff applied to the limbs in anaesthetised horses is unsatisfactory as the cuff may slip once the pressure is increased, but that the tail may be used instead. However, Hatz et al. (2015) demonstrated that, if the cuff is placed over the metatarsal or metacarpal bone when positioned in dorsal recumbency, or on the tail in horses positioned in lateral recumbency, the MAP displayed is within the acceptable accuracy limits in the majority, but not all, cases; however, they did not compare their results with the AAIM or ACVIM standards described above. All the horses in our study had the NIBP cuff placed on the base of the tail regardless of the body posture during anaesthesia, and a correction factor was applied to the results where the NIBP cuff was not at the same level as the heart. We did not examine the effects of body position on the accuracy of the NIBP method since the coccygeal artery should remain relatively uncompressed regardless of positioning,

As a result of the variability in positioning required for surgical procedures, either the facial, transverse facial or metatarsal arteries were catheterised. Blood pressure measurements may vary at different points in the arterial tree due to arterial wave reflection when the pulse wave enters the different arteries. Usually MAP is the least affected by this factor, but SAP and DAP may be different, with more peripheral arteries showing arterial pulse amplification demonstrated by a steeper SAP curve (Gardner 1981). The more peripheral the catheter placement, the tendency is for systolic pressure measurement to increase, while diastolic pressure decreases, as a result of resonance effects due to arterial branching (Muir et al. 1983, Alexander et al. 1993). These opposing changes between systolic and diastolic blood pressure measurements cause the MAP to decrease only slightly (Alexander et al. 1993). When treating abnormalities in ABP, most interventions are titrated against MAP, as this is the true driving pressure of tissue perfusion (Giguére et al. 2005). Poor perfusion may occur as a result of hypotension, and it is recommended that MAP be maintained above 65 - 70 mmHg in anaesthetised horses to avoid post-anaesthetic myopathy (Riebold & Evans 1985; Grandy et al. 1987; Duke et al. 2006). Our study obtained IBP measurements from different peripheral arteries, and the influence of catheter position may explain some of the variability in measurements. However, MAP values between the 2 techniques also showed poor LOAs and, therefore, the discrepancy is unlikely to be solely due to the different arteries cannulated.

Inaccuracy in IBP measurements may also arise from inadequacies in the dynamic response of the monitoring system. Objective analysis of this is possible using the fast-flush test and measuring the frequency and amplitude of oscillations following rapid closure of the flush valve (Gardner 1981). Whilst this is possible clinically, it is rarely measured. In our study, analysis of the system dynamics was subjectively assessed as per normal clinical practice and this does introduce minor limitations to the methodology. However, as MAP is little affected by these dynamic response characteristics, these results are likely to be accurate.

All individuals in this study received α_2-agonists either as premedication or by intra-operative infusion or bolus. This group of drugs have predictable and well-described cardiovascular effects, including bradycardia and increased peripheral vascular resistance (Yamashita at al. 2000). Grosenbaugh & Muir (1998) suggested that vasoconstriction may contribute to failure of pulse detection and underestimation of NIBP values when using oscillometric devices in anaesthetised dogs. Therefore the administration of α_2-agonists may have influenced signal quality and detection by the oscillometric device in this study. Indeed, the error message "weak signal" was often observed when the monitor was unable to report a BP value, although failure to obtain a reading was of relatively low incidence (8.6%) when compared to other studies (Giguere et al. 2005, Hatz et al. 2015, Tunsmeyer et al. 2014). Hatz et al. (2015) concluded that the administration of medetomidine as a continuous rate infusion to horses as part of an anaesthetic protocol, may have resulted in erroneous or absent readings from the NIBP device examined. In this present study, however, medetomidine infusion did not appear to interfere with NIBP measurements and readings from these animals followed a similar trend to IBP values.

Arterial catheterisation is relatively straightforward to perform in horses and provides convenient access for arterial sampling for blood gas analysis. However, as with any invasive technique, there are some risks associated with this. In humans, there appears to be little difference in complication rates and types between different arteries cannulated (Scheer et al. 2002). Whilst Dolente et al. (2005) demonstrated that the development of jugular catheter-associated thrombophlebitis in horses was associated with conditions such as hypoproteinaemia, endotoxaemia, large intestinal disease and salmonellosis, to the authors' knowledge there are no similar studies to assess the complications of arterial catheterisation in this species. Risk factors for the latter may not necessarily be the same as with venous catheterisation given that arterial catheters are usually in place for significantly shorter periods of time. Despite the lack of published evidence, based on extrapolation from the human studies, it is probable that there is some morbidity associated with arterial catheterisation in horses.

Oscillometric measurement of blood pressure, on the other hand, has the advantage of being non-invasive and, therefore, is not associated with any of the complications described above. Unfortunately, however, due to the unpredictability of the technique using the monitor tested in this present study, there may be indirect complications arising from inappropriate treatment of blood pressure: as the NIBP tended to over-read compared with IBP, this may lead to a failure to recognise and treat hypotension. Previous studies have shown variable results regarding the reliability of the NIBP technique using several different oscillometric technologies, ultrasonic Doppler, and automated and manual sphygmomanometry in awake and anaesthetised adult horses and foals (Riebold & Evans 1985; Muir et al. 1983; Bailey et al. 1994; Nout et al. 2002; Giguere et al. 2005; Hatz et al. 2015). In an early study with a small number of horses, Riebold & Evans (1985) found good correlation between the NIBP methods tested and IBP measurements. Muir et al. (1983) demonstrated good correlation between automatic sphygmomanometry and IBP in adult horses, although the presence of arrhythmias and hypotension interfered with NIBP readings. Hatz et al. (2015) found high variability between IBP and NIBP measurements and did not recommend using NIBP as an alternative. Nout et al. (2002) tested an oscillometric device in conscious and anaesthetised foals and administered a variety of drugs in order to manipulate ABP during comparative measurements. In their study there was good agreement between the IBP and NIBP methods, particularly so for MAP.

Giguere et al. (2005) suggested that values reported for NIBP in the foal are generally more accurate because they have a thinner layer of soft tissue surrounding peripheral arteries. In our study, all horses were adults and this may have influenced our results.

However, despite the wide LOAs, when the results from individual horses were examined, some showed very good correlation, despite the different cuff position and anatomical structure.

In this study, in order to mirror variations in clinical practice, no attempt was made to standardise the anaesthetic protocol, and the drugs used reflected the choices of the individual anaesthetists. Given that the purpose of the investigation was to examine the intra-individual variability between the NIBP and IBP readings, this should not influence the accuracy of the results obtained. Moreover, for an NIBP monitor to be of value in anaesthetised horses, its reliability must be demonstrated across the range of anaesthetic protocols commonly used in this species. Consequently, while inclusion of horses receiving medetomidine or dobutamine infusions, for instance, would have resulted in variation in vascular tone between animals, this is reflective of normal clinical practice. Although some individual horses in this study demonstrated good correlation between NIBP and IBP readings, there did not appear to be any obvious relationship between the anaesthetic protocol used and the accuracy (or otherwise) of the NIBP results obtained.

Conclusion

The Datex Ohmeda S/5 multiparameter monitor in anaesthetised adult horses conforms to ACVIM standards, when the cuff is placed on the tail, but not to the strict AAMI standards. However, there was significant variability between arterial blood pressure results obtained invasively and those obtained non-invasively. Consequently, we have reservations recommending this oscillometric system for arterial blood pressure measurement in anaesthetised adult horses, particularly when the measurements are used to guide therapeutic interventions.

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Authors' contributions

T.T.Y.: Study design, data collection, data management, data interpretation, preparation of manuscript

D.F.: Study design, preparation of manuscript

P.P.: Study design, data interpretation, preparation of manuscript

M.S.: Statistical analysis, data management, data interpretation

A.A.: Study design, data interpretation, statistical analysis, preparation of manuscript

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Figure 1 Bland Altman for repeated measurements plots to demonstrate the variability and limits of agreement for (a) systolic arterial blood pressure (SAP), (b) mean arterial blood pressure (MAP) and (c) diastolic arterial blood pressure (DAP) measurements recorded from an arterial catheter (IBP) and from the Datex S5 oscillometric device (NIBP) in anaesthetised adult horses. The upper and lower lines represent the limits of agreement between the two measurement methods.

Figure 1a

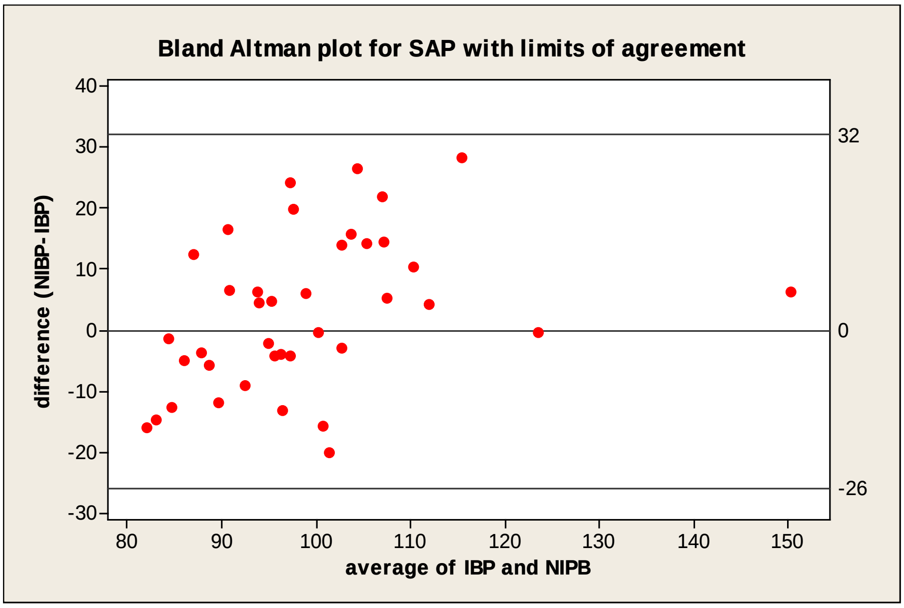


Figure 1b

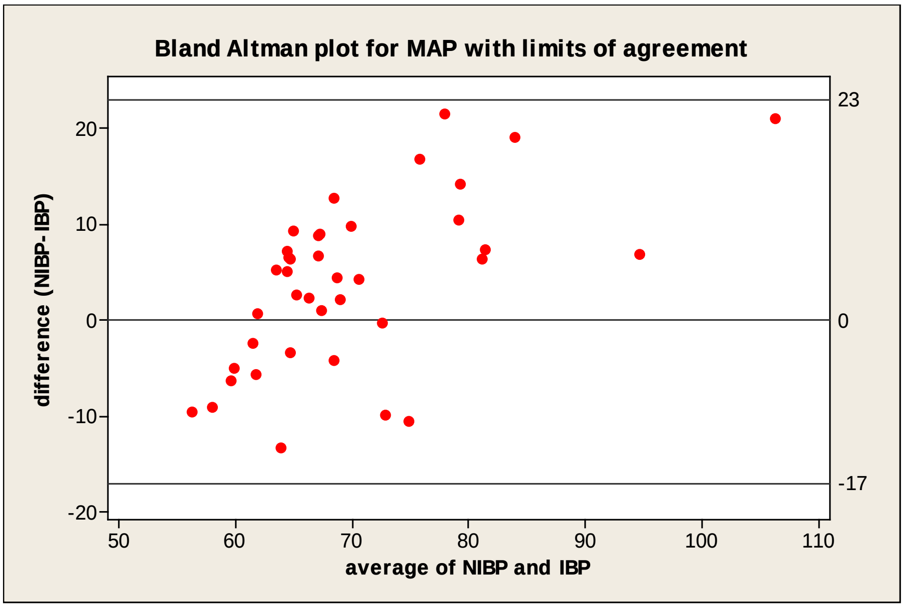
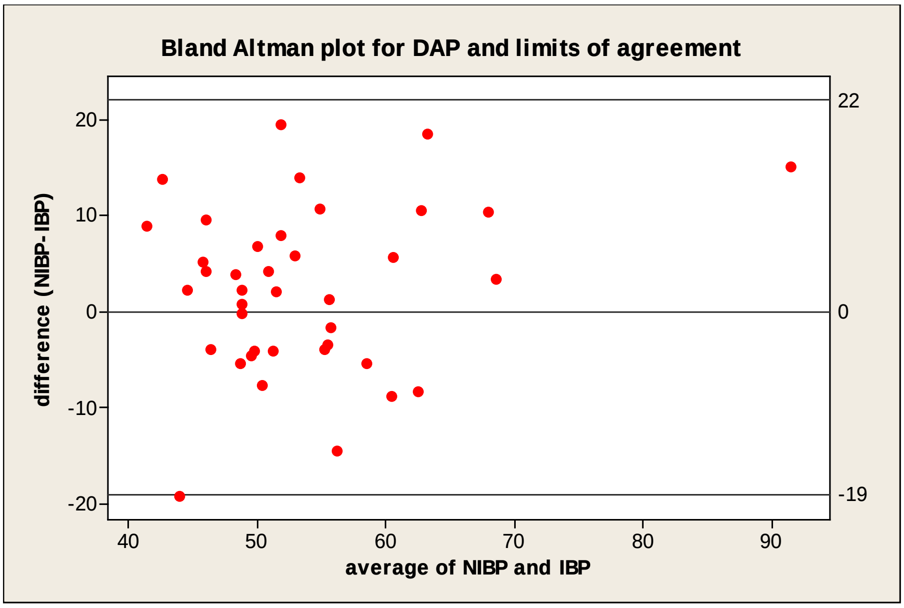


Figure 1c

545



Bland Altman plot for DAP and limits of agreement
difference (NIBP- IBP)
20
10
0
-10
-20
22
0
-19
40
50
60
70
80
90
average of NIBP and IBP

Table 1 Drugs used for premedication, induction and maintenance of general anaesthesia in 40 horses.

Premedication	**Dose**	**Number of horses (out of 40)**
Acepromazine	20 mcg kg^{-1} IM	40
Medetomidine	7mcg/kg IV	5
Detomidine	20 mcg/kg IV	3
Romifidine	80 mcg/kg IV	31
Xylazine	1.1 mg/kg IV	1
Morphine	0.1 mg/kg	36
Butorphanol	0.05 mg/kg IV	1
Induction		
Ketamine	2.2 mg/kg IV	39
Diazepam	0.05 mg/kg IV	39
Thiopentone	5 mg/kg IV	1
Guaifenesin	25 - 75 mg/kg by infusion	1
Maintenance		
Isoflurane in oxygen	-	38
Sevofurane in oxygen	-	1
Triple drip (xylazine, ketamine, GGE)	1 ml/kg/hour (GGE 100mg/ml, xylazine 1mg/ml, ketamine 2mg/ml)	1
Intraoperative drugs		

administered		
Dobutamine infusion	0.5 - 2 mcg/kg/minute	29
Medetomidine infusion	3.5 mcg/kg/hour	5
Romifidine bolus	20 mcg/kg IV	21
Morphine bolus	0.1 mg/kg IV	7
Butorphanol bolus	0.025 mg/kg IV	1
Ketamine bolus	0.1 - 0.2 mg/kg IV	18
Ketamine infusion	0.1 - 0.5 mg/kg/hour	1
Thiopentone bolus	0.5 - 1 mg/kg IV	7
Atracurium bolus	0.1 mg/kg IV	2
Edrophonium bolus	0.2 mg/kg IV	2

Table 2 Simple descriptive statistics for paired readings (non-invasive and invasive) for systolic, mean and diastolic blood pressure measurements recorded from an arterial catheter (IBP) and from the Datex S5 oscillometric device (NIBP) in anaesthetised adult horses.

Arterial blood pressure	**Mean Difference**	**Standard Deviation**
Systolic (mmHg)	2.96	12.69
Mean (mmHg)	3.78	8.77
Diastolic (mmHg)	2.30	8.65