Research in Veterinary Science 97 (2014) 111–117

Contents lists available at ScienceDirect

Research in Veterinary Science

journal homepage: www.elsevier.com/locate/rvsc

Evaluation of oscillometric and Doppler ultrasonic devices for blood pressure measurements in anesthetized and conscious dogs

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ARTICLE INFO

Article history:
Received 29 July 2013
Accepted 4 May 2014

Keywords:
Blood pressure measurement
Doppler
Oscillometry
petMAP®
Dogs
Conscious
Anesthetized

ABSTRACT

Two non-invasive blood pressure (NIBP) devices (oscillometry and Doppler) were compared to invasive blood pressure using a Bland–Altman analysis, in anesthetized and conscious dogs. When considering the systolic arterial pressure only during general anesthesia, both NIBP devices slightly underestimated the systolic arterial blood pressure however the precision and the limits of agreement for the Doppler were of a greater magnitude. This indicates a worse clinical performance by the Doppler. The performance of both NIBP devices deteriorated as measured in conscious animals. In general, for the oscillometric device, determination of invasive diastolic and mean arterial pressures was better than the invasive systolic arterial pressure. Overall, the oscillometric device satisfied more of the criteria set by the American College of Veterinary Internal Medicine consensus statement. Based upon these results, the oscillometric device is more reliable than the Doppler in the determination of blood pressure in healthy medium to large breed dogs.

1. Introduction

Blood pressure (BP) is commonly measured in veterinary medicine. It is not only routinely used for the monitoring of anesthetized and critically ill animals but also for the detection of systemic hypertension. In the clinical setting, accurate and reproducible measurement of blood pressure is essential for proper detection and management of hypo- or hypertension.

Direct measurement of blood pressure is accomplished by intra-arterial catheterization. Although recognized as the gold standard in canine BP measurement, this invasive method is not routinely performed or practical (Bodey et al., 1994, 1996; Gains et al., 1995; Haskins, 2007; Sawyer et al., 1991; Stepien and Rapoport, 1999). It requires high technical skills, specialized and expensive equipment, which may be painful or at least difficult to set up in a conscious and alert animal. Possible adverse effects include hemorrhage, infection and hematoma. For these reasons, non-invasive blood pressure measurement techniques (NIBP) are more commonly used. Several commercially available NIBP devices are used to assess blood pressure. These NIBP devices however appear to have a lower reliability in awake patients (Bosiack et al., 2010; Haberman et al., 2006; Stepien and Rapoport, 1999). Each method has advantages and disadvantages. The oscillometric technique analyzes the effect of the arterial turbulence as caused by the arterial compression by the cuff, on the oscillations generated by the device itself. The appearance and disappearance of perturbations on these generated oscillations indicate the SAP and DAP respectively. The ultrasonic Doppler detects blood flow using the Doppler effect on moving red blood cells and measures the arterial blood pressure during the restoration of blood flow when deflating a sphymomanometer cuff. Several studies have evaluated NIBP methods in dogs but most have used anesthetized animals and have only compared a single device to the invasive blood pressure (IBP).

The aim of this prospective study was to assess the bias and precision of estimates of BP provided by a widely available veterinary oscillometric device and a Doppler ultrasonic flow detector by comparison with direct BP measurements obtained simultaneously in normotensive anesthetized and conscious dogs.

2. Materials and methods

2.1. Animals

This study was conducted at the Veterinary Teaching Hospital of the University of Montreal. The institutional committee of ethical principles of animal care and use approved this study based on the policies and guidelines of the Canadian Council on Animal Care. Dogs were recruited after written consent from the owners was obtained. Ten intact, female dogs weighing more than 10 kg, aged over 5 months and admitted for routine ovariohysterectomy were

Presented as an abstract at the Annual Meeting of the European College of Veterinary Internal Medicine in Maastricht, Netherlands, September 2011.

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http://dx.doi.org/10.1016/j.rvsc.2014.05.003
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recruited. Dogs were determined to be healthy based on an unremarkable history, normal physical examination and normal pre-anesthetic blood work (hematocrit, total solids and blood urea nitrogen).

For all dogs, sedation was achieved with intramuscular hydromorphone[1] (0.1 mg/kg) and acepromazine[2] (0.03–0.05 mg/kg). A cephalic intravenous catheter[3] was introduced and the induction of anesthesia was performed with ketamine[4] (5 mg/kg) and diazepam[5] (0.25 mg/kg). The animals were then intubated and permitted to ventilate spontaneously. Anesthesia was maintained using isoflurane[6] in oxygen. Fluid therapy (LRS[7] 5–10 ml/kg/h) and antibiotics (cefazolin[8] 22 mg/kg IV) were administered during surgery. An arterial catheter[9] was placed in the right or left dorsal pedal artery in a random manner and was connected to a transducer[10] using non-compliant saline-filled tubing. Patency of the arterial catheter was ensured by use of a pressurized, heparinized, flushing system. The transducer was connected to a monitor.[11] The transducer was zeroed at the level of the shoulder prior to the surgical procedure or at the level of the manubrium prior to measurements in conscious animals. The arterial catheter was flushed prior to each series of measurements. A visual check was performed to ensure the absence of air bubbles in the tubing and to ensure a normal arterial pressure waveform on the monitor. At the end of surgery, the arterial catheter was left in place and flushed with 3 ml of 0.9% heparinized (10 UI/ml) saline[12,13] hourly until all measurements were obtained. A certified technician prior to the start of the experiment calibrated the blood pressure monitor.

2.2. Blood pressure measurements

All BP measurements were obtained according to the ACVIM (American College of Veterinary Internal Medicine) consensus statement (Brown et al., 2007). The first measurement was systematically discarded and the subsequent five consecutives measurements were averaged. The corresponding IBP were recorded simultaneously for each NIBP device. Both non-invasive devices were used alternatively as the first device. A single observer made all measurements. The Doppler ultrasonic flow detector[14] and oscillometric device[15] measurements were obtained on the ipsilateral forelimb with respect to the arterial catheterized hind leg. Cuffs of both NIBP devices were placed proximal to the carpus. All devices were operated according to manufacturer's directions. Measurements were obtained during a period of anesthetic stability for at least 15 min, without any change in fluid rates, anesthesia or apparent nociceptive level. The ECG was used to confirm a regular sinus rhythm prior to all BP measurements. In conscious dogs, measurements were made 4–6 h after the end of surgery. Measurements were taken on the non-dependent front leg with the dog placed in lateral recumbency.

[1] Hydromorphone HP, Chlorhydrate d'hydromorphone, Sandoz, Québec, Canada.
[2] ATRAVET® Acepromazine maleate, USP, Boehringer, Ontario, Canada.
[3] 20 Ga BD angiocath, Becton Dickinson Infusion Therapy System, Utah, USA.
[4] VETALAR®, Ketamine hydrochloride injection USP., BIONICHE Animal Health, Ontario, Canada.
[5] Diazepam injection USP, Sandoz, Québec, Canada.
[6] Isoflurane USP, Pharmaceuticals Partners of Canada Inc, Ontario, Canada.
[7] Lactate de Ringer USP, Baxter, Ontario, Canada.
[8] Cefazolin, Novopharm, Ontario, Canada.
[9] 20 Ga BD Insyte W, Becton Dickinson Infusion Therapy System, Utah, USA.
[10] Pressure monitoring kit with TruWave disposable pressure transducer, model: PX272, Edwards Lifesciences LLC, Irvine, California USA.
[11] LifeWindow TM 6000V Veterinary Multi-Parameter Monitor, Digicare Animal Health, Florida, USA.
[12] 0.9% Sodium chloride, Baxter, Ontario, Canada.
[13] Heparin LEO, 10000 UI/ml, LEO Pharma, Thornhill, Ontario, Canada.
[14] Model 811-B, Parks Medical Electronics Inc, Oregon, USA.
[15] petMAP, RAMSEY Medical Inc, Florida, USA.

Doppler measurement – The cuff selected was approximately 40% of the limb circumference (width of cuff/limb circumference ratio approximating 0.4). At the site of probe placement, over the palmar common digital artery, the area was clipped and coupling gel was applied. It was positioned and taped to have a clear audible signal from the Doppler device and it was reassessed prior to each measurement to ensure signal quality. The cuff was inflated 40 mmHg over the point where the pulse signal was no longer audible and then progressively deflated. When the pulse signal was audible again, it was recorded as the systolic blood pressure (SAP_d). The cuff was completely deflated, between each measurement. The operator wore headphones for all Doppler measurements.

Oscillometric measurement – The cuff provided by the manufacturer was selected according to the animal's limb circumference and to the manufacturer's instructions. The device measured indirectly the mean BP (MAP_o) and heart rate (HR_o) and calculated the systolic BP (SAP_o) and diastolic BP (DAP_o).

2.3. Statistical analysis

All five values obtained with either the invasive or the non-invasive devices, for the systolic, mean, and diastolic arterial blood pressure were averaged prior to statistical analysis. Each average obtained from each non-invasive device was compared to the corresponding averaged IBP obtained simultaneously to assess the agreement between the two techniques by use of the Bland–Altman method. Mean differences ($\Sigma[\text{NIBP} - \text{IBP}]/n$) between invasive and non-invasive devices were calculated to obtain the bias. The standard deviation (SD) and the 95% limits of agreement (mean $\pm$ 1.96 $\times$ SD) were also calculated. A linear regression was performed to assess the relationship between the difference of the IBP and NIBP blood pressure measurements as compared to the average of both measurements. The percentages of non-invasive measurements lying within 10 and 20 mmHg of the IBP were calculated. The percentage of error was also assessed ($\pm 2\text{SD}/((\Sigma[\text{NIBP} + \text{IBP}]/2)/n)$. A commercial software package was used for statistical analysis (SAS v. 9.2, Cary, N.C.). A P value less than 0.05 was considered statistically significant.

3. Results

The median age of the dogs was 12.5 months, ranging from 5 to 60 months, while the median weight was 23.4 kg, ranging from 12.8 to 34.2 kg. A total of 100-paired measurements were taken from conscious (50 readings) and anesthetized (50 readings) dogs for each non-invasive device with the corresponding invasive blood pressure measurement. The range of blood pressure measurements observed for each device can be seen in Table 1 (anesthetized dogs) and Table 2 (conscious dogs). The summary of means and standard derivations for each device can be seen in Table 3.

3.1. Anesthetized dogs

The comparisons between both NIBP devices with the IBP are shown as Bland–Altman plots in Figs. 1–4. The bias and the LOA for each device as compared to IBP are summarized in Table 1 (anesthetized dogs) and Table 2 (conscious dogs). As indicated by the bias, the oscillometric device underestimated the IBP as measured by the SAP_o (−6.1), MAP_o (−2.9), and DAP_o (−6.9), while the SAP_d (−4.1) underestimated the invasive systolic blood pressure (SAP_i) in anesthetized dogs. The lowest bias was observed between the IBP and the oscillometric device for MAP_o. The limits of agreement were narrower for SAP_o, DAP_o and MAP_o compared to the SAP_d.