Comparison of arterial blood pressure measurements and hypertension scores obtained by use of three indirect measurement devices in hospitalized dogs

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Objective—To evaluate the agreement of blood pressure measurements and hypertension scores obtained by use of 3 indirect arterial blood pressure measurement devices in hospitalized dogs.

Design—Diagnostic test evaluation.

Animals—29 client-owned dogs.

Procedures—5 to 7 consecutive blood pressure readings were obtained from each dog on each of 3 occasions with a Doppler ultrasonic flow detector, a standard oscillometric device (STO), and a high-definition oscillometric device (HDO).

Results—When the individual sets of 5 to 7 readings were evaluated, the coefficient of variation for systolic arterial blood pressure (SAP) exceeded 20% for 0% (Doppler), 11% (STO), and 28% (HDO) of the sets of readings. After readings that exceeded a 20% coefficient of variation were discarded, repeatability was within 25 (Doppler), 37 (STO), and 39 (HDO) mm Hg for SAP. Correlation of mean values among the devices was between 0.47 and 0.63. Compared with Doppler readings, STO underestimated and HDO overestimated SAP. Limits of agreement between mean readings of any 2 devices were wide. With the hypertension scale used to score SAP, the intraclass correlation of scores was 0.48. Linear-weighted inter-rater reliability between scores was 0.40 (Doppler vs STO), 0.38 (Doppler vs HDO), and 0.29 (STO vs HDO).

Conclusions and Clinical Relevance—Results of this study suggested that no meaningful clinical comparison can be made between blood pressure readings obtained from the same dog with different indirect blood pressure measurement devices. (*J Am Vet Med Assoc* 2012;240:962–968)

Measurement of blood pressure in dogs has become a commonly performed technique in veterinary practice over the past few decades as the importance of detecting systemic hypertension, associated with various disease states, and hypotension, particularly in anesthetized dogs and cats, has become increasingly recognized.[1–3] The accepted reference (gold) standard for measuring blood pressure in dogs is direct intra-arterial measurement, but this technique is invasive and technically demanding.[4–8] Instead, several noninvasive techniques and devices are widely used.[1]

Because no specific requirements for the validation of veterinary devices exist, some devices currently marketed have not been validated. Validation reports have been published for some devices, but the manner in which each device was assessed differs widely among devices and reports. As a result, direct comparison between devices is often difficult or impossible. Nonetheless, clinicians expect that marketed devices can be used to obtain meaningful blood pressure measurements so that clinically important low or high values can be reliably identified.

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Abbreviations

ACVIM	American College of Veterinary Internal Medicine
CV	Coefficient of variation
DAP	Diastolic arterial blood pressure
HDO	High-definition oscillometric
MAP	Mean arterial blood pressure
SAP	Systolic arterial blood pressure
STO	Standard oscillometric
TODR	Target organ damage risk

In 2007, a consensus statement was issued by the ACVIM to provide guidelines in an attempt to standardize blood pressure measurement and systemic hypertension identification in dogs and cats.[1] This document includes a suggested protocol for measuring blood pressure with guidelines for patient restraint, device cuff size and position, patient positioning, and reliable blood pressure determination. The ACVIM recommends performing serial measurements, discarding the first measurement, and calculating the mean of 3 to 7 consecutively obtained, consistent (< 20% variability in SAP) values.[1] In addition, suggested cutoff values for diagnosing systemic hypertension by use of indirect devices, on the basis of TODR, are given.

Studies involving assessment of indirect blood pressure measurement devices in dogs have been conducted in an attempt to define reference ranges,[8,9] compare results with direct intra-arterial measurements in anesthetized dogs[2,5,6,9–14] or conscious dogs,[3,4,8,9] assess re-

peatability of blood pressure measurements over time[15] or within 1 session with repeated measurements,[16,17] compare readings from different anatomic sites[4,5] or cuff sizes,[18] and evaluate the usefulness of devices in diagnosing hypotension or hypertension[11,19,20] or in determining the effect of disease on blood pressure.[21] Even so, the measurement protocol differs widely among reports. Moreover, the within-subject CV or measurement error of serial measurements obtained from dogs in clinical settings has rarely been evaluated, and only 1 report[1] describes direct comparison of results from different indirect blood pressure measurement devices in a clinical setting involving conscious dogs.

Reports of the validation of HDO devices, which have been marketed for several years for use in dogs, are scarce. Only 2 such reports exist: one[14] on validation of HDO device use in anesthetized dogs and the other[17] on the variability of HDO readings in healthy dogs. Furthermore, the agreement between hypertension scores obtained by use of different devices has not been evaluated. The purpose of the present study was to assess the agreement between measurements obtained with 3 indirect devices when used on hospitalized dogs as well as the agreement between scores obtained with the 3 devices by use of a TODR hypertension scale.

Materials and Methods

Animals—Twenty-nine client-owned dogs were enrolled from among dogs hospitalized for any reason at the Small Animal Clinic, Department of Clinical Veterinary Medicine, Vetsuisse Faculty, University of Bern, Switzerland. Owner consent was obtained for all participating dogs. Overly excitable or anxious dogs were excluded from the study. Dogs were also excluded when the primary clinician determined that participation in the study would be detrimental to the physical or mental health of the dog. The study protocol was evaluated and approved by the institution's ethics committee.

Instruments and measurement protocol—Blood pressure measurements were obtained by use of a Doppler ultrasonic flow detector,[a] an STO device,[b] and an HDO device.[c] Prior to each set of measurements, an aneroid manometer that met the standards for nonautomated sphygmomanometers established by the Association for the Advancement of Medical Instrumentation[22] was used to test the accuracy of the oscillometric devices and the manometer used in conjunction with the Doppler device.

All measurements were obtained following the same protocol, which conformed exactly to the 2007 ACVIM guidelines with the exception that owners were not present.[1] Measurements were performed in a quiet room. Each dog was positioned in sternal recumbency and with minimal restraint. The left or right forelimb was randomly selected for blood pressure measurement, unless an IV catheter was present, in which situation the limb without the catheter was used. For the STO and Doppler devices, a blood pressure cuff was placed around the midantebrachium overlying the median artery, and cuff size was selected to account for approximately 40% of the circumference of the limb at the placement site. For the HDO readings, a cuff was selected from 1 of 2 cuffs provided with the device for use in dogs, in accordance with the manufacturer's guidelines (ie, one cuff for dogs < 11 kg [24.2 lb] and another cuff for all other dogs). For the Doppler reading, the blood pressure cuff was connected to a sphygmomanometer. The Doppler probe was placed on the area over the common digital artery arch, which had been clipped of hair and to which coupling gel was applied. The position of the probe was adjusted until a clear signal was obtained from the loudspeaker, and the probe was fixed in position with adhesive tape. The same individual (MBW), who was familiar with all devices, performed all measurements.

Measurements were collected from each dog during 3 sessions on the same day (morning, noon, and evening). After dogs had remained quiet for 5 minutes, measurements were obtained, with care taken to ensure that the blood pressure cuff and the Doppler probe were at the level of the heart base. During each measurement session, 8 consecutive readings were obtained, with each of the devices used sequentially. The order in which devices were used for each of the 3 daily sessions was such that each device was used first, second, and last in 1 session for each dog. For each reading, SAP, DAP, and MAP were recorded with the STO and HDO devices and SAP was recorded with the Doppler device, with 5- to 10-second intervals between readings. When readings could not be obtained, the cuff was repositioned and readings were repeated as many as 15 times.

A measurement failure was defined as failure of the device to provide a complete set of values (SAP for the Doppler device; SAP, DAP, and MAP for the STO and HDO devices) after 15 trials. During measurement sessions, no medications or IV infusions were administered. At the end of the study, the devices were recalibrated to ensure their accuracy had been maintained.

Statistical analysis—Statistical calculations were performed with the aid of commercial software.[d] In accordance with ACVIM guidelines,[1] the first reading obtained in each measurement session for each measurement device was discarded. Data from any measurement session were eliminated from analysis when < 5 readings could be obtained because of measurement failure. Also in accordance with ACVIM guidelines, data from each device measurement session were eliminated when the CV for SAP exceeded 20% for that session. After elimination of these data sets, the CV for SAP with the Doppler device and SAP, DAP and MAP with the STO and HDO devices for each set of 5 to 7 measurements in each session was calculated. An overall CV for each device was estimated as the square root of the mean of the CVs squared.

The within-session SD was estimated by use of a 1-way ANOVA to determine SAP with the Doppler device and SAP, DAP, and MAP with the STO and HDO devices. Measurement error (1.96 SDs) and repeatability (2.77 SDs) were then calculated. Measurement error was defined such that the difference between a measurement and the mean of all measurements within a session was less than the value for the measurement error in 95% of observations, and repeatability was defined such that the difference between any 2 measurements for the

Table 1—Coefficients of variation, repeatability, and measurement error of sequential blood pressure measurements obtained from 29 hospitalized dogs with 3 types of indirect blood pressure monitors: a Doppler ultrasonic flow detector (Doppler), STO device, and HDO device.

	Doppler	STO			HDO		
Variable	**SAP**	**SAP**	**DAP**	**MAP**	**SAP**	**DAP**	**MAP**
Overall CV (%)	6.24	14.21	19.45	16.78	18.22	32.37	23.74
Range of CV (%)	1.3–19.6	1.2–57.4	2.9–63.4	3.3–59.2	1.2–45.8	2.40–73.6	1.7–70.9
Measurement error for all data (mm Hg)	18	34	31	32	49	46	45
Measurement error for data sets with a CV < 20% for SAP (mm Hg)	18	26	26	26	28	32	29
Repeatability for all data (mm Hg)	25	47	44	45	70	65	63
Repeatability for data sets with a CV < 20% for SAP (mm Hg)	25	37	36	36	39	46	41
Range of mean blood pressure values for all dogs (mm Hg)	82–243	97–200	52–135	69–161	113–221	50–131	72–156

same dog in a session would be expected to be less than the value for repeatability in 95% of observations. Error and repeatability were assessed before and after sets of measurements with a CV for SAP > 20% were eliminated.

The relationship between mean values obtained from each device for each dog and session was evaluated by calculating the Pearson correlation coefficient. The agreement between mean values obtained with each device was evaluated by use of Bland-Altman limits of agreement plots, in which the differences between the mean readings from each of 2 devices were plotted against the mean of the 2 mean readings for each measurement session. The bias (mean difference between values from 2 devices), SD of differences, and 95% limits of agreement were calculated. In addition, the percentage of mean values within 5, 10, and 20 mm Hg of each other was calculated for each pair of devices.

The mean values for SAP calculated for each device and session were rated according to the following hypertension (TODR) scoring system: 1, SAP < 150 mm Hg; 2, 150 mm Hg ≤ SAP ≤ 180 mm Hg; and 3, SAP > 180 mm Hg. The agreement between ratings determined with the 3 devices was evaluated by calculating the intraclass correlation, which estimates the between-ratings effect in relation to the between-dog effect and corresponds to a fully crossed 2-way ANOVA in which subject (dog) and raters (devices) are separate effects. The agreement between ratings from each device, compared with those of each of the other 2 devices, was evaluated by calculating the κ coefficients (interrater reliability), which estimate the proportion of concordant measurements, discounting those that agree because of mere chance, with linear weights applied to take into account

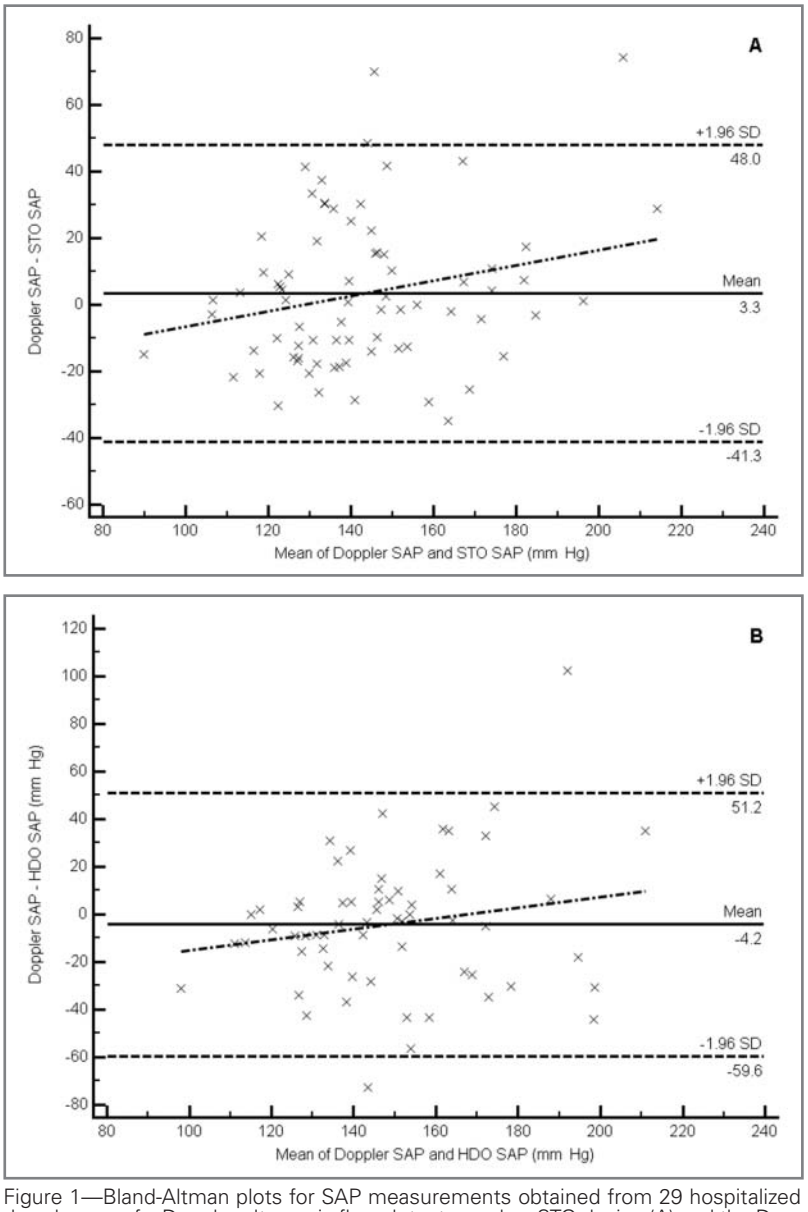

Figure 1—Bland-Altman plots for SAP measurements obtained from 29 hospitalized dogs by use of a Doppler ultrasonic flow detector and an STO device (A) and the Doppler device and an HDO device (B). The mean overall difference is indicated by the solid line, the 95% limits of agreement by the dashed lines, and the regression line of differences versus means by the dashed and dotted line.

the degree of disagreement between devices.[23] The strength of the agreement was interpreted as follows: < 0.2 = poor; 0.21 to 0.40 = fair; 0.41 to 0.60 = moderate; 0.61 to 0.80 = substantial; and > 0.81 = almost perfect.[24]

Results

Animals—Twenty-nine dogs representing 21 breeds were enrolled in the study. The most common breeds were mixed (n = 3), Malinois (3), Dogo Argentino (2), and Golden Retriever (2). Dogs were between 11 months and 12 years of age (mean, 5 years) and weighed between 5 and 76 kg (11.0 and 167.2 lb; mean, 27.5 kg [60.5 lb]). One dog was available for only 2 of the 3 blood pressure measurement sessions because of early discharge from the hospital, resulting in 688 attempted measurements for each device (8 measurements 3 times/d from each of 28 dogs and 2 times/d for 1 dog).

Device comparisons—Readings were obtained for all 688 (100%) measurements with the Doppler ultrasonic flow detector, 668 (97%) measurements with the STO device, and 683 (99%) measurements with the HDO device. Missing readings were attributable to measurement failure, which occurred 20 times with the STO device and 5 times with the HDO device. After discarding the first measurement, between 5 and 7 consecutive measurements were obtained for each device at each time point in all but 2 sessions, in which only 2 readings were obtained with the STO device. The range of mean blood pressure values obtained with the devices was wide, although blood pressure was rarely measured as low with any device (**Table 1**; **Figures 1 and 2**).

The CVs differed greatly for all 3 devices, with the Doppler device having the least variation and lowest estimated overall CV (Table 1). Estimates of overall CVs were lower for the STO device than for the HDO device. Measurement error was highest for the HDO device and lowest for the Doppler device. Repeatability was poorest for the HDO device. The CV for SAP obtained from 5 to 7 readings exceeded 20% in 0 of 86 sets of readings with the Doppler device, 9 of 84 (11%) sets of readings with the STO device, and 24 of 86 (28%) sets of readings with the HDO device.

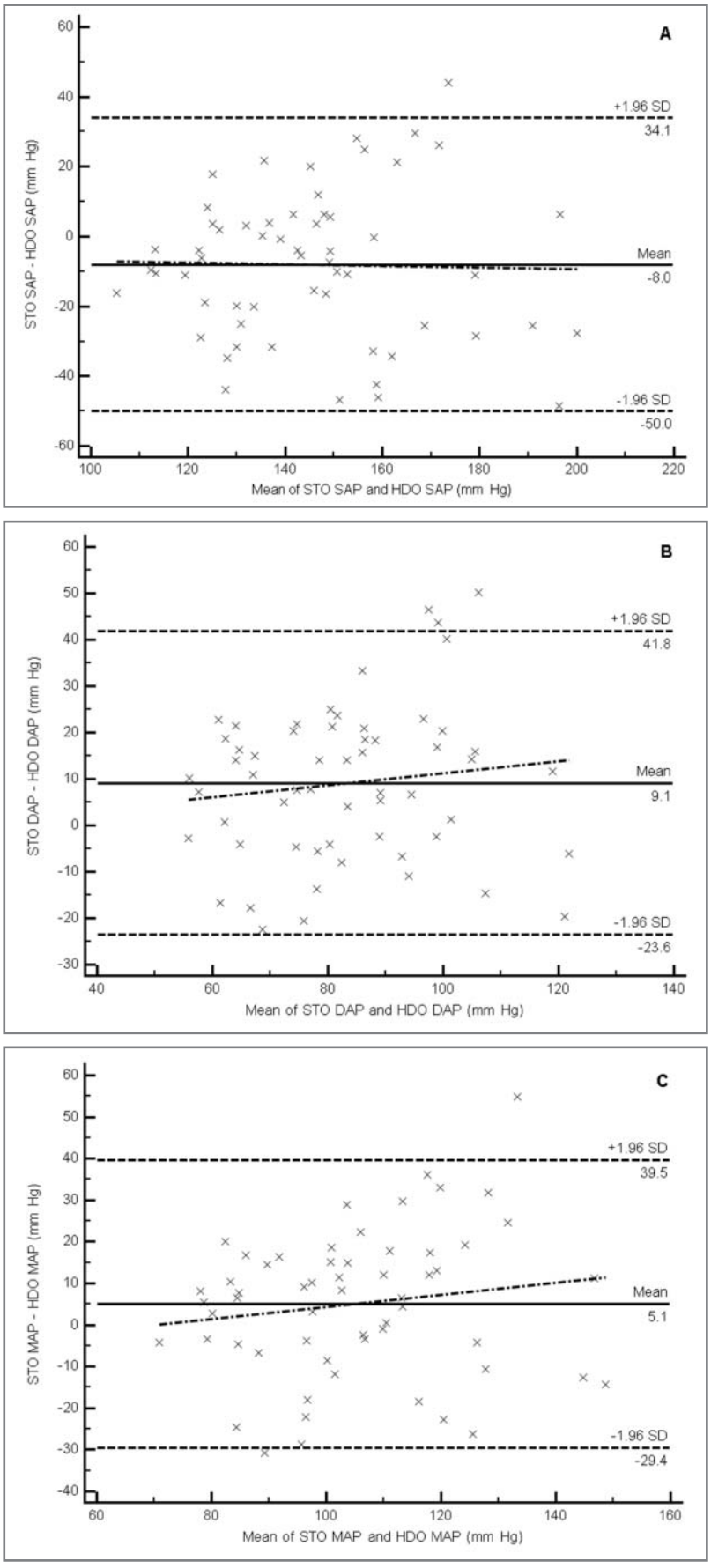

Figure 2—Bland-Altman plots for SAP (A), DAP (B), and MAP (C) in 29 hospitalized dogs as measured with the STO and HDO devices. *See* Figure 1 for remainder of key.

Table 2—Agreement and correlation of the mean for sets of 5 to 7 sequential blood pressure measurements obtained from 29 hospitalized dogs with the devices in Table 1.

Variable	Doppler vs STO (SAP)	Doppler vs HDO (SAP)	STO vs HDO (SAP)	STO vs HDO (DAP)	STO vs HDO (MAP)
Total measurement sets	75	62	58	58	58
Correlation (95% confidence interval)	0.62 (0.46 to 0.74)*	0.47 (0.25 to 0.64)*	0.62 (0.43 to 0.76)*	0.60 (0.41 to 0.75)*	0.63 (0.44 to 0.76)*
SD (mm Hg)	22.77	28.27	21.45	16.68	17.59
95% limits of agreement (mm Hg)	–41.3 to 48.0	–59.7 to 51.2	–50.0 to 34.1	–23.6 to 41.8	–29.4 to 39.5
Mean difference (bias; mm Hg)†	3.35	4.24	–7.98	9.12	5.06
Difference of ≤ 5 mm Hg (% of measurement sets)	21	21	21	17	21
Difference of ≤ 10 mm Hg (% of measurement sets)	36	40	38	34	34
Difference of ≤ 20 mm Hg (% of measurement sets)	67	56	55	71	69

*Indicated correlations are significant ($P < 0.001$). †Sets of measurements for which the CV for SAP was > 20% were excluded from data analysis.

Table 3—Number of blood pressure measurements assigned hypertension score 1, 2, or 3 as obtained from hospitalized dogs with the devices in Table 1.

	Score for second device		
Score for first device	**1**	**2**	**3**
STO vs Doppler			
1	40	11	2
2	6	7	3
3	1	2	3
HDO vs Doppler			
1	26	7	2
2	6	8	2
3	3	4	4
HDO vs STO			
1	28	6	0
2	10	2	3
3	2	5	2

Degree of hypertension was scored as 1 (SAP < 150 mm Hg), 2 (150 mm Hg ≤ SAP ≤ 180 mm Hg), or 3 (SAP > 180 mm Hg).

Measurement error and repeatability were substantially improved and somewhat improved by removing measurements for which the CV was > 20% from results of the HDO and STO devices, respectively. After such sets of readings were eliminated, paired mean values were available for 75 sessions for the Doppler and STO devices, 62 sessions for the Doppler and HDO devices, and 58 sessions for the STO and HDO devices for comparisons. The correlation between sets of mean blood pressure values obtained during the same session from each device was only moderate among devices (**Table 2**). Bland-Altman plots revealed lower SAP values with the STO device and higher SAP values with the HDO device, compared with results of the Doppler device (Figure 1). Both oscillometric devices increasingly underestimated the SAP as blood pressure increased, relative to the Doppler device. Typically, the STO device yielded lower SAPs but higher DAPs and MAPs than did the HDO device, with minimal changes across blood pressure ranges (Figure 2). The mean differences were not large, but the SDs were large, leading to wide limits of agreement. The means of the values obtained with the 2 devices differed from each other by no more than 5, 10, and 20 mm Hg in 17% to 21%, 34% to 40%, and 55% to 71% of the sessions, respectively.

When measurements were scored by use of the TODR system, the intraclass correlation for the 3 devices was 0.48 (95% confidence interval, 0.33 to 0.63). Thus, the absolute agreement between hypertension scores for the 3 devices was considered only moderate. When scores for each device were compared with those for each of the other 2 devices, absolute agreement between scores was found in 67% (Doppler vs STO), 61% (Doppler vs HDO), and 55% (STO vs HDO) of the time, respectively (**Table 3**). The interrater reliability of hypertension scores for each of the 2 devices was 0.40 for the Doppler versus STO device, 0.38 for the Doppler versus HDO device, and 0.29 for the STO versus HDO device, all of which were considered only fair.

Discussion

In the present study, blood pressure measurements obtained with 3 indirect measurement devices (Doppler ultrasonic flow detector and STO and HDO devices) from hospitalized dogs were compared. No attempt was made to validate these devices or to evaluate the consistency of readings for the same dog. Data from each measurement session were therefore evaluated independently. The sole purpose of including 3 sessions for each dog was to eliminate any possible effect of the order in which devices were used.

When blood pressure is evaluated in dogs, the general practice is to obtain several readings sequentially and to calculate the mean to obtain an estimate of SAP, DAP, and MAP. The ACVIM advocates that at least 3 and preferably 5 to 7 readings be obtained for this purpose and that sets of readings with a CV > 20% be eliminated.[1] In a previous study,[17] the within-day CVs of a Doppler device and the same HDO device as was used in the present study were similar. However, that study[17] involved only 6 healthy Labrador Retrievers. In contrast, a study[16] of 100 conscious dogs in a clinical setting revealed a CV of 5 consecutive readings that was significantly lower with the Doppler device (mean ± SD CV, 4.1 ± 3.2%), compared with the CV of the STO device (18.7 ± 11.3%). Those findings were corroborated by results of the present study, suggesting greater precision with Doppler rather than oscillometric technology. The CVs of the STO and HDO devices were all < 20% in a previous study[14] involving

anesthetized dogs. However, > 10% and 25% of sets of readings yielded a CV of > 20% with the STO and HDO devices, respectively, in the conscious dogs of the present study.

Although the investigators who compared blood pressure measurements obtained with HDO and Doppler devices from Labrador Retrievers suggested that the HDO device permits rapid readings of reliable blood pressures,[17] this is unlikely to be the situation in clinical practice if > 25% of reading sets must be repeated because of poor CVs. In the study reported here, various dog breeds were included and no attempt was made to independently evaluate readings on large or small-breed dogs or on dogs with a specific conformation. It is therefore possible that readings obtained with the STO or HDO device had lower CVs when used only on large-breed dogs or on those that are not chondrodystrophic. However, additional studies with larger numbers of dogs grouped by size and conformation would be necessary to evaluate this possibility. In the present study, the CVs for DAP and MAP calculated for both oscillometric devices were higher and more variable than were the CVs for SAP, suggesting that elimination of data with high CVs on the basis of SAP alone may lead to unreliable values for DAP and MAP.

A weakness of the present study was that only a few blood pressure measurements were found to be abnormally low with any device. This was likely attributable to exclusion of hypotensive dogs by clinicians that perceived possible detrimental effects for study participation (eg, removal of dogs from intensive care and discontinuation of drugs and IV fluids during measurements). However, inclusion of more hypotensive dogs would have increased the range over which blood pressure was measured, which would have likely increased measurement error and further decreased agreement between devices. Additional studies are required to assess agreement between the devices in hypotensive conditions.

We excluded from the study any uncooperative or anxious dogs, discounted readings when at least 5 measurements could not be obtained after discarding the first measurement, and discarded sets of data for which the CV was > 20% for SAP. However, such actions cannot always be performed in clinical practice when the clinician's goal is to obtain a blood pressure reading of a particular dog at a particular time. The results of our study are therefore likely to be conservative estimates of repeatability for devices and agreement between devices when applied to general clinical practice.

Individual readings were obtained for all attempted measurements with the Doppler device, yet measurement failure occurred in a few situations for both oscillometric devices. This observation corroborates findings from previous studies[10,12,16,19] in which readings were obtained in most attempts when a Doppler or STO device was used. In 1 study[17] involving a comparison between the HDO and Doppler devices, readings with the HDO device were always successful, but readings with the Doppler device were not. However, measurement failure with the Doppler device in that study was always due to an inability of inexperienced investigators to obtain a DAP reading, although SAP readings were always successful.

The importance of eliminating sets of readings with a high CV for SAP is underscored by the improvement in measurement error and repeatability demonstrated in the present study. Yet even after elimination of these data, error remained high for both oscillometric devices. Moreover, if results of our study are representative of blood pressure measurements obtained in general practice, repeatability within 40 mm Hg suggests that any one blood pressure reading may be clinically meaningless.

The correlation between device readings was not particularly high in our study. This was also the situation when indirect device readings were compared with direct arterial measurements in conscious dogs.[8,9] Such findings may be expected when comparing direct measurements, which assess blood flow, with indirect measurements, which assess blood pressure. However, a modest correlation becomes a concern when comparing methods that essentially measure the same thing because it suggests that a change in pressure detected by one device may not reflect a similar change with another device.

When the mean blood pressure values were compared in the present study, only two-thirds were within 20 mm Hg for the Doppler device versus the STO device but only slightly more than a half were within this range for the HDO device versus either of the other 2 devices. Moreover, only 34% to 40% of mean values were within 10 mm Hg of each other when any 2 of the 3 devices were compared. This discrepancy may be partly attributable to the fact that measurements were not strictly simultaneous but consecutive and that some minute-to-minute variation in blood pressure may have existed. However, this discrepancy in such a large proportion of measurement sessions suggests that serial measurements of blood pressure in dogs must be performed with the same device for meaningful clinical interpretation and that absolute mean values cannot be interpreted without knowledge of the device used.

Because the Doppler device has been extensively evaluated and has become the standard reference for indirect measurement of SAP in dogs, clinicians need to be aware of the particularly great discrepancy between values obtained with this device and values obtained with the HDO device evaluated in the present study. The mean differences (biases) evident in Bland-Altman plots that compared blood pressure values between pairs of devices were not large, but the limits of agreement were so wide that this would lead to blood pressure values with clinically relevant differences, further emphasizing the discrepancies in readings between devices.

Categorization of arterial blood pressure on the basis of the TODR scale with cutoffs for SAP, as suggested in the ACVIM guidelines,[1] would be a practical approach when assessing the need for treatment in potentially hypertensive dogs. However, results of the study reported here suggested that this may be an inappropriate approach, given the discrepancy of readings from different devices and the poor agreement between devices with the use of such a rating scale, particularly because some dogs were scored as grade 1 with one device and grade 3 with another device. If TODR is to be

used in dogs in a clinical setting, then it is likely that cutoff values for scoring would be useful only when established specifically for a particular device.

a. Ultrasonic Doppler Flow Detector, Model 811-B, Parks Medical Electronics Inc, Aloha, Ore.
b. Dinamap, Model 8300, Critikon Inc, Tampa, Fla.
c. Memo Diagnostic MD15/90 Pro, S+B MedVET GmbH, Babenhausen, Germany.
d. Medcalc, version 11.0.1.0, MedCalc Software bvba, Mariakerke, Belgium.

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