

Comparison of Doppler ultrasonography and high-definition oscillometry for blood pressure measurements in healthy awake dogs

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Objective—To determine the intra- and interobserver variability of systolic arterial pressure (SAP) and diastolic arterial pressure (DAP) measurements obtained with 2 indirect methods in awake dogs and percentage of successful measurements.

Animals—6 healthy conscious adult dogs.

Procedures—4 observers with different levels of training measured SAP and DAP on 4 days by use of Doppler ultrasonography (DU) and high-definition oscillometry (HDO). The examinations were randomized. Measurements for each technique were recorded 5 consecutive times, and mean values (total, 720 measurements) were used for statistical analysis.

Results—All within- and between-day coefficients of variation (CVs) for SAP were < 15% irrespective of the observer or method (HDO, 3.6% to 14.1%; DU, 4.1% to 12.4%). Conversely, half the CVs for DAP were > 15% with the highest within- and between-day CVs obtained by the least experienced observer by use of DU (19.5% and 25.9%, respectively). All attempts with HDO were successful, whereas DAP could not be measured by use of DU by the least experienced observer in 17% of attempts.

Conclusions and Clinical Relevance—SAP may be assessed in healthy dogs by use of DU and HDO with good repeatability and reproducibility after a short period of training. Conversely, the variability of DAP is higher and longer training is required to assess DAP via DU than via HDO. (*Am J Vet Res* 2010;71:766–772)

Systemic arterial hypertension is defined as a sustained increase in arterial BP, which may occur in the absence of any identifiable cause or may be secondary to various conditions or pathological processes, including chronic kidney disease and several endocrine diseases (eg, hyperadrenocorticism, diabetes mellitus, primary hyperaldosteronism, pheochromocytoma, and hypothyroidism).^{1–6}

Over the past 10 years, systemic hypertension has been increasingly recognized as a potential cause of severe irreversible organ lesions in veterinary medicine. The main target organs in cats and dogs

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ABBREVIATIONS

ACVIM	American College of Veterinary Internal Medicine
BP	Blood pressure
CV	Coefficient of variation
DAP	Diastolic arterial pressure
DU	Doppler ultrasonography
HDO	High-definition oscillometry
MAP	Mean arterial pressure
SAP	Systolic arterial pressure

include the kidneys (glomerular sclerosis and interstitial fibrosis^{3,4}), eyes (retinopathy and choroidopathy),^{7,8} CNS (hemorrhage, edema, and infarction),^{9,10} and heart (myocardial hypertrophy with systolic and diastolic dysfunction^{11–13}). An early and accurate diagnosis of systemic arterial hypertension is therefore highly recommended to limit the degree of such injuries or prevent their occurrence in patients at risk.¹ A reliable diagnosis is also needed to follow-up and control the efficacy of antihypertensive treatments.^{1,9,14–18}

Diagnosis of systemic hypertension relies on measurements of systemic BP, which may be directly obtained by arterial blood puncture. However, in clinical

practice, indirect measurements made by use of devices incorporating a compressive cuff are usually preferred because of their noninvasive aspect. The most commonly used methods are therefore DU and oscillometry or HDO.¹ In dogs, the accuracy of these indirect techniques has been reported in normotensive^{19–21} and hypertensive²¹ animals, either conscious^{19,20} or anesthetized,²¹ in comparison with direct intra-arterial methods. The comparative diagnostic abilities of oscillometric and DU methods in detecting systemic hypertension in dogs have also been assessed.^{22,23} A consensus statement of the ACVIM has recently been published, providing guidelines to veterinarians regarding their correct use in practice.¹ According to the guidelines, a well-defined standard protocol involving suitably trained observers should be followed because technical errors associated with personnel inexperience are major causes of unreliable BP measurements.¹ However, to the best of our knowledge, the precise definition of suitable training has not been established and the intra- and interobserver within- and between-day variability of BP measurements have not been evaluated in dogs in clinical settings.

The purpose of the present study was to determine the intra- and interobserver variability and percentage of successful measurements of SAP and DAP measurements by use of 2 indirect methods in awake dogs.

Materials and Methods

Dogs—Six healthy female Labrador Retrievers (mean \pm SD age, 4.9 ± 0.9 years, [range, 2.8 to 7.8 years]; weight, 25.8 ± 0.7 kg, [24.8 to 27.1 kg]) from a canine cohort of the National Veterinary School of Alfort were used, and procedures were conducted in accordance with guidelines established by the National Institutes of Health Guide for the Care and Use of Laboratory Animals. The dogs were considered healthy on the basis of results of a complete clinical examination, electrocardiography, and conventional echocardiography performed before inclusion in the study. The dogs were not familiar with the investigators or the BP measurement procedure.

BP measurements—An indirect measurement of BP was carefully obtained in conscious dogs by use of a standardized method according to manufacturers' instructions^{a,b} and guidelines of the ACVIM consensus statements.¹ The same single DU^a and HDO^b devices were used throughout the study. Stress and anxiety were reduced as much as possible by performing all BP measurements in the same isolated quiet room and use of a 10-minute period of acclimatization each day before starting the measurements. For both techniques, the dogs were gently restrained in right or left lateral recumbency and the inflatable cuff was placed on the tail. In accordance with the ACVIM consensus statement,¹ several consecutive BP measurements were performed during each session to obtain a stable set of 5 values and the mean was used for the statistical analyses. Observers could choose to discard the first value if it was considered abnormally high and anxiety-induced.¹ The time required to obtain the BP measurements, from cuff placement to end of recording of the 5 consecutive conserved BP values, was recorded by another person.

DU method—An appropriate-size cuff^c was placed around the tail. Coupling gel was applied between the 8-MHz probe and the skin to improve contact. The hair was not clipped before placing the probe. As described,^{22,23} the sound volume of the Doppler device was adjusted to obtain a clearly audible signal. The cuff was manually inflated until the pulse signal was no longer audible and then was gradually deflated. The BP (read on the manometer) at which the audible pulse signal was again detected was considered to be the SAP. The cuff was further deflated until a change in tone of the flow sound was detected, and this was recorded as the DAP. Heart rate was calculated by each observer with a stethoscope at the end of each session of BP measurements.

HDO method—As with the DU method, an appropriate-size cuff^d was placed around the tail and automatically inflated. For each cuff inflation and deflation, the heart rate, SAP, DAP, and MAP were automatically calculated by the HDO device.

Observers—Four observers from the National Veterinary School of Alfort with different levels of experience were involved in the study. Observer 1 (VD) was a fourth-year student with only 1 hour of training in BP measurements (DU and HDO) before starting the study. Observer 2 (NJ) was an intern who underwent the same training as observer 1 but had also done some occasional training during a year of internship. Observers 3 (FS) and 4 (VG) were residents in veterinary cardiology and were both used to performing daily BP measurements by use of the 2 techniques during their residency program (observer 4 had 2 more years of experience than observer 3). Observers 1, 2, and 3 had been trained in use of the 2 methods (DU and HDO) by observer 4.

Assessment of within- and between-day intra- and interobserver variability—All BP measurements were randomized (for the order of examinations, dogs and investigators were randomly drawn), and each observer was masked to the BP values recorded by the 3 others. The study was performed on 4 consecutive days. Each day, each observer ($n = 4$) performed 3 BP measurements on 3 dogs by use of each method. Therefore, for each method, 36 BP measurements/d were performed, representing, for the whole 4-day study period, a total of 144 BP measurements (ie, 720 BP recordings because each BP value used for statistical analysis was the mean of 5 consecutive values). The same dog was not used for 2 consecutive BP measurements.

Statistical analysis—Data are expressed as mean \pm SD. A software program^e was used to perform the statistical analysis as described.²⁴ The following linear model was used for each observer and each BP measurement:

$$Y_{ijkl} = \mu + \text{day}_j + \text{dog}_k + (\text{day} \times \text{dog})_{jk} + \varepsilon_{ijkl}$$

where Y_{ijkl} is the first value measured for dog k on day j by observer i , μ is the general mean, dog_k is the differential effect (considered as fixed) of dog k , $(\text{day} \times \text{dog})_{jk}$ is the interaction term between day and dog, and ε_{ijkl} is the model error. The SD of repeatability was de-

terminated from the residual SD of the model and the SD of reproducibility from the square root of the mean square of day.

Any interaction between dog and operator was determined by use of the following general linear model:

$$Y_{ijkl} = \mu + Ob_i + day_j + dog_k + (Ob \times dog)_{ik} + (day \times dog)_{jk} + \epsilon_{ijkl}$$

where Y_{ijkl} is the first value measured for dog k on day j by observer i , μ is the general mean, Ob_i is the differential effect (considered as fixed) of observer i , dog_k is the differential effect of dog k , $(Ob \times dog)_{ik}$ is the interaction term between observer and dog, $(day \times dog)_{jk}$ is the interaction term between day and dog, and ϵ_{ijkl} is the model error. A similar general linear model was used to determine for each technique the observer effect on the time taken to measure BP. The level of significance was set at values of $P < 0.05$.

Results

Mean \pm SD values and ranges of BP values (SAP and DAP for both techniques and MAP for HDO) obtained

by the reference observer (observer 4) were determined (Table 1). The SDs and CVs for the within- and between-day intraobserver variability were determined for HDO (Table 2) and DU (Table 3).

For the BP measurements obtained by use of HDO and for all investigators, the lowest CVs of within- and between-day variability were obtained for SAP and MAP, with all values ($n = 16$) $\leq 15\%$ (ranges, 3.6% to 14.1% and 6.9% to 15.0%, respectively). More than half the within- and between-day CVs for SAP (5/8) were $\leq 10\%$. Conversely, all within- and between-day CVs of HDO-assessed DAP were $> 10\%$ (range, 10.9% to 18.0%) and half (4/8) were $> 15\%$.

Table 1—Repeated measurements of SAP (mean \pm SD [range]) performed by a reference observer (observer 4) in 6 healthy dogs by use of HDO and DU.

Variable	HDO	DU
SAP (mm Hg)	117 \pm 12 (93–149)	107 \pm 10 (91–127)
DAP (mm Hg)	56 \pm 8 (43–76)	70 \pm 13 (45–91)
MAP (mm Hg)	78 \pm 9 (54–97)	—
Heart rate (beats/min)	77 \pm 15 (53–118)	65 \pm 14 (40–100)

Table 2—Within- and between-day intraobserver SDs and CVs for indirect measurement of BP in 6 healthy Labrador Retrievers by use of HDO.

Variable	Observer 1	Observer 2	Observer 3	Observer 4
SAP (mm Hg)				
Within-day variability				
SD	12.8 mm Hg	10.0 mm Hg	10.2 mm Hg	13.1 mm Hg
CV	10.7%	8.6%	8.8%	11.2%
Between-day variability				
SD	16.9 mm Hg	8.5 mm Hg	4.2 mm Hg	11.4 mm Hg
CV	14.1%	7.3%	3.6%	9.7%
DAP (mm Hg)				
Within-day variability				
SD	9.2 mm Hg	8.0 mm Hg	9.6 mm Hg	8.4 mm Hg
CV	15.5%	13.7%	16.3%	14.9%
Between-day variability				
SD	6.4 mm Hg	10.2 mm Hg	10.5 mm Hg	8.2 mm Hg
CV	10.9%	17.6%	18.0%	14.6%
MAP (mm Hg)				
Within-day variability				
SD	9.7 mm Hg	7.7 mm Hg	9.6 mm Hg	9.6 mm Hg
CV	12.1%	9.8%	12.2%	12.4%
Between-day variability				
SD	8.2 mm Hg	11.8 mm Hg	5.4 mm Hg	10.3 mm Hg
CV	10.2%	15.0%	6.9%	13.3%

Table 3—Within- and between-day intraobserver SDs and CVs for indirect measurement of BP in 6 healthy Labrador Retrievers by use of DU.

Variable	Observer 1	Observer 2	Observer 3	Observer 4
SAP (mm Hg)				
Within-day variability				
SD	11.4 mm Hg	7.3 mm Hg	7.0 mm Hg	7.9 mm Hg
CV	10.0%	6.6%	6.2%	7.4%
Between-day variability				
SD	14.2 mm Hg	8.8 mm Hg	4.6 mm Hg	10.1 mm Hg
CV	12.4%	7.9%	4.1%	9.4%
DAP (mm Hg)				
Within-day variability				
SD	13.5 mm Hg	10.3 mm Hg	6.3 mm Hg	9.1 mm Hg
CV	19.5%	13.7%	10.4%	13.1%
Between-day variability				
SD	18.0 mm Hg	7.8 mm Hg	11.1 mm Hg	13.8 mm Hg
CV	25.9%	10.4%	18.3%	19.9%

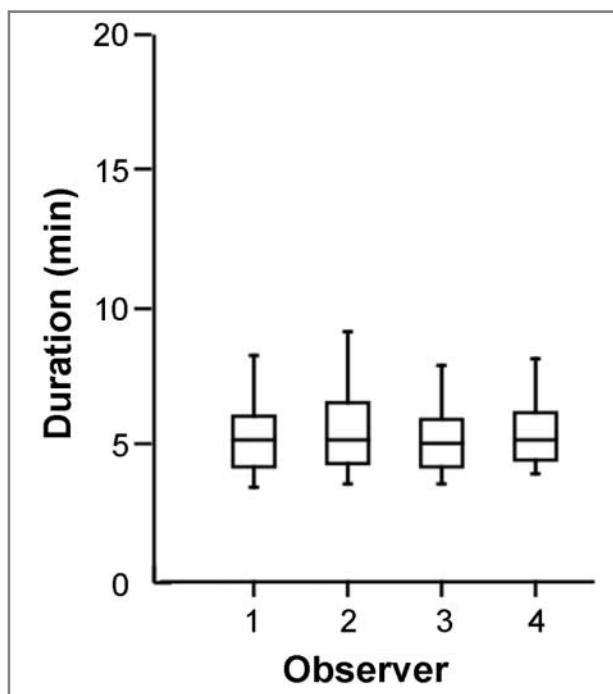


Figure 1—Box plots representing the total durations of blood pressure measurements performed by 4 observers with different levels of experience (observers 1, 2, 3, and 4) by use of the HDO method. The horizontal line within the box represents the 50th percentile, the box represents the 25th to 75th percentiles, and the whiskers represent the 5th and 95th percentiles. Each measurement ($n = 144$ [36/observer]) was obtained 5 consecutive times, and the time required for the 5 readings was recorded.

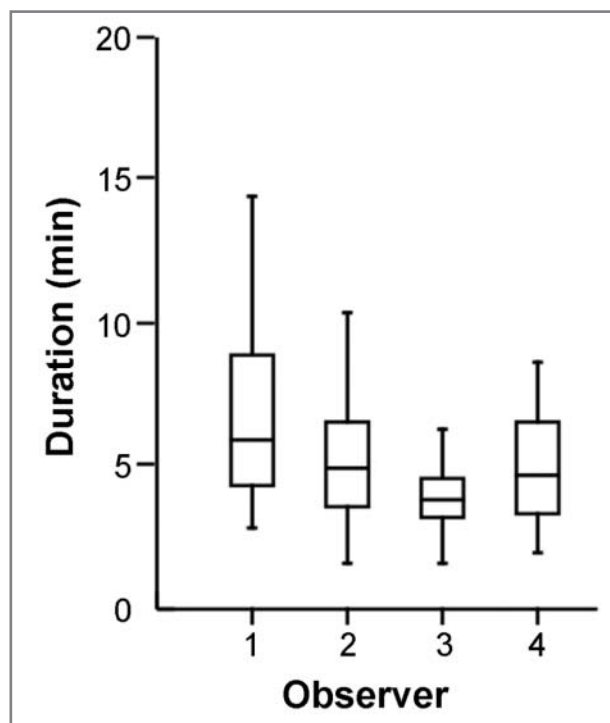


Figure 2—Box plots representing the total durations of blood pressure measurements performed by 4 observers with different levels of experience (observers 1, 2, 3, and 4) by use of the DU method. Each measurement ($n = 144$ [36/observer]) was obtained 5 consecutive times, and the time required for the 5 readings was recorded. See Figure 1 for key.

For the BP measurements obtained by use of DU (Table 3) and for all investigators, the lowest CVs of within- and between-day variability were obtained for SAP, with all values $\leq 15\%$ (range, 4.1% to 12.4%), and all except 1 (7/8) were $\leq 10\%$. Conversely, all CVs of DU-assessed DAP were $> 10\%$ (range, 10.4% to 25.9%), with the highest values obtained by observer 1 (within- and between-day CVs of 19.5% and 25.9%, respectively). No observer effect and no interaction between dog and observer or between dog and day were observed with either technique.

Duration of measurements and comparison of values—No significant observer effect was observed for the time taken to obtain BP measurements by use of the HDO technique (5.7 ± 2.1 minutes [range, 3.5 to 17 minutes] for all 4 observers and 5.4 ± 1.5 minutes, 6.0 ± 2.3 minutes, 5.3 ± 1.4 minutes, and 6.2 ± 2.9 minutes for observers 1, 2, 3, and 4, respectively; Figure 1). Regarding HDO, no significant day or dog effect or any interaction between day and dog or dog and observer was observed. Conversely, the time taken to obtain BP measurements by use of DU (5.9 ± 4.0 minutes [range, 3.5 to 31 minutes]) was significantly ($P = 0.001$) dependant on the observers (7.7 ± 4.7 minutes, 6.1 ± 4.8 minutes, 4.3 ± 1.6 minutes, and 5.4 ± 3.6 minutes for observers 1, 2, 3, and 4, respectively; Figure 2). A significant ($P =$

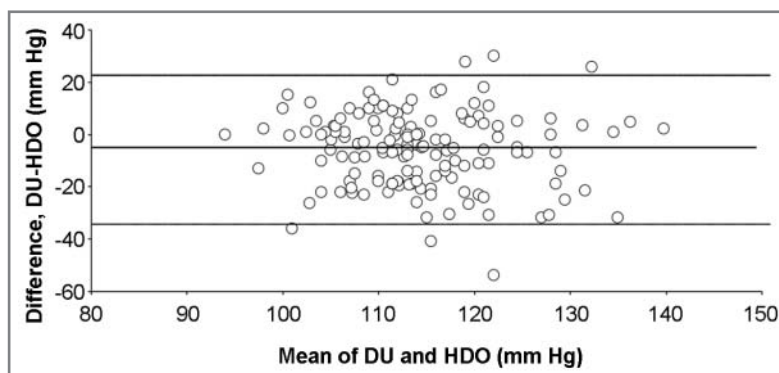


Figure 3—Bland-Altman analysis illustrating the difference between SAP values assessed by use of 2 indirect methods (SAP DU-HDO) versus the mean of those 2 values. Mean difference is indicated as the middle horizontal line, and the limits of agreement (95% confidence interval) are indicated as the upper and lower horizontal lines.

0.024) dog effect was also found for the DU technique. However, no day effect or interactions between day and dog or dog and observer were observed.

For the DU technique, but not for HDO, observers 1 and 2 could not obtain DAP values in 6 of 36 (17%) and 2 of 36 (6%) sessions, respectively, because they were totally unable to detect a clear change from systolic to diastolic Doppler signal tone.

No significant differences were observed between the systolic or DAP values obtained by use of DU and HDO after each examination. Further comparisons were made by examining the differences in SAP (Fig-

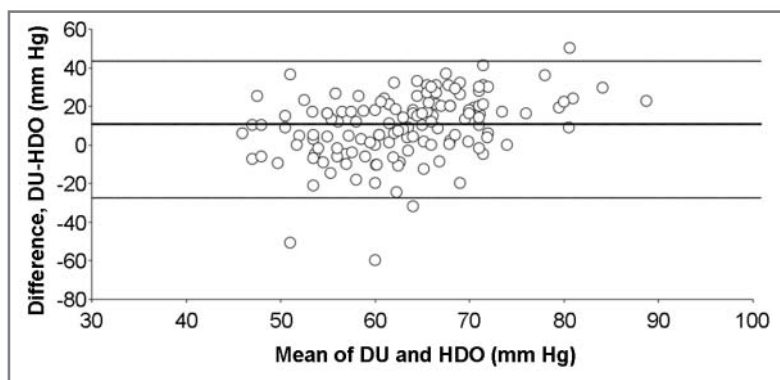


Figure 4—Bland-Altman analysis illustrating the difference between DAP values assessed by use of 2 indirect methods (DAP DU–HDO) versus the mean of those 2 values. Mean difference is indicated as the middle horizontal line, and the limits of agreement (95% confidence interval) are indicated as the upper and lower horizontal lines.

ure 3) and DAP (Figure 4) values obtained with the 2 methods by use of Bland-Altman representations. Bland-Altman analysis revealed that the DU method underestimated SAP, compared with the HDO method (mean difference between SAP assessed by use of DU and HDO, -5.8 mm Hg [95% confidence interval, -34.2 to 22.4 mm Hg]). Conversely, the DU technique overestimated DAP, compared with HDO (mean difference between DAP assessed by DU and HDO, $+9.7$ mm Hg [95% confidence interval, -23.5 to 42.8 mm Hg]).

Discussion

Few studies^{23,25,26} have focused on BP variability in veterinary medicine. To the authors' knowledge, the present report is the first in which the intra- and interobserver variability of BP measurements have been assessed in dogs in relation to the method used (HDO or DU). Such data are prerequisite to any longitudinal studies performed with repeated BP measurements to avoid misinterpretation of the results. Repeated measurements are used to assess antihypertensive drug efficacy in clinical trials and experimental studies,^{14–18} and the amplitude of BP change should always be interpreted in relation to observer variability. If the decrease in BP is less than the observer's SD of variability, this change should not be interpreted as a therapeutic improvement. Although results of the present study cannot be extrapolated to other conditions (ie, investigator or device), the proposed procedure can easily be applied by other investigators to evaluate their own performance.

The main goal of this study was not to document biological (ie, interdog) variability but to obtain numerous data from different investigators on the same small number of subjects ($n = 6$), to determine inter- and intraobserver variability. For both techniques, HDO and DU, the total number of sessions of BP measurements was high (288, representing 1,440 readings).

In this study, the 3 most experienced observers (1 intern and 2 residents) were representative of investigators who might be involved in longitudinal studies. A beginner (a student) was also deliberately involved in the protocol to evaluate whether a short training period (1 hour) was sufficient to obtain satisfactory to good re-

peatability and reproducibility of BP measurements in dogs.

The authors decided that, to reproduce conditions similar to those of clinical trials and also respect the recommendations for standard BP measurement procedures in the ACVIM consensus statement,¹ the dogs should not have been acclimatized to the examination procedure or accustomed to the observers, the dogs should not be sedated or anesthetized, and the procedure should be performed, as in a clinical situation, near the consulting room in a quiet place. Moreover, to better compare the variability of the 2 techniques and minimize other factors of variation, the same site of cuff placement (tail) and the same dog position (lateral recumbency) were used

for both techniques. The same HDO and DU devices were used by all 4 observers. Healthy dogs were selected to limit daily pathological variations in BP values during the protocol, which might have interfered with the assessment of the intra- and interobserver intrinsic variability.

In the present study, the procedure used for BP measurements, which was in accordance with the ACVIM consensus statement,¹ allowed each observer to discard the first BP values if these were considered abnormally high. This could have led to an underestimation of BP variability, and the present results are only valid under these conditions. Nevertheless, the objective of this study was to assess the variability of BP measurement as actually done by the general practitioner following published guidelines.¹

Mean values of repeated BP measurements obtained in the 6 healthy dogs were similar to those described in conscious dogs but in the lower ranges for systolic and diastolic values, irrespective of the technique used.¹ These results may be explained by the fact that the Labrador Retrievers were docile, as indicated by the low heart rates recorded during the BP measurement sessions (77 ± 15 beats/min and 65 ± 14 beats/min for HDO and DU, respectively). Moreover, low BP values have already been described in Labrador Retrievers, compared with other canine breeds.²⁷

In the present study, the SAP and DAP values obtained by use of DU and HDO devices were not significantly different. Similarly, in a previous study²³ performed in conscious healthy cats, no significant difference was observed between mean SAP readings when results obtained with DU and HDO devices were compared. However, the HDO machine produced significantly higher estimates of DAP in that previous study. In the study reported here, results did not indicate similar findings in dogs, thus confirming the need to obtain specific reference values for each species with each technique. However, the present study was performed in a small number of healthy dogs. Further studies involving large populations of healthy and diseased dogs are needed.

The present study revealed several advantages of the HDO device, compared with the DU device, when used in dogs. The HDO technique requires minimal

skill, probably because HDO measurements are automatically done by the device after cuff placement. Thus, the technique does not rely on detection of the arterial Doppler signal or on the interpretation of flow sound variations by the observer.

For the 2 most experienced observers (observers 3 and 4), the mean time taken to obtain the BP measurements by use of the DU technique was similar to that recorded in another study.²⁶ Hsiang et al²⁶ reported that 5 consecutive systemic BP readings were obtained via Doppler sphygmomanometry in all dogs within 6 minutes. Similarly, in the present study, the time taken to obtain BP measurements via DU was 4.3 ± 1.6 minutes and 5.4 ± 3.6 minutes for observers 3 and 4, respectively. However, the 2 less experienced observers (observers 1 and 2) took longer to do the BP measurements, suggesting that the DU technique requires a minimum degree of training. In contrast, all 4 observers took similar times (5.7 ± 2.1 minutes) to obtain BP measurements via HDO.

In the present study, all 4 observers obtained SAP, DAP, and MAP values in 100% of their attempts with the HDO device. Similarly, SAP was measured in all attempts by all 4 observers using the DU technique. In contrast, observers 1 and 2 were unable to obtain DAP values in 17% and 6% of cases, respectively, with the DU device, whereas observers 3 and 4 were able to detect a clear change from systolic to diastolic tone in 100% of their attempts. Diastolic arterial pressure is reported to be more difficult to assess in conscious dogs and cats.^{19,23} In the report of Jepson et al,²³ combining the data from both examiners involved in their study, with 5 attempts each for 28 cats, the DU device gave an SAP reading in all 280 attempts, whereas DAP readings were determined in only 144 of 280 (51.4%) attempts.

Results of the present study indicated that investigators may have different variabilities for BP measurements with the highest within- and between-day CVs obtained for DAP by the least experienced observer with the DU technique (19.5% and 25.9%, respectively). These data are of importance to ensure correct interpretation of BP variations in practice. For example, if a decrease in DAP of 17 mm Hg is observed by observer 1 between 2 consecutive DU measurements after the administration of an antihypertensive drug, it cannot be concluded that this change is an effect of treatment because it is lower than the between-day SD of variability. Conversely, the same decrease obtained by observer 4 might result from the hypotensive drug effect.

In conclusion the HDO machine allowed assessment of SAP, DAP, and MAP within a short period in 100% of attempts with correct to good repeatability and reproducibility even after a minimal period of training (1 hour). Conversely, differences among investigators were observed regarding speed, variability, and percentage of successful DAP measurements with the DU machine.

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- a. 811-BL, Parks Medical Electronics Inc, Aloha, Ore.
 - b. Memodiag HDO, S + B medVet, Babenhausen, Germany.
 - c. Soft-cuff, Ref 2525, 5 cm-large, Parks Medical Electronics Inc, Aloha, Ore.
 - d. Blue cuff, D2, S + B medVet, Babenhausen, Germany.
 - e. Systat, version 10.0, SPSS Inc, Chicago, Ill.
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