Ph.D. Dissertation of Veterinary Medicine

Evaluation of the Tongue for Indirect Measurement of Arterial Blood Pressure in Dogs

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Department of Veterinary Medicine
Graduate School
Seoul National University
Major in Veterinary Clinical Sciences

Dalhae KIM

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Supervised by Professor Inhyung LEE

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Dalhae KIM

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Evaluation of the Tongue for Indirect Measurement of Arterial Blood Pressure in Dogs

Abstract

This study was performed 1) to prove the validity of the non-invasive (indirect) blood pressure (NIBP) measurements using an oscillometric blood pressure monitor measured from tongue under general anesthesia and to compare cuff placement sites with the NIBP values measured from the pelvic limbs and tail; 2) to prove validity of various NIBP measurements equipment using tongue and to compare with the thoracic limbs; and 3) to evaluate clinical application of the tongue for NIBP measurements.

In Chapter 1, the blood pressure measurements using an oscillometric monitor measured from the tongue (OBP_{TONGUE}) was confirmed by evaluating the degree of agreement with invasive blood pressure (IBP) measurements, and compared with oscillometric blood pressure measured from the pelvic limbs and tail, which are known as high accuracy in NIBP measurements in anesthetized dogs. Mean and diastolic OBP_{TONGUE} showed good agreement with IBP from hypotension to hypertension, but systolic OBP_{TONGUE} did not. In hypotension, the OBP_{TONGUE} showed better agreement with IBP than oscillometric blood pressure measured from the pelvic limbs and tail, and the better performance from the

tongue was considered that tongue is muscular organ with no bony structures, making it easier to check pulse oscillation.

In Chapter 2, blood pressure was measured using Doppler ultrasound and oscillometric blood pressure method based on the tongue and thoracic limbs of anesthetized Beagle dogs. In systolic blood pressure, the Doppler ultrasound blood pressure method showed clinically interchangeable with IBP in hypotension and normotension and oscillometric blood pressure method showed clinically interchangeable with IBP only in hypotension. In mean and diastolic arterial blood pressure, oscillometric device showed clinically significant agreement with IBP regardless of cuff placement sites.

In Chapter 3, clinical application of OBP_{TONGUE} was evaluated in client owned 45 dogs under general anesthesia. The 45 dogs were divided into two groups based on body weights because oscillometric blood pressure measurements are known to be less accurate at less than 5 kg. In both groups, mean and diastolic blood pressure showed good agreement with IBP, and the accuracy was higher in the group of >5 kg. Systolic blood pressure showed poor agreement with IBP.

Through the present studies, it was verified that the measurement of mean and diastolic NIBP based on the tongue was a clinically interchangeable with IBP measurement that could replace other NIBP measurement sites. Since the anesthetized dog's face could be easily accessed by anesthesiologists through the anesthesia window, it was judged that blood pressure measurement at the tongue could be considered when the cuff was needed to be re-attached. The agreement of systolic NIBP measurements with IBP was poor regardless of the cuff placement sites, so a careful interpretation was required. In addition, placing the cuff at the tongue might be useful for reliable detection of hypotension, compared to pelvic limbs and tail.

Keywords: oscillometric blood pressure measurement, Doppler ultrasound blood pressure measurement, tongue, general anesthesia, dog

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List of Abbreviations

AAMI	American association for medical instrumentation
ACVIM	American college of veterinary internal medicine
BP	Blood pressure
DAP	Diastolic arterial pressure
DAP_{TAIL}	Diastolic oscillometric arterial pressure at tail
DAP_{TONGUE}	Diastolic oscillometric arterial pressure at tongue
$DAP_{PELVIC\ LIMB}$	Diastolic oscillometric arterial pressure at pelvic limb
DUBP	Doppler ultrasound blood pressure
Fe'Iso	End-tidal isoflurane concentration
f_R	Respiratory rate
HR	Heart rate
IBP	Invasive blood pressure
IV	Intravenous
LOA	Limits of agreement
MAP	Mean arterial pressure
MAP_{TAIL}	Mean oscillometric arterial pressure at tail
MAP_{TONGUE}	Mean oscillometric arterial pressure at tongue
$MAP_{PELVIC\ LIMB}$	Mean oscillometric arterial pressure at pelvic limb
NIBP	Noninvasive blood pressure
OBP	Oscillometric blood pressure

List of Abbreviations (cont'd)

OBP_{TAIL}	Oscillometric blood pressure at tail
OBP_{TONGUE}	Oscillometric blood pressure at tongue
$OBP_{PELVIC\ LIMB}$	Oscillometric blood pressure at pelvic limb
$Pe'CO_2$	End-tidal carbon dioxide concentration
SAP	Systolic arterial pressure
SAP_{TAIL}	Systolic oscillometric arterial pressure at tail
SAP_{TONGUE}	Systolic oscillometric arterial pressure at tongue
$SAP_{PELVIC\ LIMB}$	Systolic oscillometric arterial pressure at pelvic limb
SD	Standard deviation

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General Introduction

Arterial blood pressure (BP) measurement has long been recognized as a critical part of monitoring in anesthetized patients to prevent and/or treat hypotension, a common peri-anesthetic complication in small animals (Haskins 2007). Several techniques can be used to measure BP, including direct or invasive methods, which are generally considered the “gold standard” (Haskins 2007), as well as indirect or non-invasive methods, such as the Doppler ultrasound blood pressure (DUBP) and oscillometric blood pressure (OBP) measurement techniques.

Invasive blood pressure (IBP) monitoring is more reliable than non-invasive blood pressure (NIBP) methods. However, IBP monitoring is more expensive than NIBP methods and is more technique sensitive; hence, IBP monitoring can be lead to inaccurate results in the hands of inexperienced operators (Waddell 2000; Vachon *et al*. 2014; Moll *et al.* 2018). Possible adverse effects of IBP monitoring include infection, hemorrhage, and hematoma (Vachon *et al.* 2014). Consequently, clinicians often make therapeutic decisions based on NIBP readings (Bosiak *et al.* 2010).

The NIBP measurements are used frequently by clinicians because the equipment is relatively inexpensive and portable, and the measurements are easier to perform than the measurements of the IBP method (Brown *et al.* 2007; Moll *et al.* 2018). However, these measurements show variable degrees of precision and accuracy compared to those obtained using the IBP method and are prone to inaccurate reading under certain circumstances, such as incorrect cuff placement, wrong cuff size, under 5 kg, and hypothermia (Brown *et al.* 2007; Garofalo *et al.*

2012). Therefore, it is principal to understand the accuracy of certain NIBP measurement devices, as failure to properly recognize abnormalities in arterial BP can lead to therapeutic or diagnostic errors (Bosiak *et al.* 2010; Garofalo *et al.* 2012).

The accuracy of NIBP monitors in estimating their "true" values can be determined using the Bland-Altman method (Garofalo *et al.* 2012), although direct comparisons between devices are often difficult or impossible (Moll *et al.* 2018). Differences between IBP and NIBP, recorded on the same subject, were analyzed against the average of both methods (Bland & Altman 2007). The American College of Veterinary Internal Medicine (ACVIM) issued a consensus statement recommending validation studies for BP measurement devices in small animals based on the criteria and recommendations of the Association for the Advancement of Medical Instrumentation (AAMI), which provides the NIBP device guidelines for human medicine. The AAMI criteria postulate that the mean bias and precision of the NIBP device in relation to the reference standard should be <5 and <8 mmHg, respectively (ANSI/AAMI/SP10:2002/(R) 2008). The ACVIM criteria for NIBP monitors state that the mean bias and precision in comparison with IBP measurements should be ≤ 10 and ≤ 15 mmHg, respectively (Brown *et al.* 2007) and that the absolute differences between IBP and NIBP should also lie within 10 mmHg for 50% of all NIBP measurements and within 20 mmHg for 80% of all IBP measurements (Brown *et al*. 2007).

The commonly used cuff attachment sites for NIBP measurements in dogs are the thoracic limbs, pelvic limbs, and tail. However, when approaching the limbs or tail is impossible during surgery, or if a cuff attached preoperatively becomes loose during surgery, other anatomical locations may need to be used instead. The tongue is a useful site to check the pulse in anesthetized dogs as it is easily palpable and accessible through the anesthetic window (Clarke *et al.* 2014; Schauvliege 2016). However, catheter placement at the lingual artery has a high probability of failure in small breeds. In addition, several complications can result, such as pain, sublingual hematoma, and air embolism of the cerebral arteries due to air injection during flushing (Pascoe 2011; McMurphy *et al.* 2006). Therefore, it was necessary to determine whether NIBP measurements could be obtained from the tongue when the standard cuff positions are difficult to access.

Therefore, this study was performed to 1) identify the agreement between IBP and OBP measured from the tongue and compare other cuff placement sites (pelvic limb and tail) for OBP measurements in Chapter 1, 2) compare IBP measurements and tongue-based NIBP monitors using DUBP and OBP device in Chapter 2, and 3) assess the clinical application of tongue-based OBP measurements in dogs on various body weights in Chapter 3.

Chapter 1

Evaluation of Tongue for Oscillometric Measurement of Arterial Pressure in Anesthetized Beagle Dogs

Abstract

This Chapter aimed to evaluate the agreement between OBP measured from the tongue and IBP, and to compare OBPs measured from the tongue with OBPs measured from the pelvic limb and tail.

The study was designed as a prospective study. A total of eight adult Beagle dogs weighing 11.1 ± 1.2 kg were included. Animals were premedicated with intravenous (IV) acepromazine (0.005 mg kg^{-1}). Anesthesia was induced with alfaxalone (3 mg kg^{-1}) IV and maintained with isoflurane. The dorsal pedal artery was catheterized for IBP measurements. Systolic (SAP), diastolic (DAP), and mean (MAP) arterial pressure were simultaneously measured from the tongue, pelvic limb and tail. Based on invasive SAP, hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg) were induced by controlling end-tidal isoflurane concentrations and/or dobutamine/dopamine administration. Agreement between paired IBP and OBP measurements were analyzed with reference standards for NIBP devices used in small animals and humans.

Regardless of cuff placement, the mean bias ± standard deviation between IBP and OBP met veterinary (≤10 ± 15 mmHg) and human (<5 ± 8 mmHg) standards for MAP and DAP. However, SAP measurements provided by the OBP device showed unacceptable agreement with IBP and the bias between methods increased at higher blood pressures, regardless of cuff site placement. During hypotension, tongue-based OBP showed the largest percentage of absolute difference <10 mmHg in relation to IBP for SAP (90%), MAP (97%), and DAP (93%), compared with pelvic limb (60, 97, and 82%, respectively) and tail (54, 92, and 77%, respectively).

The tongue would be a clinically useful site for measuring OBP in anesthetized Beagle dogs, providing reliable estimates of MAP and DAP. The tongue could replace other cuff placement sites and might be a relatively suitable site for assessing hypotension.

Introduction

Arterial blood pressure is a variable that should be routinely monitored during general anesthesia. Because of a reliable performance over a wide range of pressures, from hypotension to hypertension, IBP devices are preferred during major surgery and other procedures likely associated with hemodynamic instability. NIBP monitoring is frequently the method of choice during anesthesia for elective surgeries and procedures unlikely to result in substantial changes of hemodynamic status. Doppler and oscillometric methods have been used to obtain NIBP measurements, and the agreement of some commercially available NIBP monitors with IBP measurement has been evaluated in dogs (Bodey *et al.* 1994; Haberman *et al.* 2006; Wernick *et al.* 2010; Garofalo *et al.* 2012; Drynan & Raisis 2013; Vachon *et al.* 2014; da Cunha *et al.* 2016). Furthermore, the level of agreement between IBP and NIBP measurements can vary according to cuff placement at different sites (Sawyer *et al.* 1991; Bodey *et al.* 1994; Garofalo *et al.* 2012).

In anesthetized dogs, the tongue is a useful site to check the pulse as it is easily palpable and accessible during surgery of the body and limbs (Clarke *et al.* 2014; Schauvliege 2016). The tongue consists of extrinsic and intrinsic muscles with no bony structure and no fur (Eubanks 2007; Hermanson 2020), and the lingual artery located close to the ventral midline surface of the tongue is one of the largest collateral branches of the external carotid artery (Séguin 2012; Hermanson 2020). Therefore, the lingual artery can be catheterized for IBP measurements during general anesthesia (Pascoe 2011; Clarke *et al.* 2014).

However, suitability of the lingual artery as an anatomical site for measuring OBP has not been evaluated.

The aim of this study was to evaluate the agreement between OBP measured from the tongue (OBP_{TONGUE}) and IBP and to compare OBP_{TONGUE} with OBP measured at the pelvic limb ($OBP_{PELVIC\ LIMB}$) and tail (OBP_{TAIL}). The hypotheses were that OBP_{TONGUE} measurements provide acceptable agreement with IBP and that OBP_{TONGUE} measurements compare favorably with $OBP_{PELVIC\ LIMB}$ and OBP_{TAIL} measurements.

Materials and Methods

Animals

The study protocol was approved by the Institute of Animal Care and Use Committee of the Seoul National University (SNU-190211-4). A group of eight male Beagle dogs was part of Laboratory Animal Resources Seoul National University research colony and housed in individual stainless steel kennels. The dogs' age and body weight [mean ± standard deviation (SD)] were 3.0 ± 1.0 years and 11.1 ± 1.2 kg, respectively. They were judged as healthy based on a physical examination, thoracic radiographic imaging, and blood analysis (complete blood cell count and serum chemistries). Two dogs were studied in one day and the total duration of the experiment was 4 days. Each dog was anesthetized once.

Anesthetic procedures

Each dog was fasted for at least 12 hours with free access to water before being anesthetized. The right cephalic vein was catheterized with an over-the-needle polyurethane 22-gauge catheter (Sewoon Medical Co. Ltd, Republic of Korea). Hartmann's solution (JW Pharmaceutical Corporation, Republic of Korea) was infused at 5 mL kg^{-1} $hour^{-1}$ during anesthesia. Acepromazine (0.005 mg kg^{-1}; Sedaject injection; Samu Median Co. Ltd, Republic of Korea) was administered intravenously (IV) and anesthesia induced 5 minutes later with alfaxalone (3 mg kg^{-1}; Alfaxan; Jurox Pty Ltd, NSW, Australia) IV for orotracheal intubation. Anesthesia was maintained with isoflurane (I-Fran Liquid; Hana Pharm Co. Ltd, Republic of Korea) in oxygen (2 L $minute^{-1}$) using a rebreathing system (Datex

Ohmeda 9100c; GE Healthcare, Finland) under pressure-controlled ventilation. The tidal volume (10 mL kg^{-1}), inspiration-to-expiration ratio (1:2), and inspired O_2 fraction (0.9–1.0) were maintained constant throughout the anesthetic procedure. The respiratory rate (f_R) was individually adjusted to maintain end-tidal carbon dioxide partial pressure ($P_{E'}CO_2$) between 35 and 45 mmHg (4.6–6.0 kPa) and the vaporizer was adjusted at a target of 1.8% end-tidal isoflurane concentration ($F_{E'}Iso$). An infrared gas analyzer (Carescape respiratory module E-sCAiOVX, GE healthcare, Finland), calibrated with a reference gas mixture (755583-HEL Quick Cal calibration gas; GE healthcare, Finland), was connected to the distal end of the endotracheal tube for continuous measurement of $F_{E'}Iso$ and $P_{E'}CO_2$.

After intubation, with the dog in lateral recumbency, the left dorsal pedal artery was cannulated with a 22 gauge, 2.5 cm catheter. The arterial catheter was connected to a transducer system (Truwave; Edward Lifescience, Germany; Carescape Monitor B650; GE Healthcare, Finland) via fluid-filled (heparinized 0.9% sodium chloride; 2 IU mL^{-1}) noncompliant tubing (500 mm length) and the transducer was previously calibrated against an atmospheric pressure. The noncompliant tubing was replaced for each dog. The system was connected to a pressurized (300 mmHg) 500 mL bag of 0.9% sodium chloride to produce a continuous flow (3 mL $hour^{-1}$) through the system. After arterial catheterization, in dorsal recumbency, the zero-level reference for the transducer was set level with the thoracic inlet and the connecting tubing was periodically flushed to remove air bubbles and prevent clots. The accuracy of the arterial pressure waveform was verified based on visual inspection of presence of two wave deflections after the fast flush test. The fast flush test was performed by pulling the fast flush tab and quickly releasing it several times. The zeroing to atmospheric pressure, leveling and flushing were performed before the beginning of each data collection (hypotension, normotension, and hypertension).

Heart rate (HR) and rhythm were monitored continuously with lead II electrocardiography, and IBP measurements, including SAP, MAP, DAP, f_R, $P_E'CO_2$, $F_E'Iso$, esophageal temperature, and oxygen saturation were continuously monitored with a multiparameter monitor (Carescape Monitor B650; GE Healthcare, Finland).

Experimental protocol

Single-tube disposable cuffs (SunTech Medical Inc., NC, USA), which were placed rostral to the lingual frenulum (Figure 1), above the tarsus and on the base of the tail and were each connected to identical veterinary OBP monitors (Vet25; SunTech Medical Inc., NC, USA). The cuff size was selected using the manufacturer's recommendation (range indicator with an index line that indicates that the cuff sites should fall within the specified range of that cuff). The tongue (rostral to the lingual frenulum), pelvic limb (above the tarsus), and tail (base of the tail) circumferences at the cuff placement sites were measured to calculate the ratio between cuff bladder width and limb or tongue circumference (cuff bladder width: circumference). The cuff bladder width was confirmed from the brochure. After instrumentation, based on the systolic IBP readings, conditions of hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg) were induced by pharmacological manipulation. Changes in pressure ranges were induced in the order of normotension, hypotension, and hypertension and not randomized. Hypotension was induced by increasing $F_E'Iso$. Hypertension was induced by decreasing $F_E'Iso$ and adjusting infusions of IV dobutamine or dopamine administration through a fluid pump. The initial infusion rate of dobutamine was 0.005 mg kg^{-1} $minute^{-1}$ with increments of 50–100% from the infusion rate to achieve the desired SAP. Dopamine was added when the SAP did not increase despite the dobutamine increment or when the HR increased without an appreciable increase in SAP. The initial infusion rate of dopamine was 0.005 mg kg^{-1} $minute^{-1}$ with increments of 50–90% as needed. Hypotension was induced by increasing F_E'Iso.

Paired comparisons between the IBP and OBP methods were conducted when SAP was maintained in the desired range for at least 5 minutes and did not alter more than ± 5 mmHg. Thereafter, the IBP and OBP from the tongue (SAP_{TONGUE}, MAP_{TONGUE}, and DAP_{TONGUE}), pelvic limb ($SAP_{PELVIC\ LIMB}$, $MAP_{PELVIC\ LIMB}$, and $DAP_{PELVIC\ LIMB}$), and tail (SAP_{TAIL}, MAP_{TAIL}, and DAP_{TAIL}) were recorded simultaneously. The first discarded and five consecutive measurements recorded (=total 6 measurements). After data collection, each dog was recovered from anesthesia and was returned to the research colony.

Statistical analyses

All statistical analyses were conducted using MedCalc Version 20 (MedCalc Software BVBA, Belgium). The sample size was determined using the ACVIM guidelines, which state that at least eight animals are required for comparisons with an intra-arterial method. Agreement between IBP and OBP measurements was examined using Bland-Altman analysis with multiple measurements per individual (Bland & Altman 2007). Positive and negative biases denoted underestimation and overestimation of the IBP method, respectively, and precision was defined as the SDs of the mean bias between the paired results

(Bland & Altman 2007). Overall measurements of mean bias (bias = IBP − OBP), precision (standard deviation of the mean bias) and 95% limits of agreement (LOA) [mean bias ± (1.96 × precision)] were tabled (Bland & Altman 2007).

A clinically acceptable performance of OBP measurement was based on either one of two sets of criteria: those of the ACVIM and the AAMI. The ACVIM criteria for OBP monitors states that the mean bias and precision compared with IBP should be ≤10 mmHg and ≤15 mmHg, respectively (Brown *et al.* 2007). Absolute differences between IBP and OBP should also lie within 10 mmHg of 50% of all OBP measurements and within 20 mmHg of 80% of all IBP measurements (Brown *et al.* 2007). The magnitude of the absolute differences between IBP and OBP was classified into three categories: <10 mmHg, 10–20 mmHg, and >20 mmHg. The second set of criteria, established by the AAMI, postulated that the mean bias and precision of the OBP device in relation to the reference standard should be <5 and <8 mmHg, respectively (ANSI/AAMI/SP10:2002/(R) 2008).

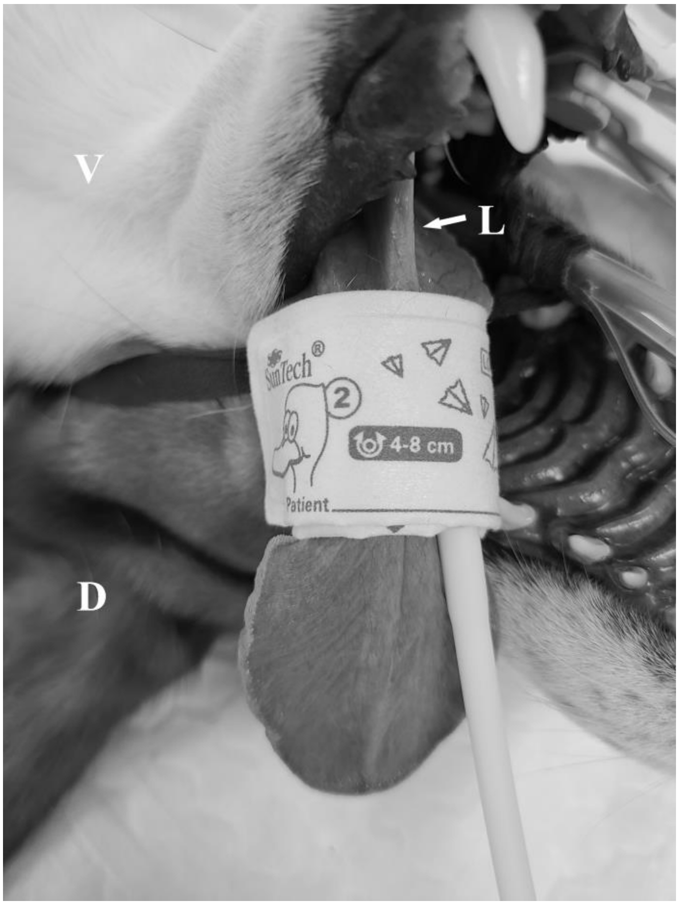

Figure 1. A cuff for oscillometric arterial pressure measurement placed around the tongue rostral to the lingual frenulum of an anesthetized Beagle dog.

D, dorsal; L, lingual frenulum; V, ventral.

Results

The cuff circumference ratio was 0.42 ± 0.04 for the tongue, 0.44 ± 0.02 for the pelvic limb, and 0.42 ± 0.02 for the tail (mean ± SD). To achieve the targeted SAP values, F_E′Iso ranged from 0.8 to 4% with or without dobutamine infusion (0.005–0.01 mg kg^{-1} minute^{-1}) or dopamine infusion (0.005–0.009 mg kg^{-1} minute^{-1}). Invasive SAP was maintained in the hypertensive range (>140 mmHg) for 15 ± 5 minutes, and in the hypotensive range (<90 mmHg) for 10 ± 5 minutes. All dogs recovered from anesthesia without systemic abnormalities. The dogs' behaviors were observed for 10 minutes per a day over 2 weeks after anesthesia, and no complications were found.

The Bland-Altman analysis with multiple measurements per individual of the agreement between IBP and OBP measurements according to the cuff position and BP range was presented in Table 1–3. The mean bias and precision between the invasive and oscillometric MAP met the ACVIM and AAMI criteria for a wide range of pressures, regardless of cuff positioning. Although DAP_{TONGUE} met the ACVIM and AAMI criteria for all pressure ranges, DAP_{TONGUE} did not meet the AAMI criteria during hypertension when the BP ranges were separated into hypotensive, normotensive, and hypertensive conditions. The $DAP_{PELVIC\ LIMB}$ and DAP_{TAIL} showed acceptable agreement with IBP over the pressure ranges based on the ACVIM and AAMI criteria.

The overall accuracy and precision of oscillometric SAP was poor as reflected by the large mean bias and wide LOAs, and oscillometric SAP met the ACVIM criteria only in hypotension regardless of cuff positioning. The AAMI criteria were met only with SAP_{TONGUE} in hypotension. For oscillometric measurements at all specified sites, the SAP was underestimated (positive bias) IBP measurements in normotension and hypertension. The positive bias recorded for SAP was substantially larger, indicating that SAP was underestimated by the OBP monitor.

The OBP measurements categorized according to their absolute difference from IBP revealed that the level of discrepancy between oscillometric MAP/DAP and invasive MAP/DAP was acceptable based on ACVIM criteria, regardless of pressure range and cuff site (Table 4). The oscillometric SAP measurements met the ACVIM criteria during hypotension regardless of the cuff positioning. As the SAP increased, the percentage of OBP readings showing clinically acceptable differences (<10 mmHg) from IBP decreased (Table 4). The percentage of OBP_{TONGUE} differed from IBP by <10 mmHg (SAP_{TONGUE}, 90%; MAP_{TONGUE}, 97%; DAP_{TONGUE}, 93%) was higher than that recorded with $OBP_{PELVIC\ LIMB}$ ($SAP_{PELVIC\ LIMB}$, 60%; $MAP_{PELVIC\ LIMB}$, 97%; $DAP_{PELVIC\ LIMB}$, 82%) and OBP_{TAIL} (SAP_{TAIL}, 54%; MAP_{TAIL}, 92%; DAP_{TAIL}, 77%) during hypotension (Table 4).

Table 1. Mean bias, standard deviation of the mean bias (precision), and 95% limits of agreement (LOA) between invasive arterial blood pressure (BP) and oscillometric BP measurements from tongue in eight anesthetized Beagle dogs. Measurements were obtained under three conditions based on the invasive systolic BP: hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg).

Variable	Pressure range	Tongue		
		Mean bias (mmHg)	Precision (mmHg)	95% LOA
SAP	Hypertension	35.7	16.4	3.6;67.9
	Normotension	18.4	8.5*	1.7;35.1
	Hypotension	3.1*†	5.4*†	-7.5;13.7
	Total range	19.1	17.1	-14.5;52.7
MAP	Hypertension	0.4*†	7.5*†	-14.4;15.1
	Normotension	3.2*†	4.6*†	-5.9;12.3
	Hypotension	4.9*†	3.8*†	-2.6;12.3
	Total range	2.8*†	5.6*†	-8.3;13.9
DAP	Hypertension	-6.1*	7.4*†	-20.6;8.4
	Normotension	-0.9*†	6.0*†	-12.7;10.9
	Hypotension	3.1*†	4.8*†	-6.4;12.6
	Total range	-1.3*†	7.1*†	-15.2;12.6

DAP, diastolic arterial pressure; MAP, mean arterial pressure; SAP, systolic arterial pressure.

*Readings within the American College of Veterinary Internal Medicine criteria.
†Readings within the American Association for Medical Instrumentation criteria.

Table 2. Mean bias, standard deviation of the mean bias (precision), and 95% limits of agreement (LOA) between invasive arterial blood pressure (BP) and oscillometric BP measurements from pelvic limb in eight anesthetized Beagle dogs. Measurements were obtained under three conditions based on the invasive systolic BP: hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg).

Variable	**Pressure range**	**Pelvic limb**		
		Mean bias (mmHg)	Precision (mmHg)	95% LoA
SAP	Hypertension	30.0	12.3*	6.0;54.1
	Normotension	11.1	8.7*	-5.9;28.1
	Hypotension	-7.2*	8.3*	-20.3;9.0
	Total range	11.3	17.7	-23.4;46.1
MAP	Hypertension	2.1*†	5.7*†	-9.0;13.2
	Normotension	1.4*†	4.7*†	-7.8;10.6
	Hypotension	0.6*†	5.3*†	-9.7;10.9
	Total range	1.4*†	5.2*†	-8.7;11.5
DAP	Hypertension	-2.6*†	6.6*†	-15.7;10.4
	Normotension	-0.6*†	7.3*†	-17.4;16.1
	Hypotension	2.8*†	6.1*†	-9.2;14.8
	Total range	-0.2*†	7.4*†	-14.7;14.3

DAP, diastolic arterial pressure; MAP, mean arterial pressure; SAP, systolic arterial pressure.

*Readings within the American College of Veterinary Internal Medicine criteria.
†Readings within the American Association for Medical Instrumentation criteria.

Table 3. Mean bias, standard deviation of the mean bias (precision), and 95% limits of agreement (LOA) between invasive arterial blood pressure (BP) and oscillometric BP measurements from tail in eight anesthetized Beagle dogs. Measurements were obtained under three conditions based on the invasive systolic BP: hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg).

		Tail		
Variable	**Pressure range**	Mean bias (mmHg)	Precision (mmHg)	95% LoA
SAP	Hypertension	39.1	16.1	7.5;70.7
	Normotension	19.1	13.8[*]	-7.9;46.2
	Hypotension	2.6[*†]	10.5[*]	-18.0;23.2
	Total range	20.3	20.1	-19.1;59.7
MAP	Hypertension	3.9[*†]	5.1[*†]	-6.0;13.8
	Normotension	3.0[*†]	3.8[*†]	-4.5;10.4
	Hypotension	4.7[*†]	3.9[*†]	-3.1;12.4
	Total range	3.8[*†]	4.3[*†]	-4.6;12.3
DAP	Hypertension	-1.9[*†]	4.0[*†]	-9.8;6.0
	Normotension	-1.2[*†]	4.8[*†]	-10.6;8.2
	Hypotension	4.7[*†]	5.0[*†]	-5.1;14.5
	Total range	0.5[*†]	5.4[*†]	-10.2;11.2

DAP, diastolic arterial pressure; MAP, mean arterial pressure; SAP, systolic arterial pressure.

[*]Readings within the American College of Veterinary Internal Medicine criteria.

[†]Readings within the American Association for Medical Instrumentation criteria.

Table 4. Percent (%) of oscillometric measurements of systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressures obtained at three sites (tongue, pelvic limb, and tail) classified according to absolute differences from invasive arterial pressure: <10 mmHg, between 10 and 20 mmHg and >20 mmHg. Data were categorized according to blood pressure conditions of hypertension (SAP >140 mmHg), normotension (SAP 90–140 mmHg), and hypotension (SAP <90 mmHg).

		Tongue			**Pelvic limb**			**Tail**		
Variable	**Pressure range**	<10 mmHg (%)	10-20 mmHg (%)	>20 mmHg (%)	<10 mmHg (%)	10-20 mmHg (%)	>20 mmHg (%)	<10 mmHg (%)	10-20 mmHg (%)	>20 mmHg (%)
SAP	Hypertension	0	25	75	0	13	87	2	13	85
	Normotension	22	35	43	52	28	20	53	28	19
	Hypotension	90	10	0	60	40	0	54	43	3
MAP	Hypertension	85	15	0	90	10	0	85	15	0
	Normotension	95	3	2	97	3	0	95	5	0
	Hypotension	97	3	0	97	3	0	92	8	0
DAP	Hypertension	68	32	0	80	20	0	97	3	0
	Normotension	90	10	0	77	23	0	100	0	0
	Hypotension	93	7	0	82	18	0	77	23	0

Discussion

This study demonstrated that oscillometric pressure measurements of MAP and DAP from the tongue met the ACVIM and AAMI criteria for NIBP devices. Most MAP_{TONGUE} and DAP_{TONGUE} measurements were interchangeable with IBP measurements, although the mean bias of DAP_{TONGUE} (–6.1 mmHg) exceeded the AAMI standards of <±5 mmHg by 1 mmHg in hypertension. The SAP_{TONGUE} showed increasingly poor agreement as the blood pressure increased. Compared with $OBP_{PELVIC\ LIMB}$ and OBP_{TAIL}, OBP_{TONGUE} had the most satisfactory performance when considering the absolute difference between IBP and OBP in hypotension.

Similarly, to the findings of the present report, substantial underestimation of SAP by OBP devices on the thoracic and pelvic limb has been reported in dogs (Sawyer *et al.* 2004; McMurphy *et al.* 2006; Deflandre & Hellebrekers 2008; Garofalo *et al.* 2012). However, during hypotension, OBP devices provided SAP measurements that were closer to IBP regardless of the cuff site (Sawyer *et al.* 2004; McMurphy *et al.* 2006; Deflandre & Hellebrekers 2008; Garofalo *et al.* 2012). The SAP_{TONGUE} measurements in the present study also indicated that the agreement between IBP and OBP decreased as the SAP increased. A possible explanation is that the stepwise deflation of cuff pressure led to inaccuracies in the peak SAP measurement, especially in hypertension (Binns *et al.* 1995; Drynan & Raisis 2013).

During hypotension, the OBP_{TONGUE} measurements provided better agreement with IBP than $OBP_{PELVIC\ LIMB}$ and OBP_{TAIL}, based on an absolute difference of <10 mmHg. In addition, SAP_{TONGUE} measurements met both ACVIM and AAMI criteria, unlike $SAP_{PELVIC\ LIMB}$ and SAP_{TAIL} measurements that satisfied only ACVIM criteria during hypotension. Considering the low oscillometric signal strength in hypotension (Alpert *et al.* 2014), the explainable cause for better performance of OBP_{TONGUE} was that the tongue did not have bony structures and fur that might interfere with the delivery of oscillometric signals (Branson *et al.* 1997).

Although MAP_{TONGUE} and DAP_{TONGUE} satisfied the ACVIM and AAMI criteria for NIBP devices and showed satisfactory performance in hypotension, there were limited situations where the tongue could replace other traditional cuff sites. The OBP_{TONGUE} measurement could only be obtained in anesthetized dogs and the need to measure OBP_{TONGUE} might be reduced when the traditional cuff sites were accessible. Notably, cuff inflation during OBP_{TONGUE} measurement disturbed the use of pulse oximetry on the tongue.

This study had some limitations. First of all, the thoracic limb was considered the primary OBP cuff placement sites (Garofalo *et al*. 2012; Ramos *et al.* 2016; Cremer *et al.* 2019), but OBP measured from the thoracic limb was not compared with OBP_{TONGUE} in the present study. However, the thoracic limb may be an inappropriate cuff site in animals with a conical antebrachium, such as Dachshunds and other breeds of hound-type dogs, because blood pressure cuffs are designed to fit a relatively cylindrical structure (Ramos *et al.* 2016). Oscillometric pressure measurements from the pelvic limb (over the cranial tibial artery) and tail (over the median caudal artery) have been verified to be more reliable sites in anesthetized dogs than from the thoracic limb (Bodey *et al.* 1994; Sawyer *et al.* 2004). The present study identified OBP_{TONGUE} measurements be an acceptable alternative to OBPs measured from the pelvic limb or tail as OBP_{TONGUE} measurements satisfied the ACVIM and AAMI criteria. Second, the present study was performed using only one OBP monitor device and only in eight Beagle dogs. Although this study met the ACVIM criteria, a larger sample size and the inclusion of different breeds with different tongue sizes and conformations, such as encountered in clinical practice, could result in different findings. Third, because OBP_{TONGUE} could only be measured during general anesthesia, it was assumed to be used in elective surgeries such as ovariohysterectomy or castration and the present experiment was performed in dorsal recumbency. The site of cuff placement should be level with the base of the heart to account for errors related to the hydrostatic pressure gradient (Brown *et al.* 2007); error of 0.8 mmHg for every 1 cm of vertical difference between the site of pressure measurement and the base of the heart. Therefore, if not corrected by positioning or adjustment for distance, the OBP_{TONGUE} measurements with the dog in dorsal recumbency might be falsely elevated, particularly in large-breed dogs.

Conclusions

The tongue was clinically useful for OBP measurement in anesthetized dogs, and placing the cuff on the tongue might also be useful for reliable detection of hypotension, compared with other cuff sites.

Chapter 2

Comparison of Doppler Ultrasound and Oscillometric Blood Pressure Measured from Tongue in Anesthetized Beagle Dogs

Abstract

This Chapter aimed to compare the DUBP and OBP devices at different cuff positions (tongue and thoracic limb) in anesthetized Beagle dogs.

Eight adult female Beagle dogs weighing 9.2 ± 1.4 kg were sedated IV acepromazine (0.01 mg kg^{-1}), anesthesia was induced with IV alfaxalone (2 mg kg^{-1}) and maintained with isoflurane. The dorsal pedal artery was catheterized for IBP measurements. DUBP and OBP evaluations of SAP, MAP, and DAP were performed based on the tongue and thoracic limb under hypertension (>140 mmHg), normotension (90–140 mmHg), and hypotension (<90 mmHg). Agreement between IBP and DUBP/OBP measurements was analyzed using the criteria for NIBP in humans and small animals.

Regardless of cuff sites, the mean bias ± SD between IBP and DUBP met the veterinary medicine (≤10 ± 15 mmHg) but not human (<5 ± 8 mmHg) standards for SAP measurements in hypotension and normotension. SAP measurements using the OBP device did not show acceptable agreement with IBP measurements except in hypotension. For MAP and DAP measurements, the mean bias ± SD between IBP and OBP met both veterinary and human standards

regardless of cuff sites.

The measurements of SAP with DUBP at the tongue and thoracic limb in anesthetized beagle dogs are clinically useful in hypotension and normotension according to the animal standards. The measurements of oscillometric MAP and DAP provide most reasonable estimates of IBP satisfying human and animal standards regardless of cuff sites.

Introduction

Non-invasive blood pressure monitoring techniques using DUBP and OBP devices are commonly used in veterinary medicine. These techniques are routinely used for monitoring anesthetized and critically ill animals and for detecting systemic hypertension (Garofalo *et al.* 2012; Vachon *et al.* 2014; da Cunha *et al.* 2016). Optimization of the accuracy of NIBP measurements is crucial, as failure to properly recognize abnormalities in arterial BP can lead to diagnostic and therapeutic errors (Garofalo *et al.* 2012). Although IBP measurements are considered to be more accurate than NIBP measurements, non-invasive measurements have been shown to be clinically useful (Haberman *et al.* 2006; Garofalo *et al.* 2012; da Cunha *et al.* 2016). Since IBP measurements may not be always obtainable, a thorough understanding of the interpretation of NIBP measurements is essential to ensure appropriate decision-making in the management of BP abnormalities in anesthetized dogs.

The NIBP techniques are easier to perform than IBP measurement. The DUBP technique only provides SAP estimates. However, the advantage is that blood flow can be heard continuously when the Doppler probe is left in place between measurements (Schauvliege 2016). The OBP technique provides SAP, MAP, DAP, and HR. OBP monitors calculate SAP and DAP electronically using fixed or variable parameter identification points based on the MAP values (Vachon *et al.* 2014). However, the device may not be reliable or may fail to provide readings in smaller patients, especially during peripheral vasoconstriction or hypotension (Schauvliege 2016).

The thoracic limb is a primary cuff placement site, and cuff positions above or below the hock, above or below the carpus, or the tail, have been compared in previous studies (Sawyer *et al.* 1991; Bodey *et al.* 1994; Garofalo *et al.* 2012). OBP measurements obtained from the tongue was evaluated as an indirect cuff placement site (Kim *et al.* 2022). However, the limitations of the study were considered that OBP was measured in dorsal recumbency with cuffs attached to the tongue, pelvic limbs, and tail using a single NIBP device (Kim *et al.* 2022).

Thus, the objectives of this study were (1) to determine whether tongue BP measurements obtained with various NIBP monitors provide favorable estimates of IBP in anesthetized beagle dogs and (2) to compare tongue-based NIBP measurements with NIBP measurements obtained from the thoracic limb in lateral recumbency.

Materials and Methods

Animals

All experimental procedures were approved by the Institute of Animal Care and Use Committee of the Seoul National University (SNU-220306-1). Eight female Beagle dogs from the university's laboratory animal research colony were housed in individual kennels. The dogs were aged (mean ± SD) 2.0 ± 0.5 years weighing 9.2 ± 1.4 kg. All dogs were judged as healthy on the basis of a physical examination, thoracic and abdominal radiographs, and blood analysis (complete blood cell count and serum chemistry assessments). The total duration of the experiment was 2 days and each dog was anesthetized once.

Anesthetic procedures

Prior to general anesthesia, food was on hold for at least 12 hours but the dogs had free access to water. An over-the-needle polyurethane 22-gauge catheter (Sewoon Medical Co. Ltd, Republic of Korea) was used for catheterization at right cephalic vein, and Hartmann (sodium lactate) solution (JW Pharmaceutical Corporation, Republic of Korea) was infused at 5 mL kg^{-1} $hour^{-1}$ during experiment. After an IV injection of acepromazine (0.01 mg kg^{-1}; Sedaject injection; Samu Median Co. Ltd, Republic of Korea), IV alfaxalone (2 mg kg^{-1}; Alfaxan; Jurox Pty Ltd, NSW, Australia) was injected to induce anesthesia. Following orotracheal intubation, anesthesia was subsequently maintained with isoflurane (I-Fran Liquid; Hana Pharm Co. Ltd, Republic of Korea) in oxygen (2 L $minute^{-1}$) using a rebreathing circuit system (Datex Ohmeda 9100c; GE Healthcare, Finland). The f_R was adjusted to maintain the $P_{E'}CO_2$ between 35 and 45 mmHg (4.6–6.0 kPa), while the vaporizer was adjusted to a target $F_{E'}Iso$ of 2.0%.

The dog was maintained in lateral recumbency, and arterial catheterization at the left dorsal pedal artery was performed with a 22-gauge, 2.5-cm catheter connected to a previously calibrated transducer system (Truwave; Edward Lifescience, Germany) via fluid-filled (heparinized 0.9% sodium chloride; 2 IU mL^{-1}) non-compliant tubing. This system was connected to a pressurized (250 mmHg) 500-mL bag. After arterial catheterization, with the dog in right lateral recumbency, the zero-level reference for the transducer was set at the heart base level while the connecting tubing was regularly flushed to prevent clots and remove air bubbles. The accuracy of the arterial pressure waveform was visually checked for deflection of the two waveforms after the fast flush test, which was performed by pulling and releasing the fast flush tab several times quickly. These processes were performed prior to each data collection (hypotension, normotension, and hypertension).

Heart rate and rhythm were monitored continuously with lead II electrocardiography, and IBP measurements, including SAP, MAP, and DAP, as well as f_R, $F_{E'}Iso$, $P_{E'}CO_2$, oxygen saturation, and esophageal temperature were continuously monitored with a multiparameter monitor (Carescape Monitor B650; GE Healthcare, Finland).

Experimental protocol

Single-tube disposable cuffs (SunTech Medical Inc., NC, USA) were placed on the tongue (rostral to the lingual frenulum) and thoracic limb (distal third of the antebrachium). The limb circumferences at the sites of cuff placement were measured to calculate the cuff width-to-limb or tongue circumference ratio (cuff bladder width: circumference), and cuffs with widths closest to 40% of the limb or tongue circumference were selected. BP cuffs (same cuff used for the DUBP and OBP monitor) were connected to one of the two NIBP monitors (DUBP and OBP devices) using a randomized table to organize the order of measurements.

The NIBP devices utilized included a DUBP monitor (Model 811-B; Parks Medical, OR, USA) and an OBP monitor (Suntech Vet25; SunTech Medical Inc., NC, USA). The 8.2-MHz piezoelectric crystal probes of the DUBP monitor were placed on the lingual (median aspects of the tongue) and metacarpal arteries (palmar aspects of the thoracic limbs). The area was covered with an aqueous ultrasound contact gel, the probes were adjusted to their respective locations, and secured in place tightly with adhesive tape to optimize detection of the audible pulsatile sound corresponding to the arterial blood flow (Figure 2).

The measurements of SAP with the DUBP monitor were performed by a single observer as follows: The volume control of the DUBP was set at the maximum level, and the occlusive cuff was inflated to approximately 30 mmHg above the point where the audible pulsatile flow was interrupted. The cuff was then slowly deflated at a rate of approximately 10 mmHg every 3 seconds, and SAP was identified at the moment of return of audible pulsatile flow.

The measurements of SAP, MAP, and DAP with OBP device were performed after air tubing of the cuff was attached to the OBP device. The oscillometric equipment included settings for large and small dogs, and large dog settings were used for all animals weighing more than 8 kg.

Hypertension (SAP >140 mmHg), normotension (SAP 90–140 mmHg), and hypotension (SAP <90 mmHg) were induced by pharmacological manipulation based on systolic IBP readings. Changes in these pressure ranges were induced in the order of normotension, hypotension, and hypertension. Changes in pressure range were not randomized. Hypotension was induced by increasing the $F_E'Iso$. Hypertension was induced by decreasing the $F_E'Iso$ and adjusting infusions of IV dobutamine (0.005–0.01 mg kg^{-1} $minute^{-1}$) or norepinephrine (0.0005–0.003 mg kg^{-1} $minute^{-1}$) through a fluid pump. Norepinephrine was added when the SAP did not increase despite dobutamine increment or when the HR increased without a significant increase in SAP. Hypotension was induced by increasing $F_E'Iso$.

Paired comparisons between the IBP and NIBP methods were performed when SAP was maintained in the desired range for at least 5 minutes and did not change by more than ± 5 mmHg. Thereafter, the IBP and NIBP from the tongue and thoracic limb were recorded simultaneously. Among a total of six measurements, the first measurement was discarded and the next five measurements were recorded. After data collection, each dog was returned to the research colony after removal of the vascular catheters and safe recovery from anesthesia.

Statistical analyses

For the all statistical analyses, MedCalc Version 20 (MedCalc Software BVBA, Belgium) was used to perform Bland–Altman analysis with multiple measurements per individual (Bland & Altman 2007). The sample size was concluded using the ACVIM guidelines, which stated that at least eight animals were required for comparisons with an intra-arterial method (Brown *et al.* 2007). Measurements of IBP obtained by an intra-arterial catheter connected to a fluid-filled pressure transducer system were generally considered the “gold standard” for

BP evaluations (Haskins 2007). The accuracy of NIBP monitors in estimating the "true" value can be determined using the Bland–Altman method. Overall measurements of mean bias (bias = IBP − OBP), precision, and 95% LOA [mean bias ± (1.96 × precision)] were tabled (Bland & Altman 2007).

Validation of NIBP measurements was based on the ACVIM or the AAMI criteria referring to the Bland–Altman analysis. The ACVIM criteria for NIBP monitors stated that the mean bias and precision in comparison with IBP measurements should be ≤10 mmHg and ≤15 mmHg, respectively (Brown *et al.* 2007), and that the absolute differences between IBP and NIBP should also lie within 10 mmHg for 50% of all NIBP measurements and within 20 mmHg for 80% of all IBP measurements (Brown *et al.* 2007). The second set of criteria, which were established by the AAMI, postulate that the mean bias and precision of the NIBP device in relation to the reference standard should be <5 mmHg and <8 mmHg, respectively (ANSI/AAMI/SP10:2002/(R) 2008). The AAMI standards for humans are more stringent than those established for small animals (da Cunha *et al.* 2016).

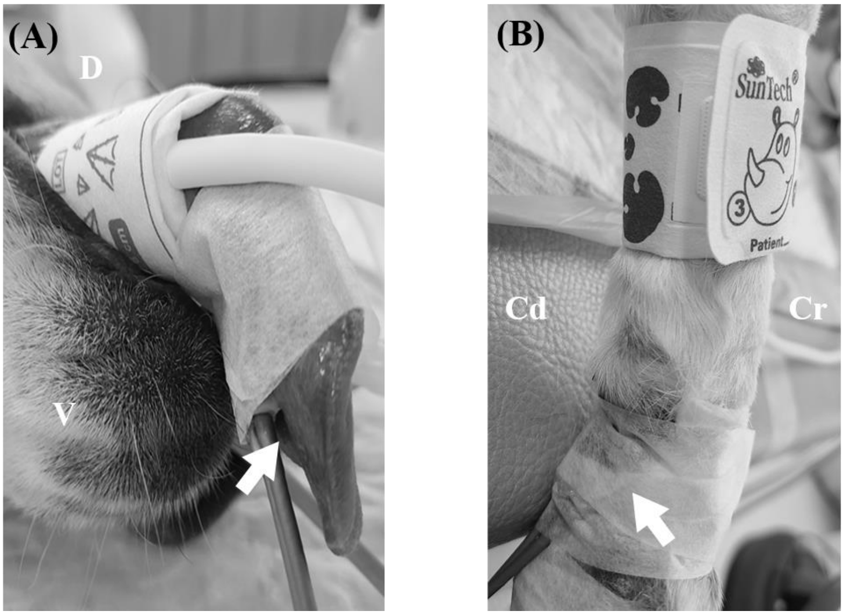

Figure 2. A cuff and crystal probe (white arrow) for non-invasive blood pressure measurements of an anesthetized dog. (A) A cuff placed around the tongue rostral to the lingual frenulum. (B) A cuff placed distal third of antebrachium.

Cd, caudal; Cr, cranial; D, dorsal; V, ventral.

Results

The cuff circumference ratio for the tongue and thoracic limb was 0.40 ± 0.02 and 0.42 ± 0.04 (mean ± SD), respectively. The targeted SAP values were achieved by F_E′Iso values ranging from 0.8% to 3.5% with or without dobutamine infusion (0.005–0.01 mg kg^{-1} $minute^{-1}$) or norepinephrine (0.0005–0.003 mg kg^{-1} $minute^{-1}$). Invasive SAP was maintained in the hypertensive range (>140 mmHg) for 10 ± 5 minutes, and in the hypotensive range (<90 mmHg) for 10 ± 3 minutes. All dogs recovered from anesthesia without systemic abnormalities.

Bland–Altman analysis of the agreement between IBP and NIBP measurements according to the cuff position and BP range with multiple measurements per individual is presented in Table 5–6. Tables 7–9 contained comparative data for each NIBP device when compared with the corresponding direct measurements according to the ACVIM and AAMI criteria.

The mean bias and precision between the IBP and Doppler SAP measurements met only the ACVIM criteria in hypotension and normotension, regardless of cuff positioning. The mean bias and precision of the oscillometric MAP and DAP measurements met the ACVIM and AAMI criteria for a wide range of pressures, regardless of cuff sites. The overall accuracy and precision of oscillometric SAP measurements were poor, as reflected by the large mean bias and wide LOAs. Oscillometric SAP measurements met the ACVIM criteria only in hypotension, regardless of cuff sites. For oscillometric measurements of two cuff sites, the oscillometric SAP was underestimated IBP measurements in normotension and hypertension (positive bias).

Table 5. Mean bias, standard deviation of the mean bias (precision), and 95% limits of agreement (LOA) for systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressure measurements using Doppler (DUBP) and oscillometric blood pressure (OBP) devices from the tongue in anesthetized Beagle dogs.

Pressure range	Pressure variable	Device	Tongue		
			Mean bias (mmHg)	Precision (mmHg)	95% LOA
Hypotension (SAP <90 mmHg)	SAP	OBP	2.8	10.2	-17.1;22.7
		DUBP	7.9	7.3	-6.4;22.1
	MAP	OBP	4.5	3.9	-3.2;12.2
	DAP	OBP	3.8	4.9	-5.9;13.4
Normotension (SAP 90–140 mmHg)	SAP	OBP	7.2	15.1	-22.4;36.8
		DUBP	6.1	6.2	-6.0;18.2
	MAP	OBP	3.7	5.2	-6.5;13.8
	DAP	OBP	-0.9	7.9	-16.4;14.7
Hypertension (SAP >140 mmHg)	SAP	OBP	18.2	18.9	-18.8;55.2
		DUBP	14.5	19.0	-22.7;51.7
	MAP	OBP	2.1	4.9	-7.6;11.7
	DAP	OBP	-4.9	4.8	-14.3;3.5

Table 6. Mean bias, standard deviation of the mean bias (precision), and 95% limits of agreement (LOA) for systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressure measurements using Doppler (DUBP) and oscillometric blood pressure (OBP) devices from the thoracic limb in anesthetized Beagle dogs.

			Thoracic limb		
Pressure range	Pressure variable	Device	Mean bias (mmHg)	Precision (mmHg)	95% LOA
Hypotension (SAP <90 mmHg)	SAP	OBP	-8.3	9.4	-26.7;10.2
		DUBP	3.9	10.3	-16.4;24.1
	MAP	OBP	1.7	4.5	-7.2;10.5
	DAP	OBP	1.6	5.8	-9.8;12.9
Normotension	SAP	OBP	7.3	15.5	-23.1;37.7
		DUBP	3.4	8.5	-13.3;20.0
	MAP	OBP	2.4	7.7	-12.7;17.5
	DAP	OBP	-3.0	7.9	-18.5;12.5
Hypertension (SAP >140 mmHg)	SAP	OBP	21.4	19.5	-16.9;59.7
		DUBP	14.8	14.7	-14.0;43.6
	MAP	OBP	-0.7	7.8	-16.0;14.6
	DAP	OBP	-4.3	7.8	-19.6;11.0

Table 7. Comparison of systolic arterial pressure (SAP) measured by tongue and thoracic limb based Doppler ultrasound blood pressure (DUBP) with invasive blood pressure (IBP) techniques in anesthetized dogs according to American College of Veterinary Internal Medicine (ACVIM) and American Association for Medical Instrumentation (AAMI) criteria.

	Cuff site	Pressure variable	Pressure range	Mean bias (mmHg)	Precision (mmHg)	DUBP measurements within 10 mmHg of IBP (%)	DUBP measurements within 20 mmHg of IBP (%)	Fulfills ACVIM* criteria?	Fulfills AAMI† criteria?
DUBP	Tongue	SAP	Hypotension	7.9	7.3	55	95	Yes	No
			Normotension	6.1	6.2	60	100	Yes	No
			Hypertension	14.5	19.0	33	80	No	No
			Total	9.5	10.8	49	92	No	No
	Thoracic limb	SAP	Hypotension	3.9	10.3	50	100	Yes	No
			Normotension	3.4	8.5	63	90	Yes	No
			Hypertension	14.8	14.7	33	95	No	No
			Total	7.4	11.2	49	95	No	No

The mean bias was calculated as follows: Σ(IBP – DUBP)/n, and precision was the standard deviation of the mean bias.

[*]The ACVIM criteria for DUBP monitors stipulate the following: (1) a mean bias and precision of ≤10 and ≤15 mmHg, respectively, in comparison with the IBP measurements, and (2) absolute differences between IBP and DUBP within 10 mmHg for 50% and 20 mmHg for 80% of all DUBP and IBP measurements, respectively (Brown *et al*. 2007).

[†]The AAMI criteria for DUBP-monitor use stipulate a mean bias and precision of <5 and <8 mmHg, respectively, in relation to the reference standard (ANSI/AAMI/SP10:2002/(R) 2008).

Table 8. Comparison of systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressure measured by tongue based oscillometric blood pressure (OBP) monitor with invasive blood pressure (IBP) techniques in anesthetized dogs according to American College of Veterinary Internal Medicine (ACVIM) and American Association for Medical Instrumentation (AAMI) criteria.

Device	Cuff site	Pressure variable	Pressure range	Mean bias (mmHg)	Precision (mmHg)	OBP measurements within 10 mmHg of IBP (%)	OBP measurements within 20 mmHg of IBP (%)	Fulfills ACVIM* criteria?	Fulfills AAMI† criteria?
OBP	Tongue	SAP	Hypotension	2.8	10.2	55	100	Yes	No
			Normotension	7.2	15.1	63	75	No	No
			Hypertension	18.2	18.9	12	48	No	No
			Total	9.4	14.7	43	74	No	No
		MAP	Hypotension	4.5	3.9	83	100	Yes	Yes
			Normotension	3.7	5.2	95	100	Yes	Yes
			Hypertension	2.1	4.9	93	100	Yes	Yes
			Total	3.4	4.7	90	100	Yes	Yes
		DAP	Hypotension	3.8	4.9	85	100	Yes	Yes
			Normotension	-0.9	7.9	83	100	Yes	Yes
			Hypertension	-4.9	4.8	50	100	Yes	Yes
			Total	-0.7	5.9	73	100	Yes	Yes

The mean bias was calculated as follows: Σ(IBP – OBP)/n, and precision was the standard deviation of the mean bias.

[*]The ACVIM criteria for OBP monitors are as follows: (1) a mean bias and precision of ≤10 and ≤15 mmHg, respectively, in comparison with the IBP measurements, and (2) absolute differences between IBP and OBP within 10 mmHg for 50% and 20 mmHg for 80% of all OBP and IBP measurements, respectively (Brown *et al*. 2007).

[†]The AAMI criteria for OBP-monitor use stipulate a mean bias and precision of <5 and <8 mmHg, respectively, in relation to the reference standard (ANSI/AAMI/SP10:2002/(R) 2008).

Table 9. Comparison of systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressure measured by thoracic limb based oscillometric blood pressure (OBP) monitor with invasive blood pressure (IBP) techniques in anesthetized dogs according to American College of Veterinary Internal Medicine (ACVIM) and American Association for Medical Instrumentation (AAMI) criteria.

Device	Cuff site	Pressure variable	Pressure range	Mean bias (mmHg)	Precision (mmHg)	OBP measurements within 10 mmHg of IBP (%)	OBP measurements within 20 mmHg of IBP (%)	Fulfills ACVIM* criteria?	Fulfills AAMI† criteria?
OBP	Thoracic limb	SAP	Hypotension	-8.3	9.4	75	88	Yes	No
			Normotension	7.3	15.5	50	95	No	No
			Hypertension	21.4	19.5	25	48	No	No
			Total	6.8	14.8	50	77	No	No
		MAP	Hypotension	1.7	4.5	98	100	Yes	Yes
			Normotension	2.4	7.7	78	100	Yes	Yes
			Hypertension	-0.7	7.8	70	100	Yes	Yes
			Total	1.1	6.7	82	100	Yes	Yes
		DAP	Hypotension	1.6	5.8	83	100	Yes	Yes
			Normotension	-3.0	7.9	78	100	Yes	Yes
			Hypertension	-4.3	7.8	50	95	Yes	Yes
			Total	-1.9	7.2	70	98	Yes	Yes

The mean bias was calculated as follows: $\Sigma(IBP - OBP)/n$, and precision was the standard deviation of the mean bias.

*The ACVIM criteria for OBP monitors are as follows: (1) a mean bias and precision of ≤10 and ≤15 mmHg, respectively, in comparison with the IBP measurements, and (2) absolute differences between IBP and OBP within 10 mmHg for 50% and 20 mmHg for 80% of all OBP and IBP measurements, respectively (Brown *et al*. 2007).

†The AAMI criteria for OBP-monitor use stipulate a mean bias and precision of <5 and <8 mmHg, respectively, in relation to the reference standard (ANSI/AAMI/SP10:2002/(R) 2008).

Discussion

In the present study, the agreement between IBP and NIBP measurements from the tongue were obtained and compared to NIBP measurements from the thoracic limb in anesthetized Beagle dogs. Oscillometric SAP measurements were not interchangeable with IBP measurements whereas SAP measurements obtained using the DUBP monitor were clinically interchangeable according to the ACVIM criteria in hypotension and normotension. Most oscillometric MAP and DAP measurements were interchangeable with IBP measurements, regardless of the cuff sites.

The DUBP method allows real time assessment of hemodynamics using changes in pitch of tone, intensity, and rhythm although the SAP does not necessarily reflect tissue perfusion pressure (Schauvliege 2016). A decrease in the pitch and intensity of the audible Doppler sound may suggest a decrease in peripheral perfusion (Garofalo *et al.* 2012) and irregular rhythms can be easily recognized. Therefore, the DUBP method is useful for assessing recognition of hypotensive or arrhythmic situations and response to therapeutic measures. In this study, the DUBP measurements satisfied the ACVIM criteria in the hypotensive and normotensive pressure ranges regardless of cuff sites indicating the systolic IBP and DUBP were interchangeable.

In hypertensive and total status, the tongue-based Doppler SAP measurements did not meet any criteria, indicating that Doppler SAP measurements were not interchangeable with invasive SAP measurements (Table

7). In previous studies, the DUBP device measured from thoracic or pelvic limbs provided more accurate results in hypotension than in hypertension (Dyson 2007; Garofalo *et al.* 2012), and in the present study was in agreement with these results: as IBP increased, there was a higher incidence of inconsistent SAP values measured by tongue-based DUBP.

The Oscillometric techniques are a popular option for obtaining NIBP measurements because of their ability to provide automated SAP, MAP, DAP, and HR measurements. Moreover, these techniques may be technically easier to perform than DUBP evaluations. These techniques involve inflation of a cuff around an extremity until arterial pulsations are suppressed, followed by monitoring of arterial oscillations as the cuff is slowly deflated (Acierno *et al.* 2018). During this process, the intensity of the arterial pulsations initially increases until it reaches a maximum point from which it subsequently reduces. The crescendo–decrescendo plot of arterial pulsations produces the "oscillometric envelope" (da Cunha *et al.* 2016).

The oscillometric SAP measurements met the ACVIM criteria only in hypotensive status regardless of cuff sites. The positive bias indicated underestimation of IBP and wide LOA as well as poor agreement between IBP and OBP methods (Tables 8–9). When the agreement between IBP and NIBP was compared according to each BP level, the underestimation of SAP values in normotension (mean bias: 7.2 and 7.3 mmHg with cuff placed tongue and thoracic limb, respectively) and hypertension (mean bias: 18.2 and 21.4 mmHg with cuff placed tongue and thoracic limb, respectively) with the OBP monitor was significantly greater than with the DUBP (mean bias of normotension: 6.1 and 3.4 mmHg with cuff placed tongue and thoracic limb, respectively; mean bias of hypertension: 14.5 and 14.8 mmHg with cuff placed tongue and thoracic limb, respectively) method (Table 5–6).

The oscillometric MAP is the point corresponding to the maximal arterial oscillations, and SAP and DAP are calculated using proprietary algorithms (Ramsey 1979). In assessments performed with OBP in this study, the reliable estimates of MAP and DAP was identified satisfying the ACVIM and AAMI criteria regardless of cuff sites.

Placing the cuff sites was not associated with agreement between IBP and DUBP/OBP regardless of BP ranges. These results supported that the tongue could be an alternative site cuff when the primary cuff site (Garofalo *et al.* 2012; Ramos *et al.* 2016; Cremer *et al.* 2019; Kim *et al*. 2022) is inaccessible.

The trend for underestimation of SAP by the NIBP (DUBP and OBP) in assessments performed at the tongue and thoracic limb should be interpreted with caution. IBP waveforms are not identical when measured simultaneously in peripheral and central arteries (Pauca *et al.* 1992). As the IBP waveform moves from central to peripheral, the SAP increases and the DAP decreases (Schauvliege 2016). Although the MAP and DAP recorded in the peripheral arteries accurately reflect the aortic MAP and DAP, the overshoot due to the resonant behavior of these vessels results in increased SAP in more peripheral arteries (Pauca *et al*. 1992). Hypotension was reported to occur in 21 to 38% of dogs undergoing inhalation anesthesia (Chen *et al.* 2007; Redondo *et al.* 2007), SAP measurement using NIBP devices could be meaningful to recognizing hypotension. However, the underestimation of SAP by NIBP could have clinical implications, including incorrect interpretation of SAP in animals with hypertension and subsequent failure to administer appropriate treatment (Moll *et al.* 2018).

The current study had certain limitations. First, all dogs were placed in lateral recumbency because it has been shown to provide a better correlation between IBP and NIBP (Bodey *et al.* 1996). However, differences in positions can yield different blood pressure readings because of hydrostatic differences in the compression of the artery by the body and other factors. Second, NIBP measurements at the tongue could only be obtained in anesthetized patients. Third, even though the ACVIM criteria recommend at least eight animals for studies involving comparisons with an intra-arterial method, the sample size was small Finally, the present study was performed only in Beagle dogs; the inclusion of dogs of different breeds with different tongue sizes and conformations, such as in clinical settings, could have resulted in differences in the findings reported herein.

Conclusion

Systolic DUBP was more reliable than OBP, but careful interpretation was required regardless of cuff sites. Oscillometric MAP and DAP measurements from the tongue were clinically useful and could replace measurements performed on thoracic cuff site.

Chapter 3

Agreement Between Tongue-based Oscillometric and Invasive Blood Pressure in Anesthetized Dogs of Various Weights

Abstract

This Chapter aimed to evaluate the agreement between tongue-based OBP and IBP in anesthetized dogs of various body weights.

Forty-five client-owned dogs undergoing general anesthesia for surgery or imaging scan were included, and the body weight range was 2.5–42.6 kg. While IBP was measured via the dorsal pedal artery, OBP was measured from the tongue. Paired comparisons between IBP- and OBP-measurement methods were conducted in normotension (systolic IBP: 90–140 mmHg). Agreement between paired IBP and OBP was verified with reference standards used in small animals and humans.

The total mean bias ± standard deviation between IBP and OBP met the veterinary (≤10 ± 15 mmHg) standards for MAP (3.0 ± 7.9 mmHg) and DAP (-2.9 ± 9.8 mmHg). In addition, upon body-weight-based dog classification (≤5 kg, >5 kg), bias ± SD of MAP (3.3 ± 7.2 mmHg), and DAP (-3.3 ± 7.9 mmHg) exhibited reliable measurements at weights >5 kg (n = 29) satisfying human standards (<5 ± 8 mmHg).

This study demonstrates that tongue-based OBP was a close estimate of MAP and DAP in anesthetized dogs according to small animals and human criteria for dogs weighing >5 kg.

Introduction

Arterial blood pressure is a vital sign that is routinely monitored during general anesthesia. IBP measurement, which exhibits reliable performance and is preferred during major surgery, is likely associated with hemodynamic instability; however, NIBP monitoring is portable, economical, and requires less technical skills (Williamson & Leone 2012). Doppler and oscillometric methods have been used to obtain NIBP, and the oscillometric method has proven to be less time consuming and require less technical skill than the Doppler method (Williamson & Leone 2012). Oscillometric devices are “hands-free” once the cuff is placed and secured, rendering them convenient tools during anesthesia. Generally, the oscillometric method provides an accurate assessment of the MAP and DAP; nonetheless, it appears to underestimate the actual SAP.

The site of cuff placement potentially affects accuracy, and it is generally agreed that the oscillometric technique is more appropriate for use in animals weighing >5 kg (Love & Harvey 2006; Kennedy & Barletta 2015). The thoracic limb is a primary cuff-placement site, and cuff positions above or below the carpus, above or below the hock, or on the tail have been compared in previous studies (Bodey *et al.* 1994; Garofalo *et al.* 2012). The OBP measured from the tongue provides an accurate assessment of MAP and DAP (Kim *et al.* 2022); however, it potentially underestimates the actual SAP compared with other cuff-placement sites. However, the experiment was conducted exclusively on Beagle dogs, and the fact that dogs of various weights and breeds were not investigated constitutes a limitation.

The congruence between certain commercially available oscillometric monitors and IBP measurement has been investigated in dogs (Bodey *et al.* 1994; Garofalo *et al.* 2012; Haberman *et al.* 2006; Wernick *et al.* 2010; Drynan & Raisis 2013; Vachon *et al.* 2014; da Cunha *et al*. 2016). NIBP validation in small animals depends on any one of the following two sets of criteria: (1) the ACVIM criteria and (2) those of the AAMI. ACVIM criteria governing NIBP-monitor use stipulate a mean bias and precision of ≤10 and ≤15 mmHg, respectively, compared with those of IBP (Brown *et al.* 2007). Absolute differences between IBP and NIBP are limited to 10 mmHg of 50% and 20 mmHg of 80% of all NIBP and IBP measurements, respectively (Brown *et al.* 2007). AAMI criteria governing NIBP-device use stipulate a mean bias and precision of <5 and <8 mmHg, respectively, in relation to the reference standard (ANSI/AAMI/SP10:2002/(R) 2008). The AAMI standards for humans are stricter than those for small animals (da Cunha *et al.* 2016).

The objectives of this clinical investigation were (1) to determine if OBP measured from the tongue is a favorable estimate of MAP and DAP in various breeds of anesthetized dogs according to the ACVIM and AAMI criteria as well as (2) to assess the accuracy of OBP measured from the tongue in anesthetized dogs weighing >5 kg.

Materials and Methods

Animals

This clinical study was approved by the Institute of Animal Care and Use Committee of Seoul National University (SNU-200712-1) and performed at the Veterinary Medical Teaching Hospital of Seoul National University between October and December 2020. A total of 45 client-owned canine dogs undergoing general anesthesia for surgery or imaging scan were included in this study. Included dogs were those that already had an arterial catheter as part of their monitoring plan for anesthesia. No exclusion criteria were applied regarding the disease state of the animals or anesthetic protocol used.

Anesthesia procedures

The dogs were classified based on the American Society of Anesthesiologists grading scale according to pre-anesthetic examination results and underlying diseases. Before anesthesia, food and water were withheld for 12 and 3 h, respectively. The cephalic vein was catheterized using an over-the-needle polyurethane catheter (Over-the-needle polyurethane catheter; Sewoon Medical, Seoul, Republic of Korea). Hartmann's solution (Hartmann's solution; JW Pharmaceutical, Seoul, Republic of Korea) or plasma solution A (Safe-Flex; HK inno.N, Seoul, Republic of Korea) was infused at 5–10 mL kg^{-1} $hour^{-1}$ during the perioperative period. Antibiotic therapy with cefazolin (Chong Kun Dang Corp., Seoul, Republic of Korea) 22–33 mg/kg intravenously (IV) was administered every 2 hours during surgery. Dogs were sedated with acepromazine (Sedaject injection;

Samu Median Co., Ltd., Seoul, Republic of Korea, 0.005 mg kg^{-1} IV) or midazolam (Midazolam; Bukwang Pharm. Co., Ltd., Seoul, Republic of Korea, 0.1–0.2 mg kg^{-1} IV). A constant infusion rate of a combination of remifentanil (Remiva; Hana Pharma Corp., Seoul, Republic of Korea, 6 μg kg^{-1} $hour^{-1}$), lidocaine (Lidocaine; Jeil Pharmaceutical, Daegu, Republic of Korea, 3 mg kg^{-1} $hour^{-1}$), and ketamine (Ketamine; Yuhan Pharmaceutical, Republic of Korea, 0.6 mg kg^{-1} $hour^{-1}$) or that of remifentanil (6 μg kg^{-1} $hour^{-1}$) and ketamine (0.6 mg kg^{-1} $hour^{-1}$) was maintained for analgesia. Induction was performed with alfaxalone (Alfaxan; Jurox, Rutherford, Australia, 1–2 mg kg^{-1} IV), and the doses were titrated to effect. Following orotracheal intubation, the patients were connected to a rebreathing circuit system (Datex-Ohmeda 9100c; GE Healthcare, Finland), and anesthesia was maintained with isoflurane (I-Fran Liquid; Hana Pharma Corp., Seoul, Republic of Korea) in oxygen 100%. The respiratory rate was individually adjusted to maintain the end-tidal carbon dioxide concentration ($P_{E}'CO_2$) within a capnometry-value range of 35–45 mmHg (4.6–6.0 kPa). An intra-arterial catheter (22–24 gauge) was inserted in the dorsal pedal artery after intubation. The arterial catheter was connected to a transducer system (TruWave; Edward Lifescience, Germany) that had previously been calibrated against a mercury column via fluid-filled (heparinized 0.9% sodium chloride; 2 IU mL^{-1}) non-compliant tubing (500-mm length). For this system, a zero-level reference was set at the height of the sternum with the patient positioned in lateral recumbency. It was intermittently flushed for purposes of eliminating air bubbles and preventing clots. A multiparameter monitor (Carescape Monitor B650; GE Healthcare, Helsinki, Finland) was connected to the transducer. Arterial-pressure waveform accuracy was established by visually inspecting the presence of two wave deflections following the fast-flush test. The fast-flush test was conducted by drawing the fast-flush tab and rapidly discharging it numerous times, and all IBP-system damping coefficients were appropriate for this study. During anesthesia, lead II electrocardiography was used to continuously monitor heart rate and rhythm. A multiparameter monitor was utilized to continuously monitor IBP measurements, including SAP, MAP, DAP, respiratory rate, oxygen saturation, $P_E'CO_2$, $F_E'Iso$, esophageal temperature, tidal volume, compliance from spirometry and oxygen saturation, which were recorded every 5 min during anesthesia.

Experimental protocol

Single-tube disposable cuffs (SunTech Medical, Inc., NC, USA), which were positioned rostral to the lingual frenulum and connected to a veterinary OBP monitor (Vet25; SunTech Medical Inc., NC, USA), were attached to the dogs. Cuff size was determined based on the manufacturer's recommendations (i.e., a range indicator with an index line stipulating specific cuff ranges for cuff sites). In cases where the OBP monitor failed to read the BP, the cuff was repositioned and the instrument restarted. Measurements were taken when systolic IBP was within normal range (90–140 mmHg).

Paired comparisons between the IBP and OBP were performed with the patients in lateral recumbency. Thereafter, IBP and OBP measured from the tongue (SAP_{TONGUE}, MAP_{TONGUE}, and DAP_{TONGUE}) were recorded concurrently. After discarding the initial measurement, five consecutive measurements were recorded. Vascular catheters were removed following data collection, and each dog recovered from anesthesia.

Statistical analyses

MedCalc (MedCalc version 20; MedCalc Software BVBA, Belgium) was used for all statistical analyses. Bland-Altman analysis was employed to examine the agreement between IBP and OBP (Bland & Altman 2007). Underestimation and overestimation of the IBP method were indicated by positive and negative biases, respectively, and precision was defined as the SD of the mean bias between the paired results (Bland & Altman 2007). Overall mean-bias measurements (bias = IBP − OBP), precision (SD of mean bias), and 95% LOA [mean bias ± (1.96 × precision)] were tabled (Bland & Altman 2007). The Bland-Altman analysis was performed by dividing the overall data by the number of cases >5 kg and those ≤5 kg.

Results

The breeds, body weight, age, and reason for anesthesia were described in Table 10. There were three intact males (7%), 16 neutered males (35%), 14 intact females (31%), and 12 female spayed dogs (27%). The mean age of the dogs was 6.8 ± 3.8 years (range, 1–15 years) and mean weight 12.3 ± 12.0 kg (range, 2.5–42.6 kg). A total of 16 dogs weighed ≤5 kg, and 29 dogs weighed >5 kg. The most represented breed was Maltese (n = 8, 17.8%), followed by Miniature Poodle (n = 7, 15.6%), Retriever (n = 5, 11.1%), Pomeranian (n = 4, 8.9%) and others (n = 21, 46.6%). A total of 17 dogs were admitted for orthopedic surgery (37.8%), 25 for soft-tissue surgery (55.6%), and three for imaging scan (6.6%). The cuff circumference ratio was 0.42 ± 0.06. A total of 225 measurements were obtained from all animals for analysis. All dogs recovered from anesthesia without systemic abnormalities.

The Bland-Altman analysis results of the agreement between IBP and OBP according to body weight (≤5 kg, >5 kg) are presented in Tables 11–12. SAP_{TONGUE} did not satisfy both the ACVIM and AAMI criteria, and it underestimated invasive SAP. The mean bias and precision of MAP_{TONGUE} met the ACVIM and AAMI criteria. However, when dogs were classified according to body weight (≤5 kg, >5 kg), the ≤5 kg group did not meet the AAMI criteria. DAP_{TONGUE} satisfied the ACVIM criteria but not the AAMI criteria. In the >5 kg group, both ACVIM and AAMI criteria were satisfied.

Table 10. Characteristics of dogs included in the study by group.

Groups	Breeds (n)	Body weight (kg)*	Age (year)*	Reason for anesthesia (n)		
				Orthopedic surgery	Soft tissue surgery	Imaging scan
≤5 kg (n = 16)	Maltese (8) Pomeranian (4) Poodle (2) Others (2)	3.6 ± 0.7	7.4 ± 4.5	4	12	0
>5 kg (n = 29)	Poodle (5) Retriever (5) Schnauzer (2) Others (17)	17.1 ± 12.6	6.4 ± 3.5	13	13	3

*Data was expressed as mean ± standard deviation

Table 11. Mean bias (invasive–noninvasive), precision (standard deviation of the mean bias), and 95% limits of agreement [LOAs; mean bias ± (1.96 × precision)] between systolic (SAP), mean (MAP), and diastolic (DAP) arterial pressure from the dorsal pedal artery and oscillometric blood pressure according to body weight (≤5 kg, >5 kg) in anesthetized dogs.

		Tongue		
Pressure variable		Total	≤5 kg	>5 kg
SAP	Mean bias (mmHg)	14.4	12.5	15.4
	Precision (mmHg)	15.0[*]	17.6	13.2[*]
	95% LOA	-15;43.8	-22.0;16.3	-10.5;41.3
	Total number (n)	45	16	29
MAP	Mean bias (mmHg)	3[*†]	2.4[*±]	3.3[*†]
	Precision (mmHg)	7.9[*†]	9.1[*]	7.2[*†]
	95% LOA	-12.5;18.5	-15.4;20.2	-10.8;17.4
	Total number (n)	45	16	29
DAP	Mean bias (mmHg)	-2.9[*†]	-3.2[*†]	-2.7[*†]
	Precision (mmHg)	9.8[*]	12.6[*]	7.9[*†]
	95% LOA	-22.1;16.3	-27.9;21.5	-18.2;12.8
	Total number (n)	45	16	29

Measurements were obtained under normotension (SAP: 90–140 mmHg).

[*]Readings within the American College of Veterinary Internal Medicine criteria

[†]Readings within the American Association for Medical Instrumentation criteria

Table 12. Comparison of blood pressure values measured by oscillometric blood pressure (OBP) monitors with invasive blood pressure (IBP) techniques in the normotensive status (SAP: 90–140 mmHg) in anesthetized dogs according to American College of Veterinary Internal Medicine (ACVIM) and American Association for Medical Instrumentation (AAMI) criteria.

	Pressure variable	Mean bias (mmHg)	Precision (mmHg)	OBP measurements within 10 mmHg of IBP	OBP measurements within 20 mmHg of IBP	Fulfills ACVIM* criteria?	Fulfills AAMI† criteria?
Total	SAP (n=225)	14.4	15.0	39%	66%	No	No
	MAP (n=225)	3	7.9	75%	99%	Yes	Yes
	DAP (n=225)	-2.9	9.8	65%	96%	Yes	No
≤5 kg	SAP (n=80)	12.5	17.6	48%	71%	No	No
	MAP (n=80)	2.4	9.1	68%	99%	Yes	No
	DAP (n=80)	-3.2	12.6	45%	96%	Yes	No
>5 kg	SAP (n=145)	15.4	13.2	34%	65%	No	No
	MAP (n=145)	3.3	7.2	79%	99%	Yes	Yes
	DAP (n=145)	-2.7	7.9	75%	95%	Yes	Yes

The mean bias was calculated as follows: Σ(IBP – OBP)/n, and precision was the standard deviation of the mean bias.

*The ACVIM criteria for OBP monitors stipulate the following: (1) a mean bias and precision of ≤10 and ≤15 mmHg, respectively, compared with those of IBP, and (2) absolute differences between IBP and OBP within 10 mmHg of 50% and 20 mmHg of 80% of all OBP and IBP measurements, respectively (Brown et al. 2007).

†The AAMI criteria for OBP-monitor use stipulate a mean bias and precision of <5 and <8 mmHg, respectively, in relation to the reference standard (ANSI/AAMI/SP10:2002/(R) 2008).

Discussion

This study aimed to determine the agreement between IBP and OBP measured from the tongue in clinical settings. According to the ACVIM, oscillometric MAP_{TONGUE} and DAP_{TONGUE} were clinically interchangeable with IBP in anesthetized dogs, whereas SAP_{TONGUE} was not. In addition, MAP_{TONGUE} and DAP_{TONGUE} in dogs weighing ≤5 kg did not satisfy the AAMI criteria, exhibiting less reliable results than those of dogs weighing >5 kg.

The tongue was previously considered an OBP cuff-placement site, demonstrating reliable estimates of MAP and DAP according to ACVIM and AAMI criteria in normotensive, anesthetized Beagle dogs, whereas SAP did not satisfy any criteria (Kim *et al.* 2022). The present study, as in previous experiments, revealed that MAP_{TONGUE} was in plausible agreement with IBP in clinical settings, based on ACVIM and AAMI criteria, and SAP_{TONGUE} exhibited poor agreement, failing to satisfy both criteria. DAP_{TONGUE} only satisfied the ACVIM guidelines in this study.

Positive bias indicated an underestimation of IBP, and wide LOA reflected a poor agreement between the two methods. Bias of SAP_{TONGUE} revealed an underestimation and a poor agreement with invasive SAP. In addition, a significant underestimation of SAP by OBP devices has been reported at other cuff-placement sites (thoracic and pelvic limbs) in dogs (Garofalo *et al.* 2012; Sawyer *et al.* 2004; McMurphy *et al.* 2006; Deflandre & Hellebrekers 2008).

The MAP_{TONGUE} proved clinically acceptable, satisfying both criteria. However, when dogs were classified into two groups, MAP_{TONGUE} did not satisfy AAMI criteria in the ≤5 kg group. In general, consensus holds that the oscillometric technique is optimal for animals weighing >5 kg (Love & Harvey 2006). Apparently, OBP measurement is less reliable in cats and small dogs owing to a smaller peripheral-artery size, thus potentially generating insufficient pulse pressure to produce detectable cuff pressure oscillations (Williamson & Leone 2012; Henik *et al.* 2005). In this study, the oscillometric equipment included a veterinary-specific OBP device with a setting for large and small dogs, and manufacturer instructions recommend the use of the small-dog setting on any animal weighing <8 kg. In this study, the small-dog setting was used when the weight was <8 kg, according to the manufacturer's recommendation, and the ACVIM criteria were satisfied, whereas those of the AAMI were not.

The DAP_{TONGUE} satisfied both sets of criteria; however, in clinical conditions, DAP_{TONGUE} failed to satisfy the AAMI criteria. The reason DAP_{TONGUE} yielded different results from those in previous experimental results was possibly due to the data of the ≤5 kg group. In this study, DAP_{TONGUE} met the AAMI criteria in the >5 kg group; however, it failed to meet the same criteria in the ≤5 kg group. For the same reason as that in MAP_{TONGUE}, the accuracy of OBP measurement decreased in the ≤5 kg group, and this was considered to affect the overall result.

The current study had certain limitations. First, OBP and IBP were exclusively obtained from the tongue and dorsal pedal artery, respectively. Blood pressure was not consistent throughout a dog's body, and that measured invasively potentially varied according to measurement site and body location (Acierno *et al.* 2018). Second, measurements were taken in the normotensive range. As these animals were client owned, anesthesiologists attempted to manipulate blood pressure pharmacologically to treat hypotension (SAP <90 mmHg) (Ruffato *et al.* 2015).

Conclusions

In summary, MAP_{TONGUE} and DAP_{TONGUE} was a fairly accurate estimate of invasive MAP in a clinical setting, according to ACVIM and AAMI criteria weighing >5 kg. SAP_{TONGUE} was not a ready replacement for invasive SAP.

General Conclusions

This study was designed to evaluate the accuracy of tongue-based indirect arterial blood pressure measurements in anesthetized dogs.

In Chapter 1, the tongue was considered clinically useful site for OBP measurement in anesthetized Beagle dogs. In addition, placing the cuff on the tongue might also be useful for reliable detection of hypotension, compared with other cuff sites.

In Chapter 2, the SAP_{TONGUE} required very careful interpretation regardless of NIBP devices. The MAP_{TONGUE} and DAP_{TONGUE} were clinically useful and could replace measurements performed on thoracic cuff sites.

In Chapter 3, the MAP_{TONGUE} and DAP_{TONGUE} was a fairly accurate estimate of invasive MAP in a clinical setting when the dogs weighs >5 kg.

These studies demonstrated that the tongue-based NIBP measurement was provided reliable estimates of IBP in dogs. Therefore, it could be useful to identify tongue-based NIBP when the usual cuff position was difficult to access during anesthesia in dogs.

References

Acierno MJ, Brown S, Coleman AE *et al.* (2018) ACVIM consensus statement: guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats. J Vet Intern Med 32, 1803–1822.

Alpert BS, Quinn D, Gallick D (2014) Oscillometric blood pressure: a review for clinicians. J Am Soc Hypertens 8, 930–938.

ANSI/AAMI/SP10:2002/(R) (2008) Manual, electronic, or automated sphygmomanometers. Association for the Advancement of Medical Instruments, USA BJM. Available form. www.aami.org. Last accessed February 2022.

Binns SH, Sisson DD, Buoscio DA, *et al.* (1995) Doppler ultrasonographic, oscillometric sphygmomanometric, and photoplethysmographic techniques for noninvasive blood pressure measurement in anesthetized cats. J Vet Intern Med 9, 405–414.

Bland JM, Altman DG (2007) Agreement between methods of measurement with multiple observations per individual. J Biopharm Stat 17, 571–582.

Bodey AR, Michell AR, Bovee KC *et al.* (1996) Comparison of direct and indirect (oscillometric) measurements of arterial blood pressure in conscious dogs. Res Vet Sci 61, 17–21.

Bodey AR, Young LE, Bartram DH *et al.* (1994) A comparison of direct and indirect (oscillometric) measurements of arterial blood pressure in anaesthetised dogs, using tail and limb cuffs. Res Vet Sci 57, 265–269.

Bosiak AP, Mann FA, Dodam JR *et al.* (2010) Comparison of ultrasonic Doppler flow monitor, oscillometric, and direct arterial blood pressure measurements in ill dogs. J Vet Emerg Crit Care 20, 207–215.

Branson KR, Wagner-Mann CC, *et al.* (1997) Evaluation of an oscillometric blood pressure monitor on anesthetized cats and the effect of cuff placement and fur on accuracy. Vet Surg 26, 347–353.

Brown S, Atkins C, Bagley R *et al.* (2007) Guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats. J Vet Intern Med 21, 542–558.

Chen HC, Sinclair MD, Dyson DH (2007) Use of ephedrine and dopamine in dogs for the management of hypotension in routine clinical cases under isoflurane anesthesia. Vet Anaesth Analg 34, 301–311.

Clarke KW, Trim CM, Hall LW (2014) Complications. In: Veterinary Anesthesia (11th edn). Clarke KW, Trim CM, Hall LW (eds). Elsevier, USA. pp. 634–638.

Cremer J, da Cunha AF, Paul LJ *et al.* (2019) Assessment of a commercially available veterinary blood pressure device used on awake and anesthetized dogs. Am J Vet Res 80, 1067–1073.

da Cunha AF, Ramos SJ, Domingues M *et al.* (2016) Agreement between two oscillometric blood pressure technologies and invasively measured arterial pressure in the dog. Vet Anaesth Analg 43, 199–203.

Deflandre CJA, Hellebrekers LJ (2008) Clinical evaluation of the Surgivet V60046, a noninvasive blood pressure monitor in anaesthetized dogs. Vet Anaesth Analg 35, 13–21.

Drynan EA, Raisis AL (2013) Comparison of invasive versus noninvasive blood pressure measurements before and after hemorrhage in anesthetized greyhounds using the Surgivet V9203. J Vet Emerg Crit Care (San Antonio) 23, 523–531.

Eubanks DL (2007) Anatomy and clinical examination of the tongue in the dog. J Vet Dent 24, 271–273.

Garofalo NA, Teixeira Neto FJ, Alvaides RK *et al.* (2012) Agreement between direct, oscillometric and Doppler ultrasound blood pressures using three different cuff positions in anesthetized dogs. Vet Anaesth Analg 39, 324–334.

Haberman CE, Kang CW, Morgan JD, *et al.* (2006) Evaluation of oscillometric and Doppler ultrasonic methods of indirect blood pressure estimation in conscious dogs. Can J Vet Res 70, 211–217.

Haskins SC (2007) Monitoring anesthetized patients. In: Lumb & Jones' Veterinary Anesthesia and Analgesia (4th edn). Tranquilli WJ, Thurmon JC, Grimm KA (eds). Blackwell, USA. pp. 533–558.

Henik RA, Dolson MK, Wenholz LJ (2005) How to obtain a blood pressure measurement. Clin Tech Small Animal Pract 20, 144–150.

Hermanson JW (2020) The muscular system. In: Miller's Anatomy of the Dog (5th edn). Hermanson JW, de Lahunta A, Evans HE (eds). Elsevier, USA. pp. 445–487

Kennedy MJ, Barletta M (2015) Agreement between Doppler and invasive blood pressure monitoring in anesthetized dogs weighing <5 kg. J Am Anim Hosp Assoc 51, 300–305.

Kim D, Kim H, Shin D *et al.* (2022) Evaluation of the tongue for oscillometric measurement of arterial pressure in anesthetized Beagle dogs. Vet Anaesth Analg 49, 149–155.

Love L, Harvey R (2006) Arterial blood pressure measurement: physiology, tools, and techniques. Compendium 28, 450–461.

McMurphy RM, Stoll MR, McCubrey R (2006) Accuracy of an oscillometric blood pressure monitor during phenylephrine-induced hypertension in dogs. Am J Vet Res 67, 1541–1545.

Moll X, Aguilar A, García F *et al.* (2018) Validity and reliability of Doppler ultrasonography and direct arterial blood pressure measurements in anaesthetized dogs weighing less than 5 kg. Vet Anaesth Analg 45, 135–144.

Pascoe PJ (2011) Perioperative management of fluid therapy. In: Fluid, Electrolyte, and Acid–Base Disorders in Small Animal Practice (4th edn). DiBartola SP (ed). Elsevier, USA. pp. 405–435.

Pauca AL, Wallenhaupt SL, Kon ND et al. (1992) Does radial artery pressure accurately reflect aortic pressure? Chest 102, 1193–1198.

Ramos SJ, da Cunha AF, Domingues M *et al.* (2016) Comparison of blood pressure measurements of anesthetized dogs obtained noninvasively with a cylindrical blood pressure cuff and an anatomically modified conical blood pressure cuff. Am J Vet Res 77, 59–64.

Ramsey M III (1979) Noninvasive automatic determination of mean arterial pressure. Med Biol Eng Comput 17, 11–18.

Redondo JI, Rubio M, Soler G *et al.* (2007) Normal values and incidence of cardiorespiratory complications in dogs during general anaesthesia. A review of 1281 cases. J Vet Med A Physiol Pathol Clin Med 54, 470–477.

Ruffato M, Lorenzo N, Clark L (2015) What is the definition of intraoperative hypotension in dogs? Results from a survey of diplomates of the ACVAA and ECVAA. Vet Anaesth Analg 42, 55–64.

Sawyer DC, Brown M, Striler EL *et al.* (1991) Comparison of direct and indirect blood pressure measurement in anesthetized dogs. Lab Anim Sci 41, 134–138.

Sawyer DC, Guikema AH, Siegel EM (2004) Evaluation of a new oscillometric blood pressure monitor in isoflurane-anesthetized dogs. Vet Anaesth Analg 31, 27–39.

Schauvliege S (2016) Patient monitoring and monitoring equipment. In: BSAVA Manual of Canine and Feline Anaesthesia and Analgesia (3rd edn). Duke-Novakovski T, de Vries M, Seymour C (eds). British Small Animal Veterinary Association, UK. pp. 77–80.

Séguin B (2012) Surgical treatment of tongue, lip and cheek tumors. In: Oral and Maxillofacial Surgery in Dogs and Cats. Verstraete FJM, Lommer MJ (eds). Elsevier, USA. pp. 431–449.

Vachon C, Belanger MC, Burns PM (2014) Evaluation of oscillometric and Doppler ultrasonic devices for blood pressure measurements in anesthetized and conscious dogs. Res Vet Sci 97, 111–117.

Waddell LS (2000) Direct blood pressure monitoring. Cl Tech Small Anim Pract 15, 111–118.

Wernick M, Doherr M, Howard J, *et al.* (2010) Evaluation of high-definition and conventional oscillometric blood pressure measurement in anaesthetised dogs using ACVIM guidelines. J Small Anim Pract 51, 318–324.

Williamson JA, Leone S (2012) Noninvasive arterial blood pressure monitoring. In: Advanced Monitoring and Procedures for Small Animal Emergency and Critical Care (1st edn). Burkitt Creedon JM, Davis H (eds). Wiley-Blackwell, pp. 134–144.

국 문 초 록

개의 혀에서 간접혈압 측정법의 평가

지도교수 이 인 형

김 달 해

서울대학교 대학원

수의학과 임상수의학 전공

본 연구의 목적은 1) 전신 마취된 개의 혀에서 oscillometry 혈압계를 사용한 간접혈압 측정 방식의 타당성을 입증하고 뒷발과 꼬리에서 측정한 간접동맥혈압 값과 비교하며, 2) 다양한 간접혈압 측정 장비(oscillometry 혈압계, Doppler 초음파 혈압계)를 이용하여 혀에서의 간접혈압 측정 방식의 타당성을 확인하고 앞발에서 측정한 간접동맥혈압 값과 비교하며, 3) 혀의 간접혈압 측정 방식의 유용성을 임상적으로 평가하는 것이다.

제1장에서는 전신 마취된 비글견의 혀에서 oscillometry 혈압계를 사용한 혈압 측정 방식의 가능성을 직접동맥혈압과의 일치도 평가를 통해 확인하였으며, 간접혈압 측정 시 정확도가 높은 부위인 뒷발 및 꼬리와 비교하였다. 혀에서 oscillometry 혈압 측정 방식을 통한 혈압 값은 저

혈압부터 고혈압에 이르는 혈압 범위에서 평균혈압과 이완기혈압은 직접동맥혈압과 높은 일치도를 보였으나, 수축기혈압은 일치도를 보이지 않았다. 혀에서 측정한 간접혈압은 저혈압일 때 뒷발 및 꼬리에서 측정한 간접혈압보다 직접동맥혈압과의 일치도가 높았으며, 이는 혀라는 기관이 근육으로만 이루어진 장기이기 때문에 다른 위치보다 맥박의 진동 확인이 용이하여 저혈압을 보다 잘 평가할 수 있을 것이라는 가능성을 제시하였다.

제2장에서는 전신 마취된 비글견의 혀와 앞발에서 Doppler 초음파 혈압계와 oscillometry 혈압계를 사용한 혈압 측정을 진행하였다. 수축기혈압의 경우 Doppler 초음파 혈압계는 저혈압과 정상혈압 범위에서 직접동맥혈압과 임상적으로 의미가 있는 일치도를 보임을 확인하였고, oscillometry 혈압계는 저혈압 범위에서 임상적으로 의미가 있는 일치도를 보임을 확인하였다. Oscillometry 혈압계에서 확인한 평균 및 이완기혈압은 cuff 위치에 상관없이 직접동맥혈압과 임상적으로 유의미한 일치도를 보임을 확인하였다.

제3장에서는 전신마취를 진행했던 45마리의 환견의 혀에서 oscillometry 혈압계를 통한 혈압 측정방식의 임상 적용을 평가하였다. Oscillometry 혈압 측정방식은 5 kg 미만에서 정확도가 떨어진다고 알려져 있으며, 따라서 45마리의 환견을 5 kg 기준으로 두 그룹으로 나누어 비교를 진행하였다. 두 그룹 모두에서 평균혈압과 이완기혈압은 직접동맥혈압과 임상적 일치도를 보였으며, 그 정확도가 5 kg 이상인 그룹에서 더 높음을 확인하였다. 수축기혈압은 두 그룹 모두에서 임상적으로 일치

하지 않음을 확인하였다.

본 연구들의 결과를 통하여, 마취된 개의 혀에서 평균과 이완기 간접동맥혈압을 측정하는 것은 다른 간접동맥혈압 측정 부위를 대신할 수 있는 임상적으로 타당한 혈압 측정 부위임을 확인할 수 있었다. 마취된 개의 얼굴 부위는 마취창을 통해 마취과 수의사가 접근하기 쉬운 신체 부위에 해당하기 때문에 cuff를 재 장착하는 상황에서 혀에서의 혈압 측정을 고려해 볼 수 있을 것으로 판단된다. 수축기혈압의 경우 cuff 장착 위치에 상관없이 직접동맥혈압과 일치도가 떨어지기 때문에 임상적으로 주의 깊은 해석이 필요하며, 5 kg 이하일 경우 평균혈압과 이완기혈압의 일치도도 낮아질 수 있음을 고려해야 한다. 또한, 저혈압일 때 혀의 일치도가 뒷발이나 꼬리에 비해 높기 때문에 저혈압이 의심되는 상황에서 이에 대한 확인 목적으로도 적용이 가능할 것으로 사료된다.

주요어: Oscillometry 혈압 측정 방식, Doppler 혈압 측정 방식, 혀, 전신 마취, 개
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