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# Comparison of high definition oscillometric and Doppler ultrasonic devices for measuring blood pressure in anaesthetised cats

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Indirect blood pressure measurements using high definition oscillometric (HDO) and Doppler devices were compared in 50 anaesthetised client-owned cats presented for various surgical procedures. Sites of cuff placement for Doppler were identified as forelimb and hindlimb and for HDO as forelimb and tail. Oscillometric and Doppler readings were obtained in 90.05% and 100% of attempts, respectively. Both devices enabled precise measurement of systolic arterial pressure (SAP), although the Doppler device gave higher precision. In the low pressure group (SAP < 100 mmHg; $n = 30$), 66.7% biases were within 10 mmHg of discrepancy, but in groups of normal (100 mmHg ≤ SAP ≤ 150 mmHg; $n = 120$) and high measurements (SAP > 150 mmHg; $n = 62$), 86.7% and 75.0% of discrepancy, respectively, were lower than 10 mmHg. Frequency of discrepancy at the range of 15 mmHg showed similar differences between pressure groups. There were significantly higher discrepancies when the cuff was positioned on the tail rather than on the leg. The SAP value obtained by HDO can be calculated from the Doppler measurement from SAP (HDO) = 0.8515 × SAP (Doppler) + 19.221 mmHg. Compared to Doppler, HDO overestimated low pressure and underestimated high pressure values.

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Blood pressure is a valuable indicator of an animal's organ and tissue perfusion. Its measurement has become a standard procedure during anaesthesia and its use is increasing in different branches of veterinary medicine.

The Doppler device is used to assess blood pressure in dogs and cats but has several limitations: only systolic blood pressure can be measured accurately, it is cumbersome and time consuming to use, particularly in conscious animals. New oscillometric devices have been developed to overcome these limitations but their accuracy, especially in small dogs and cats, has been debated.[1,2] Several studies have been published comparing direct arterial blood pressure measurements with Doppler devices and/or various oscillometric devices in canine patients.[3–8] On the other hand, studies on the efficacy and accuracy of oscillometric devices in feline patients are sparse, both those comparing oscillometric and direct arterial blood pressure measurements[1,9–11] and those comparing oscillometric and Doppler devices.[2,12]

A new, high definition oscillometric (HDO) device for blood pressure measurement in dogs and cats has been marketed. According to the manufacturer (S+B MedVet GmbH, Babenhausen, Germany) some of the characteristics of oscillometric devices have been improved in HDO, such as the sensitivity at low amplitudes, better recognition and fewer artefacts at higher heart rates, the possibility of measuring very low pressures, better precision due to an electronic valve and the capability for real-time analysis.[13]

This study aims to evaluate and compare arterial blood pressure estimations obtained by HDO and Doppler devices in anaesthetised cats. The influence of body position and cuff position was also examined.

## Materials and methods

Fifty client-owned cats, 22 females and 28 males, aged between 3 months and 15.5 years, weighing between 1.62 and 8.2 kg (4.0 ± 1.64), presented for different

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surgical procedures and dentistry, were anaesthetised with two commonly used anaesthetic protocols and chosen according to the physical status of the cat. All procedures complied with the relevant governmental regulations (Animal Protection Act UL RS, 43/2007) and formal consent of the owner was obtained before the cats entered the study.

Cats ($n = 34$), classified as ASA 1 according to American Society of Anaesthesiologists, were anaesthetised with medetomidine (Domitor; Pfizer) 0.08 mg/kg and ketamine (Ketanest 10%; Parke-Davis) 6 mg/kg administered intramuscularly. The effects of medetomidine were reversed 90 min later with atipamezole (Antisedan; Pfizer) 0.2 mg/kg. Cats ($n = 16$), classified as ASA 2, were premedicated with medetomidine 0.02 mg/kg and ketamine 3 mg/kg, induced with propofol (Propoven; Fresenius Kabi) 0.5−2 mg/kg intravenously, and maintained with isoflurane (Forane; Abbott) in oxygen and air ($FiO_2 = 0.6$). Fentanyl (Fentanyl-Janssen; Janssen-Cilag) 0.5−1 μg/kg and/or ketamine 0.5 mg/kg were administered intravenously according to the needs of the surgical procedure. Cats were given methadone (Heptanon; Pliva) 0.1−0.2 mg/kg subcutaneously and atipamezole 0.1 mg/kg intramuscularly at the end of surgery. During surgery, cats were given lactated Ringer's solution (B Braun; Melsungen) 10 ml/kg/h intravenously. All cats received carprofen (Rimadyl; Pfizer) 4 mg/kg intravenously or subcutaneously during or at the end of the surgery.

Indirect blood pressure measurements were recorded using both an HDO device (Memo Diagnostic HDO Pro, S+B MedVet GmbH, Babenhausen, Germany) and an ultrasonic Doppler device (model 811, Parks Medical Electronics, Beaverton, Oregon, USA). Blood pressure was always measured by the same operator (SJ), from the time of loss of consciousness until the administration of atipamezole at intervals of 5 min in triplicate, by both methods, first with a Doppler device and then with the HDO method. The third Doppler measurement coincided with the first HDO measurement. The appropriate sized cuff (Hewlett Packard M1868, No 2, cuff width 3.18 cm, cuff limb circumference 4.3−8 cm) for the Doppler device was selected based on the guidelines that the cuff width should equal 30−40% of the limb circumference. For the HDO method, the cuff was selected according to the manufacturer's instructions, ie, cuff size c1 was chosen for all cats. The sites of Doppler cuff placement were randomly identified as forelimb and hindlimb and for HDO as forelimb and tail, considering the requirements of the surgical procedure. Hair was not clipped over the measurement site. Cats were positioned in right lateral, left lateral or dorsal recumbence, depending on the requirements of the surgical procedure.

### Statistical evaluation

Precision evaluation of systolic arterial pressure (SAP) measured by the Doppler device and systolic, diastolic (DAP) and mean (MAP) arterial pressures obtained by HDO was determined by three repeated readings of each measurement. When two readings were obtained, duplicate readings were averaged and used as successful measurement. Coefficients of variation (CV ± SD) were calculated for each method using measurements obtained on the basis of three repeated readings. The CV between pressure groups and between paired measurements using different devices was performed on the basis of Kruskal Wallis one-way analysis of variances on ranks.

SAP measurements were organised into three groups according to the SAP obtained by the Doppler device: low pressure group: SAP < 100 mmHg; normal pressure group: 100 mmHg ≤ SAP ≤ 150 mmHg and high pressure group: SAP > 150 mmHg. Differences between paired readings of SAP obtained once by HDO and once by the Doppler device were calculated for each paired reading. The $\chi^2$ test was used for evaluating the influence of cuff position and animal position to the bias between the Doppler and HDO readings. A strong significant difference was considered at $P < 0.001$. Discrepancy ranges between the Doppler and HDO SAP were set at three levels: <10, <15 and <20 mmHg.[8]

The agreement of the SAP obtained by HDO and Doppler was analysed according to the Bland−Altman method[14,15] where the differences in measurements (HDO − Doppler) were plotted against the mean of each pair of measurement for each pressure group. In order to assess the agreement of paired measurements, the limits of agreement were determined to estimate the range of agreement between the two techniques with a 95% confidence interval (CI). The upper and lower limits of agreement were calculated as $\bar{d} + 2s_{\mathrm{diff}}$, where $\bar{d}$ is the mean of differences for all the measurements (mean bias) and $s_{\mathrm{diff}}$ is the standard deviation of the differences.[16] A positive bias reflected an overestimation, and a negative bias an underestimation, by the HDO method. Passing−Bablok regression equations were established for all groups, as noted above (low, normal, high pressure groups), to provide a mean predicting SAP by HDO from the measurement of SAP by the Doppler device.

Results are presented as means ± SD. Values of $P \leq 0.05$ were considered significant.

Statistical analysis was performed using Excel with Analyse-it, General + Clinical Laboratory statistics, version 1.71, and Sigma Stat 3.5 (SYSTAT Software Inc).

## Results

### Successful readings

Doppler measurements were successfully obtained in 100% and HDO readings in 90.05% of attempts. A total of 1899 HDO readings was performed and 90.05% of them were successful (1710 readings). While the cat was in the lateral position 858/954 (98.94%) successful readings were achieved. Among 945 readings taken when the animal was in the dorsal position, 852 readings were successful (90.16%). When the cuff of the HDO device was positioned on the tail, 943/1065 successful readings were obtained (88.55%), whereas 91.97% (767/834) of successful readings were obtained when the cuff was positioned on the leg.

### Precision of Doppler and HDO measurements

The Doppler and HDO devices both provided precise measurements, with Doppler giving higher precision. CVs were calculated from measurements, obtained on the basis of three readings (in further evaluation, measurements with two readings are also included). Therefore, for SAPs calculation of CV only 543 measurements are included.

CV for HDO SAP, DAP and MAP were $2.77 \pm 2.96\%$ ($n = 543$), $2.77 \pm 3.46\%$ ($n = 582$) and $4.06 \pm 5.27\%$ ($n = 582$). The CV for Doppler SAP was $1.19 \pm 0.75\%$ ($n = 582$). CV for the Doppler device differed significantly between pressure groups ($P < 0.001$) as was also found between all group's pairs ($P < 0.05$). No significant difference was observed between CVs obtained with the HDO device for systolic blood pressure in all three pressure groups ($P = 0.484$) (Table 1).

### Discrepancy levels as a function of animal recumbence and cuff position

Highly significant differences were observed in all discrepancy ranges when the cuff was positioned on the tail, therefore, these measurements were excluded from further evaluation. Two hundred and fifty-nine measurements obtained with the cuff position on the leg were included in further evaluation. Comparing animal position (lateral versus dorsal), there was a highly significant difference in the pressure discrepancy of $<\pm 20$ mmHg range ($P < 0.001$) (Table 2); lower significances ($P = 0.002$ and $P = 0.07$) were found in discrepancies of $<10$ and $<15$ mmHg ranges.

**Table 1**. Precision of systolic blood pressure measurements presented by pressure group.

| Pressure group | Doppler | | HDO | |
|---|---|---|---|---|
| | $n$ | CV, mean ± SD (%) | $n$ | CV, mean ± SD (%) |
| Low | 62 | 1.44 ± 0.82 | 61 | 2.88 ± 2.67 |
| Normal | 352 | 1.21 ± 0.78 | 328 | 2.78 ± 3.13 |
| High | 168 | 1.03 ± 0.64 | 154 | 2.70 ± 2.71 |
| Total | 582 | 1.19 ± 0.75 | 543 | 2.77 ± 2.96 |

Pressure groups: low = SAP < 100 mm Hg; normal = 100 mm Hg ≤ SAP ≤ 150 mm Hg; high = SAP > 150 mm Hg. $n$ = number of measurements (average of three replicates). CV = coefficient of variance.

### Agreement between SAP (Doppler) and SAP (HDO)

Values of SAP derived from the two methods are shown as a scatter plot with fitted regression line and 95% CI interval (Fig 1). Using the regression equation, the corresponding SAP value, for HDO can be calculated from the measurement given by the Doppler device using the following formula: SAP (HDO) = $0.8515 \times$ SAP (Doppler) + 19.221 mmHg.

Constant and proportional bias was detected between the two methods. The differences between measurements were obtained with cuff placement on the leg in dorsal or lateral recumbence. Measurements of SAP obtained by the HDO and Doppler devices were plotted against the mean of the measurements (Fig 2). The average bias was −0.41 mmHg with 95% CI interval between −1.38 and 0.55 mmHg. Ninety-five percent limits of agreement were set at −15.88 mmHg for the lower limit and at 15.06 mmHg for the upper limit of agreement; the difference between the upper and lower limits of agreement was 30.94 mmHg.

A negative correlation was observed between bias and the magnitude of the Doppler measurement ($r = -0.562$; $P < 0.001$). Therefore, in the second stage of method evaluation, all measurements were divided into three subgroups according to the pressure value: low pressure group, SAP < 100 mmHg ($n = 21$); normal pressure group, 100 mmHg ≤ SAP ≤ 150 mmHg ($n = 166$); and high pressure group, SAP > 150 mmHg ($n = 72$).

Passing−Bablok comparison and Bland−Altman plots were constructed for all three subgroups. Bland−Altman plots of the difference between measurements with the HDO and Doppler devices against the mean of the measurement are shown in Fig 3, with lines at the mean bias (dotted line) and at two SD above and below the mean (dashed lines). The range between the upper and lower limits was 26.17 mmHg (from −4.53 to 21.64 mmHg) for lower SAP values, 27.20 mmHg (from −12.98 to 14.22 mmHg) for normal SAP values and 27.14 mmHg (from −19.13 to 8.01 mmHg) for high SAP values. The majority of biases were positive with a positive mean bias of 8.56 mmHg in the group of low pressure values. This reflects an overestimation by the HDO measurement (Fig 3A). In contrast, in the group of high pressure values, a negative mean bias of −5.56 mmHg was observed (Fig 3C) indicating underestimation by the HDO measurement. The scatter of the biases for the normal pressure group is random around a mean bias of 0.62 mmHg (Fig 3B).

Figure 4 shows scatter plots with fitted regression lines. The dotted lines represent the 95% CI and the thick line the fitted regression line according to Passing−Bablok method of comparison. Using the regression equations, the corresponding HDO value can be calculated from the measurement given by the Doppler using the following formulae:

Low pressure group: SAP (HDO) = $1.125 \times$ SAP (Doppler) − 3.167 mmHg

**Table 2**. Frequency (number and percentage) of different discrepancy ranges between Doppler and HDO SAP measurements according to animal and cuff position.

| Animal/cuff position | *n* (number of measurements) | Discrepancy | | |
|---|---|---|---|---|
| | | <±10 mmHg | <±15 mmHg | <±20 mmHg |
| | | *n* (%) | *n* (%) | *n* (%) |
| Recumbence | | | | |
| Dorsal | 294 | 185 (62.9%) | 227 (77.2%) | 257 (87.4%) |
| Lateral | 288 | 217 (75.3%) | 241 (83.7%) | 279 (96.9%) |
| $\chi^2$ test | $\chi^2$ | 9.5 | 3.1 | 15.2 |
| | *P* | 0.002 | 0.077 | <0.001 |
| Cuff position | | | | |
| Tail | 323 | 190 (58.8) | 232 (71.8) | 279 (86.4) |
| Leg | 259 | 212 (81.9) | 236 (91.1) | 257 (99.2) |
| $\chi^2$ test | $\chi^2$ | 33.7 | 31.5 | 28.6 |
| | *P* | <0.001 | <0.001 | <0.001 |

Normal pressure group: SAP (HDO) = 0.939 × SAP (Doppler) + 8.270 mmHg
High pressure group: SAP (HDO) = 0.939 × SAP (Doppler) + 3.854 mmHg.

### *Discrepancy levels*

The numbers and percentages of measurements organised by discrepancy levels of 10, 15 and 20 mmHg, according to pressure groups, are shown in Table 3. A smaller proportion of measurements from the low pressure group (66.7%) was within 10 mmHg of discrepancy. In the groups of normal and high measurements, 86.7 and 75.0% of discrepancy, respectively, were lower than 10 mmHg. In total, 90.7% of all discrepancies were within 15 mmHg and 98.8% within discrepancy of 20 mmHg. Higher discrepancies were found in the low pressure group.

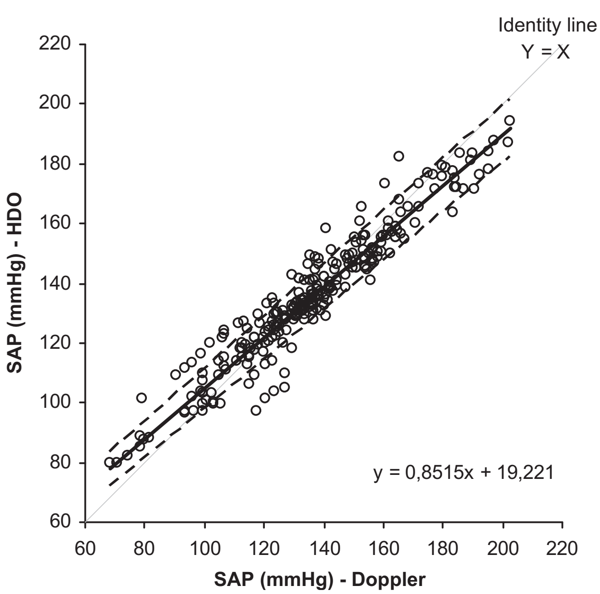


**Fig 1**. Scatter plot of SAP obtained by HDO versus Doppler for overall measurements with Passing–Bablok regression line fitted using measurements obtained with cuff position on the leg. - - - - represents the 95% CI. ——— represents fitted regression line according to Passing–Bablok method comparison.

## Discussion

Direct arterial blood pressure measurement in cats is limited mainly to experimental settings, as in most cases surgical preparation of carotid[1,9] or femoral artery[10,11] is necessary, requiring surgical skills and creating the potential for complications. Indirect blood pressure measurement is appealing because it is less invasive and can be undertaken routinely in clinical patients. Among the non-invasive techniques, the Doppler technique is most widely used in cats. Correlation of Doppler and direct measurements is

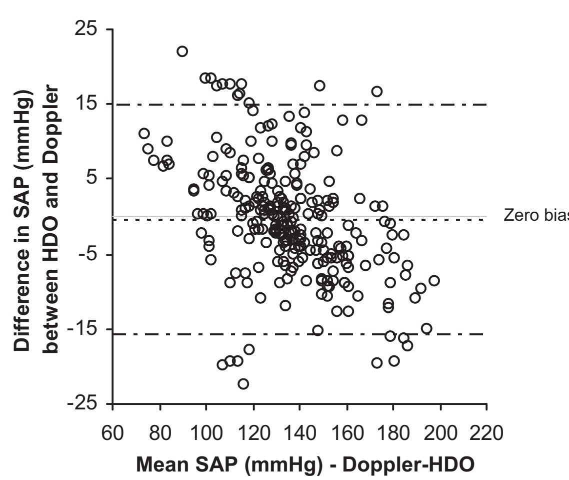


**Fig 2**. Bland–Altman plot of agreement between SAP measurement by Doppler and HDO. · - · - · - · indicates mean difference ± 2SD. ········ line indicates mean bias.

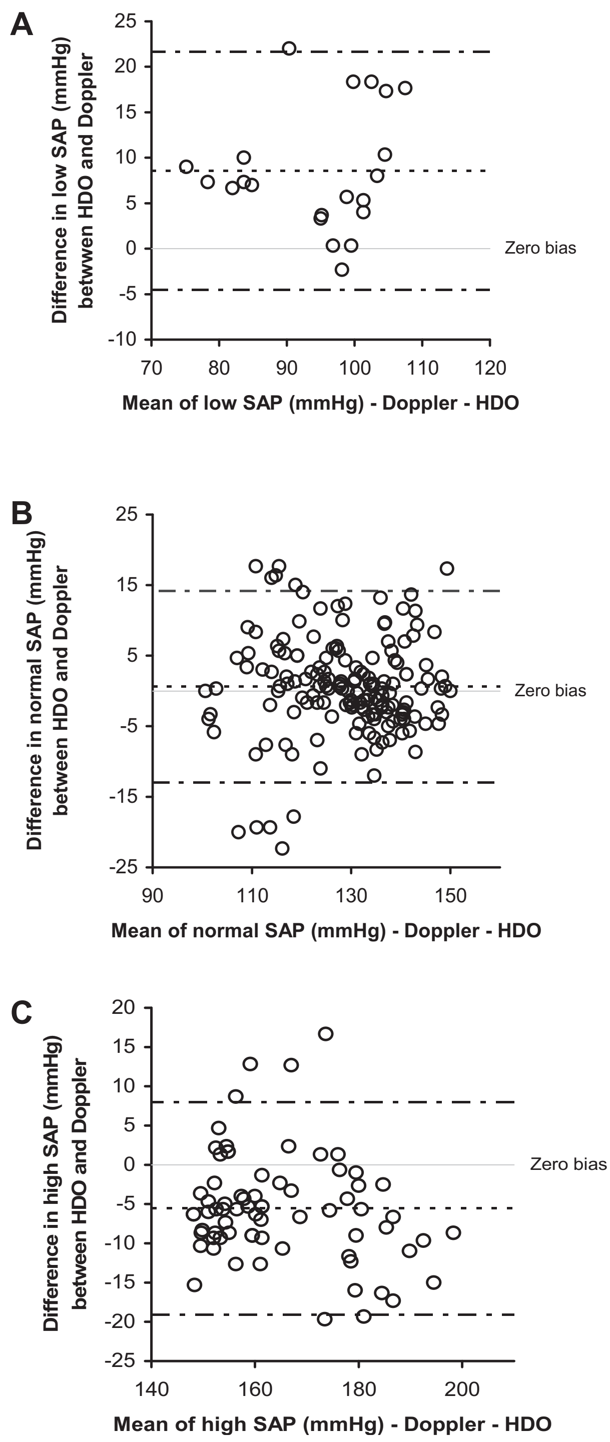


**Fig 3**. Bland−Altman plots of agreement between HDO method and Doppler device for different pressure groups. · - · - · - · indicates mean difference ± 2SD. ········ indicates mean bias.

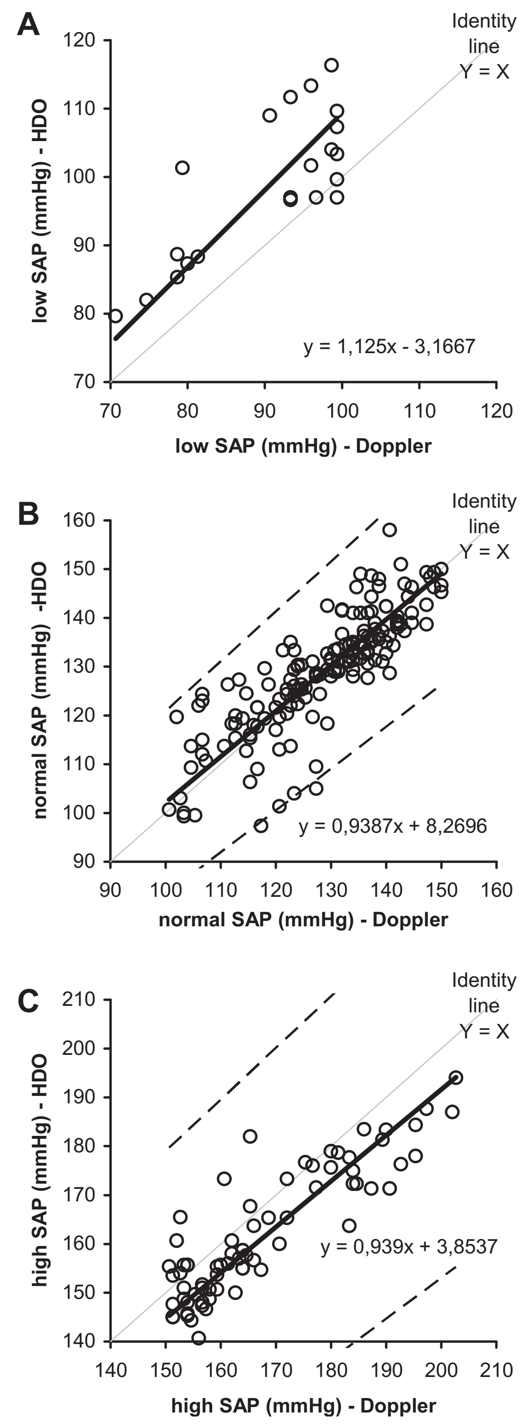


**Fig 4**. Scatter plot of SAP obtained by HDO versus Doppler device for different pressure groups, with Passing−Bablok regression line fitted.

generally high, although systolic blood pressure is consistently underestimated.[11] However, the Doppler device can be used reliably only for systolic blood pressure measurements, whereas automated oscillometric measuring devices, which give blood pressure values that are averaged over several pulse cycles, most exactly measure MAP, that corresponds to the peak amplitude of arterial oscillations; SAP and DAP are calculated using built-in algorithms.[5,8,10,13]

Oscillometric methods have been tested in conscious[2,12] and anaesthetised cats.[9−11] In the present study, the new HDO method (Memo Diagnostic HDO) has been compared with the currently used Doppler technique.

**Table 3**. Frequency (number and percentage) of different discrepancy ranges between Doppler and HDO SAP measurements according to pressure group.

| Pressure group | *n* (number of measurements) | Discrepancy | | |
|---|---|---|---|---|
| | | <±10 mmHg | <±15 mmHg | <±20 mmHg |
| | | *n* (%) | *n* (%) | *n* (%) |
| Low | 21 | 14 (66.7) | 16 (76.2) | 20 (95.2) |
| Normal | 166 | 144 (86.7) | 155 (93.4) | 164 (98.8) |
| High | 72 | 54 (75.0) | 64 (88.9) | 72 (100.0) |
| Total | 259 | 212 (81.9) | 235 (90.7) | 256 (98.8) |

Because the study was carried out in client-owned cats, comparison of the two methods with direct blood pressure measurement was not possible for ethical reasons.

The SAP was recorded using the Doppler device in all cats in the present study, similar to the study reported by Jepson et al.[2] Although the technique requires some user skills, SAP measures were obtained efficiently. The CV of $1.19 \pm 0.75\%$ obtained from three parallel Doppler readings confirms the high precision of measurement. Jepson et al[2] established that the first SAP measurement was not significantly different from the mean of five readings, indicating that a single SAP measurement may be adequate.

Oscillometric measurements in the present study were successful in only 90.05% of attempts. The oscillometric device was not able to perform the measurement and reported an error when the surgical field was close to the site of the cuff placement (eg, when the cuff was placed on the tail during abdominal surgery or during blood sampling from the jugular vein with the cuff placed on the forelimb). Surgical scrubbing of the hindlimb with the cuff placed on the forelimb, spontaneous movements of the cat and vomiting during recovery also interfered with HDO measurements. The CV of HDO measurements ranged from $2.77 \pm 2.96\%$ (SAP) to $4.06 \pm 5.27\%$ (MAP) indicating a satisfactory level of precision ($\leq\pm10\%$ mmHg), although it was higher than that obtained by the Doppler device. Other investigators also reported a greater variability for the oscillometric Memoprint device than for the Doppler device.[2] The limitation of the present study is that it was carried out in anaesthetised cats and the data cannot necessarily be extrapolated to the conscious cat. The authors presume that in conscious cats the success of oscillometric measurements would be even lower because in the present study the HDO device failed due to insignificant limb/cuff movements.

Cuff size contributes to the variation in oscillometric measurements. A cuff that is too large generally produces readings that are too low, and vice versa. In the present study the same cuff size (c1), suggested by the HDO manufacturer, was used in all cats. In cats with thin tails, it was not possible to measure blood pressure when the cuff was placed on the tail; instead a forelimb was used.

First, we evaluated the influence of the cuff position on the bias between Doppler and HDO measurements. There are important reasons for not using the tail site for cuff placement in anaesthetised cats (Table 2). Biases obtained with regard to the cuff position (tail vs leg) differed at 10, 15 and 20 mmHg discrepancy levels. Consequently, more reliable readings with the oscillometric device can be taken from the forelimb or hindlimb. Lower significant differences in biases between dorsal and lateral recumbences (Table 2) showed that recumbence does not influence the blood pressure measurements.

Using scatter plots, which give the best overview of comparisons of data,[17] with regression lines fitted using Passing−Bablok regression,[18] we established that the paired measurements of SAP obtained with Doppler device and HDO, were not close to the line of equality. Both constant and proportional biases were observed. From Bland−Altman plots it is evident that the scatter of the points is not random and, furthermore, a negative correlation between bias and the magnitude of Doppler measurements was observed. Therefore, in the second part of the evaluation, all measurements were divided into three subgroups according to the pressure value (the cut-offs for subgroups were set at 100 and 150 mmHg). In the low pressure group, the positive mean bias of 8.56 mmHg reflected an overestimation by HDO measurement. In the group of high pressure values, a negative mean bias of −5.56 mmHg indicates an underestimation by HDO measurements. In a normal pressure group, biases are positioned randomly around a mean bias of 0.62 mmHg, which shows that, in this pressure group, Doppler and HDO measurements agree most closely. Although the Doppler device was found to provide a high degree of accuracy, an adjustment factor of 14 mmHg should be added to the Doppler systolic pressure to obtain the direct systolic blood pressure.[11,19] The over- and underestimation of HDO measurements in the present study affects clinical utility of HDO at most in the high pressure group where HDO underestimates direct systolic blood pressure even more than the Doppler device. In a normal pressure group, where Doppler and HDO measurements agree most closely, the difference to direct systolic blood pressure is similar. In a low pressure group, HDO measurements are higher than those taken by the Doppler device, which suggests that in this group HDO measurements are in best accordance with direct blood pressure.[20]

Standards for the performance of automated non-invasive blood pressure (NIBP) devices have been set by the American Association of Medical Instrumentation and the British Hypertension Society. These standards require NIBP monitors to yield measurements within $5 \pm 8$ mmHg (mean $\pm$ SD) of prediction error. Few veterinary studies of NIBP monitors have met this standard.[1] In the present study, the frequency of different discrepancy ranges between Doppler and HDO SAP measurements was analysed in the three pressure groups. Discrepancy ranges were set at 10, 15 and 20 mmHg according to the study of Deflandre and Hellebrekers.[8] In the low pressure group 66.7% of biases were within 10 mmHg of discrepancy, whereas in the groups of normal and high measurements 86.7 and 75.0% of discrepancy were lower than 10 mmHg. Frequency at a discrepancy range at 15 mmHg showed similar differences between pressure groups.

In conclusion, the HDO device achieved measurements in 90.05% of attempts, while the Doppler device yielded measurements on every occasion it was used. The CV of systolic, diastolic and mean arterial blood pressure obtained by HDO indicated a satisfactory level of precision, although the precision was lower than the SAP obtained by the Doppler device. In the low pressure group HDO measurements overestimated Doppler measurements while, at high pressure values, they underestimated Doppler measurements. Cuff placement on the tail did not result in reliable measurements in this study.

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