SHORT COMMUNICATION

Agreement between two oscillometric blood pressure technologies and invasively measured arterial pressure in the dog

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Abstract

Objectives To compare two commonly used oscillometric technologies for obtaining noninvasive blood pressure (NIBP) measurements and to determine if there is a difference in agreement between these systems and invasive blood pressure (IBP) measurements.

Study design Prospective, experimental study.

Animals Twenty adult laboratory dogs.

Methods Each dog was anesthetized and its median caudal artery catheterized for IBP monitoring. An NIBP cuff was placed in the middle third of the antebrachium and attached to either monitor-1 or monitor-2. Four pairs of concurrent NIBP and IBP measurements were recorded with each monitor. Agreement between IBP and NIBP measurements was explored using Bland–Altman analysis, as well as the American College of Veterinary Internal Medicine (ACVIM) and Association for the Advancement of Medical Instrumentation (AAMI) guidelines for the validation of NIBP devices.

Results Both NIBP technologies produced results that met the ACVIM and AAMI guidelines for the validation of NIBP devices. For monitor-1, analyses of agreement showed biases of 0.2 mmHg [95% limits of agreement (LoA) –11.8 to 12.3 mmHg] in systolic arterial pressure (SAP) values, –2.6 mmHg (95% LoA –14.4 to 9.1 mmHg) in diastolic arterial pressure (DAP) values, and –2.5 mmHg (95% LoA –12.7 to 7.3 mmHg) in mean arterial pressure (MAP) values. For monitor-2, analyses of agreement showed biases of 3.4 mmHg (95% LoA –8.7 to 15.5 mmHg) in SAP values, 2.2 mmHg (95% LoA –6.6 to 10.9 mmHg) in DAP values, and 1.6 mmHg (95% LoA –5.9 to 8.9 mmHg) in MAP values.

Conclusions and clinical relevance Multi-function monitors can contain components from various manufacturers. Clinicians should consider whether these have been validated in the species to be monitored. Both of the technologies studied here seem appropriate for use in dogs.

Keywords canine, comparison, IBP, monitoring, NIBP.

Introduction

The measurement of arterial blood pressure has long been recognized as an important part of the monitoring of anesthetized patients, and of the evaluation of systemically ill animals (Rozanski & Rush 2007; Silverstein et al. 2008). Clinically, vet-
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Veterinarians often rely on noninvasive blood pressure (NIBP) measurements, such as those obtained with Doppler ultrasonography and oscillometric devices; however, validating these devices has been difficult.

Although validation studies frequently cite the make and model of the multi-function monitor utilized, they often fail to indicate the actual NIBP oscillometric technology employed in the monitor. The various brands of clinical monitors often utilize different internal components. For example, veterinary multi-function monitors are often produced with either Nelcor or Masimo pulse oximeter technologies. Although they both measure the same variable, they utilize different proprietary algorithms to calculate the percentage of oxygen saturation and, in theory, could produce discordant results. Similarly, information regarding the specific NIBP technology available in a specific clinical multi-function monitor is necessary to draw conclusions regarding the performance of the particular NIBP device.

There are two major manufacturers of NIBP oscillometric technologies commonly utilized in veterinary multi-function monitors in the USA. This study compares NIBP measurements obtained at the middle third of the antebrachial area utilizing two common NIBP technologies with invasive blood pressure (IBP) measurements obtained from the median caudal artery in anesthetized dogs. We hypothesized that similar multi-function monitors in which different NIBP oscillometric technologies were installed would differ significantly in their ability to provide readings in agreement with IBP values.

Materials and methods

The Louisiana State University Institutional Animal Care and Use Committee approved this study. Twenty dogs were premedicated intramuscularly with dexmedetomidine (0.002 mg kg\(^{-1}\); Dexdomitor; Pfizer Animal Health, Inc., NY, USA) and hydromorphone (0.2 mg kg\(^{-1}\); Hydromorphone Injection, USP; West-Ward Pharmaceutical Corp., NJ, USA). Then, anesthesia was induced with propofol (3–5 mg kg\(^{-1}\); PropoFlo; Abbott Laboratories, Inc., IL, USA), the trachea was intubated and isoflurane in 100% oxygen was delivered using a circle breathing system with subjects in left lateral recumbency and breathing spontaneously. Heart rate and rhythm, pulse oximetry, expired end-tidal partial pressure of carbon dioxide and body temperature were monitored continuously. Dogs were maintained normothermic (38–39 °C) and normocapnic \([P_{a}CO_2]\) of 35–45 mmHg (4.7–6.0 kPa).

Each dog was fitted with a single-tube, disposable blood pressure cuff that represented 30–40% of the limb’s circumference and was applied on the middle third of the antebrachial area. Two brands of blood pressure cuff were used according to the manufacturers’ recommendations: monitor-1 was connected to a Sharn latex-free cuff (Sharn Veterinary, Inc., FL, USA), and monitor-2 was connected to a SunTech cuff (SunTech Medical, Inc., NC, USA). Then one 20 gauge, 2.5 cm catheter (BD Insyte; Becton Dickinson Infusion Therapy Systems, Inc., UT, USA) was placed in the median caudal artery. The catheter was connected to a blood pressure transducer (BD DTX Plus; Becton Dickinson Infusion Therapy Systems, Inc.) via non-compliant heparinized saline-filled tubing (Microbore extension set; Hospira, Inc., IL, USA). The IBP system was calibrated against a mercury manometer using a three-point calibration technique (0, 50 and 150 mmHg) and replaced between patients. The transducer was positioned at the mid-point between the manubrium and the vertebral column at the level of the fourth to fifth thoracic vertebrae, taken to correspond with the base of the heart, and zeroed to atmospheric pressure before the start of data collection. The IBP monitoring system was visually inspected and periodically flushed to prevent clots and remove air bubbles. Before data recordings commenced, blood pressure readings were noted to be stable, with consistent waveforms present, and the fast flush test was performed to test the dynamic response of the IBP monitoring system. All damping coefficients for the IBP systems were adequate for this investigation. Blood pressure was not manipulated during the experiment and no dog received vasopressors or bolus administration of fluids before or during the study.

Blood pressure cuffs and transducers were connected to one of two multi-function monitors (monitor-1 or monitor-2) using a randomized table to organize the order of measurements. The blood pressure monitoring system utilized in monitor-1 consisted of two IBP channels and one NIBP oscillometric module (OEM MAXNIBP; CAS Medical System, Inc., CT, USA). Likewise, the monitor-2 system consisted of two IBP channels and a different NIBP oscillometric module (Advantage OEM BP Module – Veterinary Module; SunTech Medical Inc.). The two NIBP oscillometric modules were installed in multi-function monitors made by the same manufacturer (VetTrends V; SystemVET, Inc.,
In each dog, all IBP readings were collected using one of the two IBP monitors. All authors involved in data collection were unaware of the technology available in the monitors; this information was not revealed until data collection had concluded at the end of the entire study. When systems were deemed stable, four paired simultaneous readings of NIBP and IBP measurements, including systolic (SAP), diastolic (DAP) and mean (MAP) arterial pressure measurements, were recorded with 2 minute intervals between readings using one of the two monitors (monitor-1 or monitor-2). The same process was repeated using the second monitor. After data collection, catheters were removed and each dog was recovered from anesthesia.

Statistical analysis

Distributions of body weight and age were examined using the Shapiro–Wilk test of normality. Agreement between IBP and NIBP measurements was examined using Bland–Altman analysis. Bias was defined as the mean difference between the two methods; 95% limits of agreement (LoA) were calculated as bias ± [1.96 × standard deviation (SD)]. Because the sampling strategy involved a repeated-measures approach, there was a potential for underestimating the SD of the differences; therefore, the SD was corrected to account for variance within and across subjects (Bland & Altman 2007). The mean of each set of four pressure measurements was calculated and used for the purposes of graphical comparison. Good agreement between the IBP and NIBP measurements was defined as a bias and 95% LoA within 15 mmHg of the IBP value in accordance with the American College of Veterinary Internal Medicine (ACVIM) guidelines (Brown et al. 2007). All statistical analyses were performed with commercially available software (Prism Version 6.0; Graphpad Software, Inc., CA, USA).

Results

The study subjects included 20 dogs of American Society of Anesthesiologists (ASA) Class I status (13 females, seven males). Body weight and age were not normally distributed. The dogs had a median body weight of 24.7 kg (range: 21.2–25.5 kg) and a mean ± SD age of 5.3 ± 2.4 years.

For NIBP measurements obtained using monitor-1, agreement analysis for SAP revealed a bias of 0.2 mmHg (95% LoA −11.8 to 12.3 mmHg), agreement analysis for DAP revealed a bias of −2.6 mmHg (95% LoA −14.4 to 9.1 mmHg) and agreement analysis for MAP revealed a bias of −2.5 mmHg (95% LoA −12.7 to 7.3 mmHg) (Fig. 1). The adjusted SDs for SAP, DAP and MAP were 6.2, 6.0 and 5.0 mmHg, respectively. Correlations between the paired measurements across the range of values measured for SAP, DAP and MAP were 0.9, 0.9 and 1.0 mmHg, respectively.

For NIBP measurements obtained using monitor-2, agreement analysis for SAP revealed a bias of 3.4 mmHg (95% LoA −8.7 to 15.5 mmHg), agreement analysis for DAP revealed a bias of 2.2 mmHg (95% LoA −6.6 to 10.9 mmHg) and agreement analysis for MAP revealed a bias of 1.6 mmHg (95% LoA −5.9 to 8.9 mmHg) (Fig. 1). Adjusted SDs for SAP, DAP and MAP were 6.3, 4.5 and 3.8 mmHg, respectively. Correlations between the paired measurements across the range of values measured for SAP, DAP and MAP were 0.9, 1.0 and 1.0 mmHg, respectively.

Discussion

In this study, measurements of SAP, DAP and MAP determined using each of two NIBP oscillometric technologies were compared with equivalent IBP measurements obtained from the median caudal artery. Both NIBP oscillometric technologies are commonly integrated into multi-function monitors produced for the veterinary market. The ACVIM consensus statement on blood pressure measurement states that in order for an NIBP measurement device to be validated, the mean difference between the paired NIBP and IBP measurements must be ≤10 mmHg and a paired measurement SD must be ≤15 mmHg. Both monitors met this requirement. In addition, ACVIM guidelines recommend that 50% of all measurements of SAP and DAP must be within 10 mmHg of the reference method and that 80% of all measurements of SAP and DAP must be within 20 mmHg of the reference method. Both monitors met this requirement.

The ACVIM guidelines have commonly been used for comparison studies in cats and dogs. Since 2004, 11 peer-reviewed studies examining the relationship between IBP and oscillometric NIBP measurements in dogs have been published. Only three studies (Garofalo et al. 2012; Drynan & Raisis 2013; Vachon et al. 2014) have documented good agreement between a specific method of obtaining NIBP measurements and IBP measurements in dogs.
The Association for the Advancement of Medical Instrumentation (AAMI) controls the standards for NIBP equipment for use in human patients (American National Standards Institute, Association for the Advancement of Medical Instrumentation 2008). The AAMI guidelines are considered more stringent than those of the ACVIM and state that a paired reading must have a mean difference of \( \leq 5 \text{ mmHg} \) and a mean SD of \(< 8 \text{ mmHg} \). In the present study, the Bland–Altman analysis indicated that both technologies met the AAMI standard and hence it was apparent that both of the NIBP measurement technologies studied here produced results that were in good agreement with IBP measurements.

Oscillometric technologies for obtaining NIBP measurements are popular because they offer automated measurements of SAP, DAP, MAP and heart rate. In addition, they can be technically easier to use than the Doppler ultrasonographic method. These technologies work by inflating a cuff around an extremity until arterial pulsations are suppressed. They then monitor arterial oscillations as the cuff is slowly deflated. Initially, arterial

![Figure 1 Bland–Altman plots for analyses of agreement between invasive (IBP) and noninvasive (NIBP) blood pressure measurements in anesthetized dogs of systolic (SAP), diastolic (DAP) and mean (MAP) arterial pressure obtained with monitor-1 [(a) SAP, (b) DAP and (c) MAP] or monitor-2 [(d) SAP, (e) DAP and (f) MAP]. IBP measurements were obtained at the median caudal artery. NIBP measurements were obtained using cuffs placed around the antebrachial area in dogs positioned in lateral recumbency. The solid horizontal line represents the bias and the dotted lines represent 95% limits of agreement (LoA).](image-url)
pulsations increase in intensity until they reach a maximum point from which intensity decreases. A plot of the crescendo–decrescendo in arterial pulsations produces what is known as the ‘oscillographic envelope’. Mean arterial pressure is determined to be the point at which these arterial oscillations are maximized. Systolic and diastolic pressures are then calculated using proprietary algorithms (Ramsey 1979). Interestingly, both technologies produced MAP measurements that were in good agreement with the IBP measurements, which suggests that the measurement methods used by each are adequate, although monitor-2 produced results with less bias and better 95% LoA than monitor-1. However, monitor-1 was better able to determine SAP. These dissimilarities can be used to exemplify the differences in the algorithms utilized by the two NIBP technologies. The data generated by this research can be used by these two companies to adjust their proprietary algorithms to calculate SAP and DAP which, in theory, would make these technologies even more reliable. After any algorithm adjustment, the NIBP technology should be validated again.

One shortcoming of this study is that no attempt was made to manipulate blood pressure; thus most measurements were in the normotensive range. It is possible that the relationship between NIBP and IBP may change during extreme hemodynamic conditions. It is also plausible that one of the technologies may be better than the other at obtaining blood pressure measurements during extreme conditions. In human medicine, using equipment previously approved by AAMI, some NIBP monitors were found to be inaccurate in critically ill human patients (Ribezzo et al. 2014). A further limitation was that the dogs used in this study were adults within a narrow range of body weight and body condition. It is possible that bias and LoA would differ in smaller or obese dogs.

The present study described the clinically relevant differences between two commonly utilized oscillometric NIBP technologies used in multi-function monitors available in the USA. The results of this study indicate that both of the NIBP technologies met the ACVIM and AAMI guidelines for agreement between IBP and NIBP measurements. Clinicians should be cognizant of the actual NIBP technology incorporated into the clinical monitor in use and should determine whether or not the technology in the monitor has been validated for use in the species to be monitored. The two technologies compared in this study are considered to be validated for use in dogs.

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