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Comparison of Doppler ultrasonic sphygmomanometry, oscillometry and high-definition oscillometry for non-invasive blood pressure measurement in conscious cats

Marieke Knies[1,2], Erik Teske[2] and Hans Kooistra[2]

Abstract

Objectives Systemic arterial hypertension is a common occurrence and can have serious adverse consequences in cats. Therefore, measuring blood pressure is very important. There are many indirect blood pressure measurement devices available. This study compared Doppler, oscillometric (petMAP Graphic II, SunTech Vet20, the Cardell Insight-X0000) and high-definition oscillometry devices for the non-invasive measurement of blood pressure in conscious cats.

Methods In this prospective study, blood pressure was measured in 32 cats using the different devices according to the recommendations of the American College of Veterinary Internal Medicine Consensus Statement. Blood pressures (systolic blood pressure [SBP], diastolic blood pressure [DBP], mean arterial pressure [MAP]), time to complete measurements, number of attempts needed, coefficient of variation (CV) between the blood pressure measurements of the different devices, ease of completing measurements and apparent stress level of the cat were assessed.

Results There was a significant difference between devices in the time taken to obtain blood pressure readings and the number of attempts necessary to obtain six reliable measurements. The CV of the Doppler device was significantly smaller than that of the rest of the devices, but there were no other differences between the devices. The mean SBP, DBP and MAP measured by the petMAP device were significantly higher than the measurements from the other devices. The perceived ease of measurement was not significantly different between the various machines. The perceived level of stress of measurement with the Doppler device was significantly higher compared with the other devices but did not lead to an increased SBP.

Conclusions and relevance Using a Doppler device to measure blood pressure in conscious cats is fast, relatively easy and gives reliable results. A disadvantage is that the Doppler device can only measure SBP, while oscillometric devices also provide DBP and MAP. However, in veterinary medicine, systolic hypertension is considered the most relevant.

Keywords: Hypertension; indirect; systolic; non-invasive blood pressure; NIBP

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Introduction

Feline systemic hypertension is a common occurrence in senior cats.[1] One study[2] described a prevalence of persistent systolic blood pressure (SBP) >160 mmHg (measured on at least two occasions) of 14.6% in a population of apparently healthy cats aged over 10 years. Systemic hypertension is defined as a persistent elevation from normal arterial blood pressure.[1,2] Several studies have reported different values for SBP in healthy cats, but in

[1]AniCura Veterinary Referral Centre Haaglanden, Dordrecht, The Netherlands
[2]Department of Clinical Sciences, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands

Corresponding author:
Marieke Knies DVM, MANZCVS (Feline), EMSAVM (Internal Medicine), AniCura Veterinary Referral Centre Haaglanden, Frijdastraat 20a, 2288 EZ Rijswijk, The Netherlands
Email: marieke.knies@anicura.nl

general, this is thought to be approximately 125 mmHg in young cats, with a slight age-related increase.[1,3] The clinical assessment of SBP is affected by several external factors, such as the skill of the operator, anxiety level of the cat, environment, equipment, position of the cat, size of the cuff and site of measurement, making a standardised and cat-friendly technique of utmost importance.[1,3–13]

Hypertension can be classified as primary or idiopathic hypertension and secondary hypertension. Primary hypertension is diagnosed in 13–20% of hypertensive cats.[1,3,14] Most hypertensive cats have secondary hypertension, meaning an underlying disease is contributing to the hypertension. The most associated disease is chronic kidney disease (CKD), as 19–65% of cats with CKD have been found to be hypertensive and azotaemia has been diagnosed in up to 74% of hypertensive cats. Secondary hypertension has also been reported with hyperthyroidism, primary hyperaldosteronism and pheochromocytoma.[1,3,14–17] Hypertension can have several adverse clinical consequences, caused by target organ damage (TOD), affecting organs such as the eyes, kidneys, brain and heart.[1–4,18–20]

Because of the prevalence of systemic hypertension and the possible adverse consequences, the measurement of blood pressure is a vital part of the monitoring of senior cats in general, cats with diseases that are known to be associated with secondary hypertension, cats with signs of TOD and cats treated with medication with a known effect on SBP.[3,4]

The most frequently used methods for SBP measurements in cats are indirect techniques to collect non-invasive blood pressure (NIBP) measurements, because the direct assessment of SBP via arterial cannulation or radiotelemetric implants is impractical for clinical use in client-owned cats, even though it is considered the gold standard.[3,21–23] Therefore, in clinical practice, indirect non-invasive techniques, such as Doppler ultrasonic sphygmomanometry, oscillometry and high-definition oscillometry (HDO), are used.[13,24–26]

Doppler sphygmomanometry detects blood flow utilising the Doppler effect on moving erythrocytes and has been used extensively in cats.[6,7,9,12,13,27] Most often, only SBP is measured. The correlation of Doppler and direct measurements is generally high, although SBP is consistently underestimated. According to Gouni et al,[12] diastolic blood pressure (DBP) can also be measured using the Doppler method, but these measurements are more difficult to obtain and lack acceptable accuracy and repeatability.[1,12] The Doppler technique is inexpensive and easy to use in most cats. In uncooperative cats, it can be difficult to realise a successful blood pressure measurement.[25,27]

Oscillometric devices detect the oscillation in the artery and use algorithmic calculations to generate automated measurements of SBP, DBP and mean arterial pressure (MAP). Each device uses a particular algorithm created by its manufacturer and there are currently several oscillometric blood pressure monitors on the veterinary market.[22,27–32] Oscillometric monitors are simple and easy to use.[22,25,27] However, it has been suggested that traditional oscillometry is less accurate than Doppler in conscious cats, often underestimating SBP at higher values.[1,10,33]

A relatively new method of indirect SBP measurement is HDO. The HDO device for cats (S + B medVet) measures blood pressure via analysis of the waveforms of recorded pressure oscillations, directly determining SBP, DBP and MAP values. Therefore, in theory, this device should be more accurate than traditional oscillometry devices, which use algorithms to compute blood pressure values.[22,25,34]

None of the currently available devices have met the human standard nor the American College of Veterinary Internal Medicine (ACVIM) criteria for the validation of indirect SBP measurements. Nonetheless, this does not mean that the available devices cannot be used in feline medicine.[3,8,35]

The objectives of the present study were to investigate the reliability of measuring SBP using a Doppler machine, different oscillometric devices and the HDO machine in conscious, client-owned cats. In addition, agreement between machines was investigated for measuring SBP, DBP and MAP, and the ease of use of the different devices was evaluated.

Material and methods

Animals

The study was conducted in the AniCura Veterinary Referral Centre Haaglanden in The Netherlands. Hospitalised cats, healthy cats belonging to staff members and cats coming in for a routine health check were recruited for this study. The owners provided informed consent before the cats participated in the study. Data collected included date of birth (if known), sex, neuter status and breed. Cats were excluded if an SBP measurement proved impossible due to the temperament of the cat or if the cats were on medications that could influence SBP during the period of measurement.

Blood pressure measurement (general)

The devices studied were an HDO device (S + B medVet), a Doppler unit (Eickemeyer Ultrasonic Doppler; Eickemeyer Veterinary Equipment) and three oscillometric devices: the SunTech Vet20 (SunTech Medical); the Cardell Insight-X0000 (Midmark Corporation); and the petMAP Graphic II model 7300 (Ramsey Medical). All devices were used according to the manufacturers' guidelines.

Blood pressure measurements were performed using a standardised protocol following the guidelines in the ACVIM consensus statement on feline hypertension.[3] All

Table 1 Assessment of cat demeanour during blood pressure measurement

Score	Subjective assessment of stress	Description
1	No stress	Relaxed during the procedure, looking around, body position relaxed, ears forward, slow eye blinks, encourages head rubs, purring and/or kneading
2	Cooperative but slightly anxious	Generally calm and still looking around, but some signs of nervousness (such as crouched position, tail tucked between legs)
3	Moderately nervous	More signs of nervousness, sometimes trying to pull paw back or trying to hide (under blanket or into owner). Position tense/crouched. Head rubs not appreciated but avoided
4	Very nervous	Trying to hide (under blanket or into owner), crouched position, shivering, avoiding eye contact, ears sideways and downwards, tail between legs or swishing
5	Aggressive	Hissing, growling, trying to bite and/or swipe with claws

Modified from Payne et al (2017)[13]

procedures were performed by one of two people, either the first author (MK) or a well-trained veterinary nurse. The person performing the SBP measurement could switch between machines for the same cat. The measurements were made in a designated cat ward or designated cat consultation room. No randomisation of machines was performed. Cats were allowed a minimum of 30 mins between the end of one series of measurements and the start of the next acclimation period. Between measurements, the cats stayed in the designated cat ward. Blood pressure cuff size was chosen in such a way that the cuff width was 30–40% of the circumference of the limb or tail at the cuff location. For the HDO device, the designated 'cat' cuff that came with the device was chosen. For the Doppler and oscillometric devices, either a MediTech NIBP or a Hokansson cuff was used, depending on the size of the limb or tail. The default limb used for the Doppler method was the right forelimb. The left forelimb was used if the right forelimb was inaccessible because of the presence of an intravenous catheter. The tail was used for all oscillometric devices and the HDO device. Cats were allowed to choose a position that was comfortable for them.

At least six valid measurements were performed. Only appropriate measurements were recorded; faulty measurements and measurements that were rejected by the oscillometric device were not. The first measurement was discarded, and the subsequent five measurements were averaged.

The blood pressure measurement device used, the cuff size, cuff site, position of the cat and the number of attempts it took to obtain six blood pressure measurements were recorded. The assessment of the cat's demeanour (Table 1) was registered by the person obtaining the blood pressure measurements and was reassessed before each session. The time it took to perform the complete measurement, starting with measuring the circumference of the limb or tail and ending with the final measurement was noted. Finally, the perceived ease of measuring the blood pressure (a scale of 1–4, with 1 being very easy and 4 being very hard) was assessed by the person who performed the measurements. No sedation was used in any cat.

Doppler measurement

The hair over the first palmar common digital artery was moistened with a cotton pad dampened with water followed by the application of ultrasound gel. In order to reduce stress, clipping of the hair was not performed in any cat. The probe was placed over the region of the artery. The machine was then turned on, the area of the strongest signal was located, and the cuff was manually inflated until the pulse signal could not be heard anymore, then gradually deflated. The moment the pulse signal was heard again represented the SBP.

HDO measurement

SBP, DBP and MAP were measured by placing the HDO detector with a fixed size cuff (C1 cuff for cats) 1 cm distal to the base of the tail. The HDO device was always connected to a desktop computer to be able to visualise that the pulse waves were smooth with an outline approximating a bell-shaped curve.

Oscillometric measurement (Cardell, SunTech, petMAP)

Occlusion of the coccygeal artery was achieved by placing the cuff 1 cm distal to the base of the tail. The tail was chosen as the measurement site based on the results of the study by Haberman et al,[9] showing strongest correlation with directly measured blood pressure when the cuff of the oscillometric device was placed on the tail. The cat was held as still as possible.

Statistical analysis

Statistical analysis was performed using commercially available software (SPSS Statistics Data Editor version 26; IBM). The normality of continuous data was assessed

Table 2 Time and number of attempts necessary to obtain six blood pressure measurements (the first one was discarded)

Device	Time taken for measurements (s)	Number of attempts
Doppler	244 (92–900)	6 (6–8)
SunTech	357 (211–834)	6 (6–8)
PetMAP	237 (116–612)	6 (6–11)
Cardell	540 (300–1845)	7 (6–17)
HDO	347 (222–1234)	7.5 (6–15)

Data are median (range)
HDO = high-definition oscillometry

using the Shapiro–Wilk test and Q-Q plots. Univariable analysis was performed using the Mann–Whitney U-test or Kruskal–Wallis test, as appropriate, to compare continuous non-normally distributed data. Correlations were determined using Spearman's rank correlation coefficients. To compare blood pressure values between different machines, coefficients of variation (CVs) were calculated. Differences between ease of measurement and demeanour during measurements were assessed using the Friedman test followed by the Wilcoxon signed-rank test as a post-hoc test if significant differences were found. A comparison of the first and last blood pressure measurements was carried out using a paired *t*-test. The influence of order of device on mean blood pressure measurements was assessed with an ANOVA test. The significance level was set at $P<0.05$.

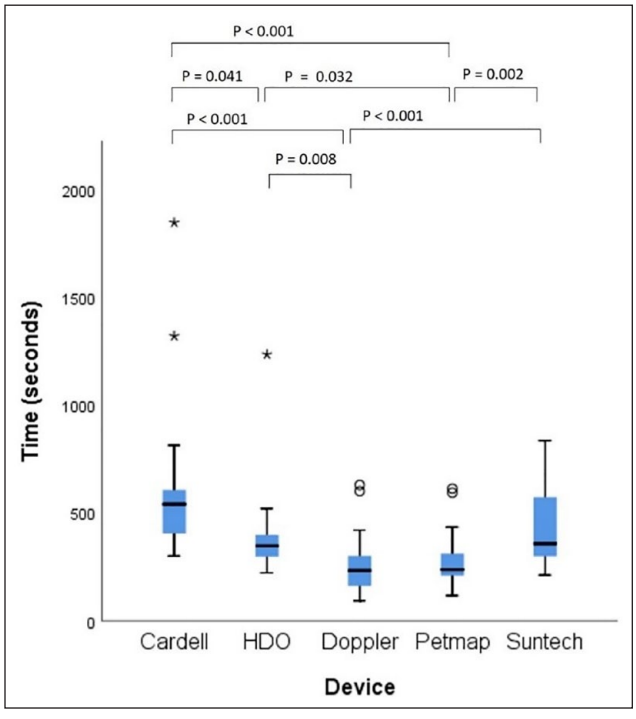

Figure 1 Box and whisker plot for the duration of measurement grouped by the different blood pressure measurement devices. Box representing median and interquartile range (IQR), whiskers using the Tukey method (values up to 75th percentile + 1.5 IQR) and dots and asterisks representing outliers (values greater than 75th percentile + 1.5 IQR). HDO = high-definition oscillometry

Results

Study population

Between March 2021 and August 2021, 32 cats were included in the study. The population consisted of 21 neutered males and 11 neutered females. Most (n = 23) were domestic shorthairs; there were also two British Shorthairs, two Ragdolls and one Bengal, Devon Rex, Maine Coon, Russian Blue and Sphynx. The median age was 10 years and 11 months (range 11 months–16 years and 8 months). The mean body weight was 4.5 ± 1.1 kg. The blood pressure measurement with the Cardell device could only be performed in 19/32 cats, because the device was regularly in use in the Emergency and Critical Care Unit for critical patients and therefore not available.

Time to obtain measurements

A Kruskal–Wallis test showed a significant difference ($P<0.001$) in time taken to obtain blood pressure measurements using the different devices. A post-hoc comparison using Dunn's pairwise tests, with Bonferroni correction, showed significant differences between the following devices: Doppler and the HDO ($P = 0.008$), Doppler and the SunTech ($P<0.001$), Doppler and the Cardell ($P<0.001$), petMAP and the HDO ($P = 0.032$), petMAP and the SunTech ($P = 0.002$), petMAP and the Cardell ($P<0.001$), and the HDO and the Cardell ($P = 0.041$). There was no statistically significant difference between the duration of measurement using the Doppler and the petMAP, the SunTech and the Cardell, and the Suntech and the HDO devices (Table 2, Figure 1).

To find out whether experience with the Doppler device made a difference to the time it took to get a blood pressure measurement, times were compared between the trained nurse and the first author (MK), who has a lot of experience with the use of the Doppler device. The median time taken by the nurse to obtain blood pressure measurements was 300 s (n = 10, range 104–900), and for MK it was 241 s (n = 22, range 92–629). However, this difference was not significant ($P = 0.19$).

Number of attempts

There was a significant difference in the number of attempts needed to collect six adequate readings between the Doppler and the Cardell ($P = 0.003$), Doppler and the HDO ($P<0.001$), SunTech and the HDO ($P<0.001$), and the petMAP and the HDO ($P<0.025$) devices (Table 2, Figure 2).

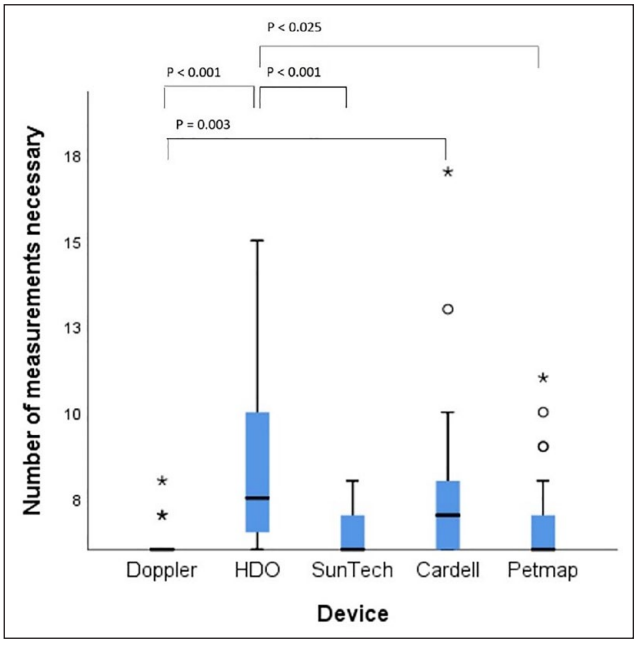

Figure 2 Box and whisker plot for the number of attempts necessary grouped by the different blood pressure measurement devices. Box representing median and interquartile range (IQR), whiskers using the Tukey method (values up to 75th percentile + 1.5 IQR), and asterisks and dots representing outliers (values greater than 75th percentile + 1.5 IQR). HDO = high-definition oscillometry

Comparison of blood pressure measurement values

To compare the blood pressure measurement values obtained by the different devices, the CV of the SBP was calculated for the different devices. CV was calculated for all devices in all 32 cats, except for the Cardell device, which was used in only 19 cats (Table 3). In all 32 cats, not including the Cardell device, the CV of the Doppler was significantly smaller than that of the rest of the devices. When the Cardell device was included in the comparison (19 cats), the Doppler device also had a significantly lower CV than the other devices, except for the SunTech device. There were no significant differences between the other devices.

Table 3 CV of the SBP and *P* value of the difference between the Doppler and other devices

Device	All 32 cats, Cardell not included		19/32 cats, Cardell included	
	CV SBP (%)	*P* value	CV SBP (%)	*P* value
Doppler	2.9	–	3.4	–
SunTech	13.7	<0.001	11.6	0.064
PetMAP	11.9	<0.001	10.4	0.049
Cardell	–	–	15.7	<0.001
HDO	11.5	<0.001	11.8	0.005

CV = coefficient of variation; HDO = high-definition oscillometry; SBP = systolic blood pressure

The mean blood pressure values in all cats, measured with the different blood pressure devices, were compared. With the Doppler device, only SBP can be reliably measured, so there were no values for DBP and MAP. Once again, there were two groups: one group consisting of all cats and one group consisting of cats in which measurements with the Cardell device were performed as well (Table 4). In both groups, the mean SBP measured by the petMAP device was significantly higher than that measured by the other devices ($P<0.001$). Furthermore, in the group with all the cats, the mean SBP measured by the HDO device was significantly higher than that measured by the SunTech ($P=0.021$) and Doppler ($P<0.001$) devices.

In the group of 19 cats in which the Cardell device was used, the mean DBP and MAP measured by the petMAP device were significantly higher than when measured by the SunTech, Cardell and HDO devices ($P<0.001$). Similarly, in the group with all the cats, the mean DBP and MAP measured by the petMAP device were significantly higher than the measurements from the SunTech and HDO devices ($P<0.001$).

Influence of order of devices and effect of multiple testing

The analysis showed that the order in which the devices were used did not have any significant effect on the mean

Table 4 Comparison of mean blood pressure values measured by the different machines

Device	All 32 cats, Cardell not included			19/32 cats, Cardell included		
	SBP (mmHg)	DBP (mmHg)	MAP (mmHg)	SBP (mmHg)	DBP (mmHg)	MAP (mmHg)
Doppler	133.6 ± 24.8	–	–	129.8 ± 26.0	–	–
SunTech	132.4 ± 26.9	86 ± 4.8	97.8 ± 15.7	131.1 ± 25.7	85.3 ± 15.7	96.0 ± 16.4
PetMAP	192.3 ± 31.3	115.2 ± 21.3	134.5 ± 21.7	183.1 ± 28.0	109.2 ± 18.0	137.2 ± 21.7
Cardell	–	–	–	139.0 ± 21.5	92.7 ± 21.5	110.0 ± 19.6
HDO	150.8 ± 23.8	84.4 ± 13.3	107.7 ± 15.8	144.8 ± 20.1	81.0 ± 12.7	103.4 ± 13.9

Data are mean ± SD
DBP = diastolic blood pressure; HDO = high-definition oscillometry; MAP = mean arterial pressure; SBP = systolic blood pressure

Table 5 Comparison of perceived stress (in 16/32 cats) between the blood pressure measurements with different devices

Device	Perceived stress	*P* value
Doppler	2.9 ± 1.4	–
SunTech	2.1 ± 0.9	0.005*
PetMAP	2.14 ± 1.0	0.015*
Cardell	2.06 ± 0.9	0.006*
HDO	1.94 ± 0.9	0.001*

Data are mean ± SD
*Significantly different from Doppler
HDO = high-definition oscillometry

SBP, DBP or MAP, except for the mean SBP measured by the SunTech device. When this device was used as the first device, it gave a significantly higher mean SBP ($P = 0.002$). This effect was not present for DBP or MAP.

In order to analyse the effect of multiple testing with one device on blood pressure measurements, the first and last of the six valid measurements were compared. After Bonferroni correction for multiple testing, there was no significant difference for any of the devices for any of the blood pressure measurements.

Perceived ease and stress of measurement

Perceived ease of measurement was noted for all devices in 15/32 cats; there was no significant difference ($P = 0.18$) between the various machines. Perceived stress of measurement according to the modified scheme by Payne et al[13] (Table 1) was noted for all devices in 16/32 cats. In these cats, measurement with the Doppler was assessed to be significantly more stressful compared with the other devices. There were no significant differences between the other devices (Table 5).

Discussion

The measurement of blood pressure in cats is a valuable clinical tool because hypertension is a common disease, with serious possible consequences if not treated in time. However, blood pressure measurement is not a routine procedure in many veterinary clinics. Current guidelines advocate annual screening of healthy senior cats (aged >7–9 years) for hypertension.[1,3] However, the results of three surveys show that only 4.4–27% of veterinarians routinely measure blood pressure in these cats.[24,26,36] In an online survey of owners of 1089 cats with CKD, owners reported only 3% of cats to be hypertensive.[37] However, in reality, the prevalence of concurrent hypertension in cats with CKD is in the range of 20–65%.[1,14–17,37,38] This means that the cohort of cats in the online survey was either very unusual or, more likely, hypertension was underdiagnosed in these cats with CKD. The most common reason for blood pressure measurement in a study carried out by Conroy et al[36] was presentation with clinical signs (63.1%), followed by monitoring of concurrent disease (31.2%). According to a survey of more than 750 veterinarians carried out by Navarro et al,[24] many veterinarians (92%) recommended blood pressure measurement in cats with a disease that predisposes them to hypertension, while 86.6% recommended it in cats with signs of TOD. Waiting for owners to present their cat with clinical signs before measuring blood pressure does not only lead to underdiagnosis of hypertension, but it also means we are still missing many cats in which early intervention could improve their quality of life.

Possible barriers to measuring blood pressure more frequently are difficulties performing measurements (including the temper of the cat), technical staff being uncomfortable performing measurements, difficulty interpreting readings due to situational hypertension, the procedure being too time-consuming or cost to the owner.[24,26] Furthermore, there are many different blood pressure measurement devices currently available and it can be difficult to make a decision on which one is the best to use. The ACVIM guidelines state that blood pressure should ideally be measured with devices that have been validated for cats. However, so far, no device has met the validation criteria used in human medicine in conscious cats. This means that the currently available devices should be used with a degree of caution.[3]

The aim of the present study was to compare the use of different indirect blood pressure measurement devices in conscious cats, to possibly make it easier for veterinary staff to decide what blood pressure device to use. The study evaluated different variables, such as the time it took to obtain a blood pressure measurement, the number of attempts necessary to get six valid measurements, precision of the devices, the perceived ease of measurement for the operator and the perceived stress of measurement for the cat.

In a survey of Canadian veterinarians, one of the most frequently selected barriers was the time involved in obtaining blood pressure measurements (64%).[26] The study by Navarro et al[24] showed similar results; when asked why blood pressure measurements were not routinely performed, 7/30 (23%) veterinarians answered that measuring blood pressure was too time-consuming. However, the present study shows that the Doppler and the petMAP devices took only about 4 mins to obtain a blood pressure measurement. Using the other devices, it took a bit longer to acquire a measurement, with the Cardell device being the most time-consuming (9 mins). The first author (MK) is very experienced at measuring blood pressure in cats using the Doppler device. This might have influenced the time it took to obtain a blood pressure measurement. However, the nurse was not very experienced with the use of the Doppler device at the

beginning of the study. Nevertheless, there was no significant difference in the time taken to get a measurement between these two people.

In the survey carried out by Navarro et al,[24] more veterinarians had an oscillometric device (89%) than a Doppler device (75%). Most of the veterinarians with an oscillometric device had traditional oscillometric devices (60%) instead of HDO devices (8%). Of the respondents with more than one device (62%), the Doppler was the most preferred (69%), followed by oscillometry (24%); 7% reported no preference.[24] In the survey by Prost,[26] 51% of respondents used an oscillometric device to obtain a routine blood pressure measurement, whereas 40% used a Doppler device. One reason mentioned in the survey by Navarro et al[24] for preferring oscillometric devices over the Doppler device was the ease of use of the former. In our study, there was no significant difference found between the various machines in their ease of use. Of course, this is a subjective finding that can vary from person to person. The respondents felt that another reason to use an oscillometric device was that it was less stressful for the cat.[24] In our study, there was a significant difference in the assessed demeanour of the cat between the Doppler and the other devices, with the cat judged to be more nervous with the use of the Doppler device. However, one of the criteria used to assess a cat's demeanour leading to a stress score of 3 was that the cat was 'trying to pull its leg back'. Given that only the Doppler cuff was placed around the leg, it was not possible for cats to fulfil this criterion where oscillometric devices were used. This may have resulted in the stress score for the Doppler device being higher than for the oscillometric machine. Ideally, either the same location should have been used for cuff placement for all devices or the scoring system should have been modified to mitigate this bias. Retrospectively, it was not possible to review the number of times that a stress score of 3 was applied due to limb movement vs the other criteria in this stress score.

Reasons for aversion to oscillometric devices included worries about untrustworthy results.[24] Our study showed that all traditional oscillometric devices and the HDO device had a significantly higher CV than the Doppler device. The CV is the ratio of the standard deviation to the mean and is commonly used as an index of reliability and repeatability. The higher the ratio, the greater the level of dispersion around the mean and the poorer the reliability of the device. Our results show that the reliability of the measurements taken with these devices is lower than the reliability of those taken with the Doppler device. Among the oscillometric devices (both traditional and HDO), there was no single device that performed better with regard to reliability than the other oscillometric devices. However, when looking at the mean SBP values among all the cats, there was one device that significantly differed from the others, namely the petMAP. When compared with the Doppler device, the mean SBP given by the petMAP was approximately 60 mmHg higher. Out of the 32 cats, 24 would have been 'misclassified' as potentially hypertensive on the basis of the mean SBP from the petMAP device while having a mean SBP <160 mmHg when measured with the Doppler device. When the petMAP was compared with the other oscillometric devices, the mean DBP and MAP were also higher. This might indicate the petMAP device tends to overestimate the cat's SBP. However, this was not a consistent finding because, in some cats, the measured SBP was lower than the blood pressure measured with the Doppler device.

A study by Haberman et al[9] concluded that the Doppler device was well correlated with direct BP measurements in conscious cats. Furthermore, several other studies have shown that traditional oscillometry is less accurate compared with Doppler in conscious cats.[9,10] Martel et al[22] found that SBP measured with an HDO device in conscious cats displayed good agreement with direct blood pressure measurements. However, the results were obtained in only six cats, which were all accustomed in advance to the measurement methods, which is different from the situation in clinical practice.[9,10,22,27,30,33]

An important limitation of the study was that no gold-standard direct BP measurement was taken to compare with the non-invasive methods. Therefore, only agreement among the devices and not accuracy could be established. Since all cats in the study were client-owned cats or cats belonging to the hospital staff, it was not considered ethical to perform direct intravessel blood measurements and therefore they were not performed. Furthermore, the study sample was fairly small. In addition, the Cardell device was not tested in every cat. The reason for this was that the Cardell device is used for continuous blood pressure monitoring in animals in the hospital's intensive care unit. Therefore, if the machine was in use, it could not be used in the study. Each cat in the study had to have >20 or >25 (if the Cardell device was also used) individual blood pressure assessments divided over several hours. This means that stress could have affected the measurements. However, the order in which the devices were used did not make any significant impact on the mean SBP, DBP or MAP in almost all devices. Not all measurements were performed in the same location. In some cases, the measurements were performed in the cat ward, while in other cats, measurements were collected in the feline consultation room. As the machines also rotated through these different locations, we do not think this was a major bias. Finally, while the measurements with the Doppler device were done in the forelimb, the measurements with the oscillometric devices and the HDO device were carried out at the tail. This choice was made because these are the recommended and most commonly used sites for the different devices. This might have influenced the results, although the literature is conflicting on this topic. Several studies have found a higher indirect SBP when

measuring at the level of the coccygeal artery compared with the radial artery, with both a Doppler device and an oscillometric device.[6,11,39] Another study, however, did not find a significant difference in SBP between the radial artery and the coccygeal artery using an oscillometric device.[40] The precision using the Doppler device seems to be lower at the level of the coccygeal artery.[1,4,6,9,11,20,35,39,40]

Conclusions

The results of our study show that using a Doppler device to measure blood pressure in conscious cats is fast, relatively easy and gives reliable results. The only drawback of the Doppler device was the assessment of a higher stress level during measurements compared with the other methods. This might have been caused because the cats had their front leg handled instead of their tail, as was done with the oscillometric methods. With the Doppler device, the average demeanour score for the cat was 2.9, which is approximately 'moderately nervous'. We feel that this small drawback does not outweigh the benefits of the Doppler device over the other devices. However, it does emphasise the need for continuing focus on cat-friendly handling during blood pressure measurement. Another point of attention is that the Doppler device can measure only SBP, while in the oscillometric devices, DBP and MAP are also provided. However, in veterinary medicine, systolic hypertension is considered most relevant. This contrasts with human medicine, where systemic hypertension is divided into isolated or combined systolic and diastolic hypertension. Furthermore, although the HDO device will also generate figures for DBP and MAP, it has been shown that in conscious cats, it is only the SBP value that has acceptable accuracy.[1,2]

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Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical approval The work described in this manuscript involved the use of non-experimental (owned or unowned) animals. Established internationally recognised high standards ('best practice') of veterinary clinical care for the individual patient were always followed and/or this work involved the use of cadavers. Ethical approval from a committee was therefore not specifically required for publication in *JFMS*. Although not required, where ethical approval was still obtained, it is stated in the manuscript.

Informed consent Informed consent (verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (experimental or non-experimental animals, including cadavers) for all procedure(s) undertaken (prospective or retrospective studies). For any animals or people individually identifiable within this publication, informed consent (verbal or written) for their use in the publication was obtained from the people involved.

ORCID iD Marieke Knies https://orcid.org/0000-0002-4586-7025

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