Received: 2 July 2020 | Accepted: 1 February 2021
DOI: 10.1111/jvim.16062

STANDARD ARTICLE

Journal of Veterinary Internal Medicine Open Access
ACVIM American College of Veterinary Internal Medicine

Impact of equipment and handling on systolic blood pressure measurements in conscious dogs in an animal hospital environment

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Abstract

Background: Situational hypertension and differences between devices complicate interpretations of systolic blood pressure (SBP) measurements in dogs.

Hypothesis/Objectives: To evaluate if time point of in-clinic SBP measurement, type of oscillometric device, and operator affect SBP measurements in conscious dogs.

Animals: Sixty-seven privately owned dogs with or without chronic kidney disease, divided into 2 study samples (A and B).

Methods: Cross-sectional diagnostic study. In part A, SBP measurements in dogs were performed using 2 different devices (HDO and petMap) after acclimatization at 3 standardized time points during a clinical visit. In part B, SBP measurements (HDO) were performed in dogs by a trained final year veterinary student and by the owner alone, at the same occasion.

Results: For all dogs, there was no difference in mean SBP (mSBP) among the 3 time points for HDO (P = .12) or petMAP (P = .67). However, intraindividual mSBP differences of up to 60 mm Hg between time points were documented. Mean SBP obtained with petMAP was on average 14 (95% CI: 8-20) mm Hg higher than mSBP obtained with HDO, and this difference increased with increasing SBP. Mean SBP measurements obtained by the trained student were 7 (95% CI: 2-11) mm Hg higher than mSBP measurements obtained by the owner.

Conclusions and Clinical Importance: According to the results of this study, time point of in-clinic SBP measurement in dogs is of minor importance, and instructing owners to perform measurements might reduce suspected situational hypertension.

Abbreviations: ACVIM, American College of Veterinary Internal Medicine; BP, blood pressure; CKD, chronic kidney disease; mSBP, mean systolic blood pressure calculated from multiple measurements with a variation of ≤20%; mSBPowner, mean systolic blood pressure calculated from measurements performed by the owner; mSBPowner_adjusted, mean systolic blood pressure calculated from measurements performed by the owner after exclusion of unreliable measurements as indicated by the HDO software; mSBPvet, mean systolic blood pressure calculated from measurements performed by the trained veterinary student; mSBPvet_adjusted, mean systolic blood pressure calculated from measurements performed by the veterinary student after exclusion of unreliable measurements as indicated by the HDO software; SBP, systolic blood pressure; TP, standardized time point during a clinical visit.

Differences in mSBP measured with HDO and petMAP underscore the need for validation of BP devices used clinically.

KEYWORDS
canine, oscillometry, situational hypertension, stress

1 | INTRODUCTION

Several factors affect results of blood pressure (BP) measurements in conscious dogs in a clinical environment. Relevant examples include breed,[1-4] sex,[5-7] age,[8-11] operator and operator experience,[12,13] and owner presence during measurements.[2] Types of measurement device,[14,15] and cuff size and placement,[16,17] are other factors that might affect BP measurement results.

An increase in BP that occurs as a consequence of stress related to the clinical environment in an otherwise normotensive animal is termed situational hypertension.[18] This phenomenon, also known as the "white coat effect," is well documented in humans and also occurs in dogs and cats.[2,6,19-25] Situational hypertension might result in uncertainty whether true systemic hypertension is present or not when measurements are high, but true systemic hypertension might also be underdiagnosed in dogs when high BP values are discarded as situational hypertension. In order to avoid situational hypertension, it is often recommended that BP measurements in dogs and cats are performed before any other interventions.[20] However, in conscious cats with implanted radio-telemetry transmittors for direct BP measurement, there is individual variation in the pattern of increases in BP during simulated office visits.[19] True hypertension, such as that associated with acute kidney injury and chronic kidney disease (CKD) in dogs, should be promptly diagnosed and treated to reduce the risk for damage to vital organs.[26,27]

The aim of the present study was to evaluate the impact of type of oscillometric device, and of time point of BP measurement during a clinical visit, on results of BP measurements in conscious dogs. Our hypotheses were that measurement results would be affected by choice of oscillometric device but not by time point of BP measurement, provided that sufficient time for acclimatization is allowed before each measurement session. Secondary aims were to evaluate whether operator (trained final year veterinary student or owner) affect BP measurement results, and to evaluate the impact of the use of graphical software on the interpretation of BP measurement results using high-definition oscillometry (HDO).

2 | MATERIALS AND METHODS

2.1 | Animals

This diagnostic cross-sectional study was performed at the University Animal Hospital, Swedish University of Agricultural Sciences, Uppsala, Sweden. Privately owned dogs were prospectively recruited and included healthy dogs and dogs with a previous diagnosis or suspicion of CKD, which were also included in another larger project concerning canine CKD.[28] The present study consisted of 2 parts, A (performed in 2015) and B (performed in 2016). In addition to dogs participating in the CKD project, seemingly healthy dogs without before experience of BP measurements were recruited specifically for part B. Informed consent was obtained from each owner before inclusion, which occurred at preplanned animal hospital visits.

All dogs (except for the healthy dogs recruited for part B only) underwent a physical examination, collection of venous blood and urine, echocardiographic examination, abdominal ultrasound examination of the urinary tract and renal scintigraphy, according to the study protocol of the primary project. Dogs that were not assigned a definitive diagnosis of CKD despite suspicion of renal disease (because of, eg, unexplained polyuria and polydipsia) were termed inconclusive.

2.2 | Blood pressure measurement

Systemic BP was measured according to published recommendations,[29] with 2 oscillometric methods, HDO (S+B medVet Babenhausen, Germany) and petMAP (Ramsey Medical Inc, Tampa, Florida). Blood pressure measurements were performed by a trained final year veterinary student (M. Lyberg) in part A and by another trained final year veterinary student (E. Ahlund), and by the dog-owner alone, in part B. Both final year veterinary students were familiarized with and trained to use the BP measurement devices before startup of the study. All measurements in both parts of the study were performed in one of the examination rooms at the animal hospital during daytime. Before each set of measurements, the dog spent 10 to 15 minutes alone in the examination room together with their owner for acclimatization. Cuff size was chosen according to the different manufacturer's instructions and the cuff was placed on the base of the tail. Measurements were performed with the cuff at the level of the heart (standing position in study A and standing or lateral recumbency, depending on in what position the dog appeared to be most at rest, in study B). The same position of the dog during BP measurement was used for all measurements of that particular dog for the duration of this study. Before each set of measurements, heart rate was documented via auscultation of the heart and pulse rate via palpation of the femoral artery. The heart and pulse rates were compared to the stated pulse rate supplied by HDO or petMAP, and measurements for which an obviously erroneous pulse rate was recorded were discarded.

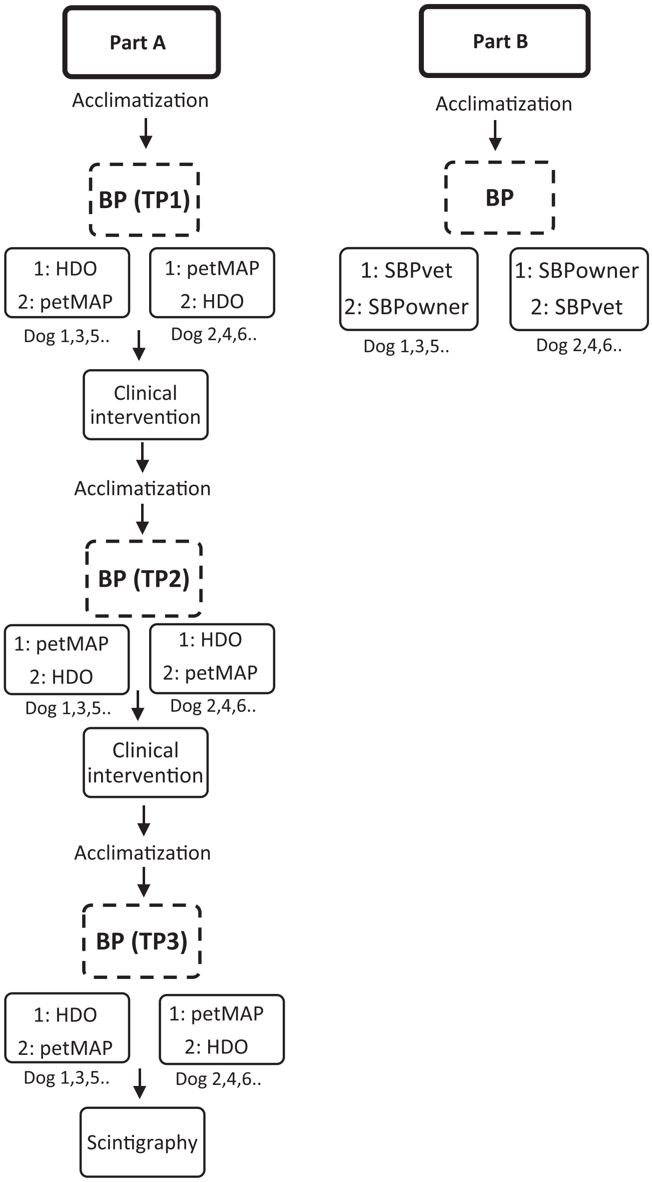

FIGURE 1 Flow chart of study parts A and B. BP, blood pressure measurement; TP, standardized time point during clinical visit; HDO, high-definition oscillometry. Clinical interventions consisted of venepuncture, abdominal ultrasound including cystocentesis, and echocardiography

2.2.1 | Part A

In part A, BP measurements were performed with the owner present in the room, using both the HDO and the petMAP systems. Measurements were performed at 3 time points during the clinical visit; before any other intervention (TP1), between peripheral venous catheter placement and abdominal ultrasound examination (TP2), and before the scintigraphic examination (TP3) (Figure 1). At each time point, BP was measured using both devices. The starting order of device (HDO or petMAP) was altered for every other dog and at every other time point according to the following: dog 1 was measured with HDO resulting in a set of measurements, followed by petMAP resulting in a second set of measurements at TP1, then with petMAP followed by HDO at TP2 and finally again with HDO followed by petMAP at TP3. Dog 2 was measured with petMAP followed by HDO at TP1, then with HDO followed by petMAP at TP2 and finally again with petMAP followed by HDO at TP3, and so on. At each time point, a minimum of 6 separate BP measurements (a set of measurements) were performed. Measurements that varied >20% were discarded and replaced by additional measurements until at least 5 measurements with a variation ≤20% were obtained. Mean systolic BP (mSBP) for each time point was calculated from 5 systolic BP measurements that varied ≤20%, for each set of measurements (for every individual and for each device, respectively).

2.2.2 | Part B

In part B, all BP measurements were performed with the HDO device. Measurements were made by EA and by the owner. The owner was present when EA performed the measurements, but the owners also performed measurements alone with the dog in the examination room. Owners were carefully instructed to keep the dog calm and document any movement or excitation if present during a specific measurement. They were also instructed how to operate the HDO device. Before the start of BP measurements performed by the owners, the cuff was positioned on the tail and the HDO device prepared for measurements by EA. The starting order of operator (EA or the owner) was altered for every other dog as follows; dog 1 was measured by EA, resulting in 1 set of measurements, followed by the owner, resulting in a second set of measurements. Dog 2 was measured by the owner, followed by EA. Dog 3 was measured by EA, followed by the owner and so on. A minimum of 8 separate BP measurements were performed by both EA and the owner of each dog. Mean systolic BP was calculated from 5 systolic BP measurements that varied ≤20% for every individual. Calculations of mSBP for measurements performed by EA (mSBPvet) were made separately from measurements made by the owner (mSBPowner).

During all BP measurements performed in part B, a software program (MDSWIN Analyse Software) was connected to the HDO via Bluetooth. After completion of part B, resulting graphs of all individual measurements (performed by both EA and the owner, respectively) were visually inspected by EA in order to identify motion artifacts or similar events that significantly changed the appearance of the graph and thereby possibly affected accuracy of measured values. Values that had been chosen for calculation of mSBPvet or mSBPowner, but were considered unreliable after inspection of the corresponding graph, were discarded and replaced by another measurement with an acceptable graph (within a 20% variation as stated previously). After exchange of unreliable measurements for reliable measurements based on inspection of graphs, a new mSBP (mSBPvet_adjusted and mSBPowner_adjusted) was calculated for each dog and for each operator, respectively.

2.3 | Statistical analysis

Statistical analyses were performed using JMP Pro 14 (SAS Institute, Cary, North Carolina) and Graph Pad Prism 8 (version 8.4.0, Graph Pad Software, San Diego, California). A *P*-value <.05 was considered significant. Age and bodyweight were presented using median and interquartile range. Wilcoxon sign rank test was used to compare measurements obtained by the 2 different devices in part A and to compare results of BP measurements for different operators in part B. Bland-Altman plots, in which the mean bias and 95% confidence intervals were calculated, were constructed. Nonparametric correlation (Spearman's ρ) was used to assess correlation between BP measurement results performed by the owner and measurement results performed by EA in part B. A mixed model analysis with interaction factors was used to investigate the relative impact of different variables (oscillometric device and time point of BP measurement in part A and operator in part B) on BP measurement results. In both mixed model analyses, "dog" was assigned a random effect.

3 | RESULTS

3.1 | Part A

3.1.1 | Dogs

Thirty-seven (25 female and 12 male) dogs were included in part A. Median age was 4.6 (1-14) years and median bodyweight was 14.8 (2.2-36.6) kg. The study sample comprised 5 mixed breed dogs, 4 Golden Retrievers, 4 Labrador Retrievers, and ≤3 individuals of 19 other breeds. In 2 of the included 37 dogs, BP was measured at only 2 time points (TP1 and TP3) because of logistic issues. Measurements were performed with the dogs in a standing position with minimal to no restraint. In total, ≈1380 single BP measurements were obtained. Including only the lowest mSBP during the day (only 1 of the 3 time points) for each dog, median (IQR) mSBP of dogs with a confirmed diagnosis of CKD (n = 14) was 141 (114-159) mm Hg for HDO, and 157 (140-193) mm Hg for petMAP. Similarly, including only the lowest mSBP during the day for each dog, mSBP of dogs without a confirmed diagnosis of CKD (healthy or inconclusive; n = 23), the median mSBP was 122 (111-145) mm Hg for HDO, and 128 (115-148) mm Hg for petMAP. The mSBP values for all dogs at all 3 time points are provided in Supplementary Table S1.

3.1.2 | Time points of measurement and devices

On a group level, there was no difference in mSBP between the 3 time points for the HDO (*P* = .12) or the petMAP (*P* = .67; Figure 2). For HDO, the median (IQR) difference between the highest and the lowest mSBP obtained at the 3 time points was 21 (13-43) mm Hg, and for petMAP 19 (8-42) mm Hg. Maximum individual differences in mSBP between time points for all dogs and both devices are shown in Figure 3.

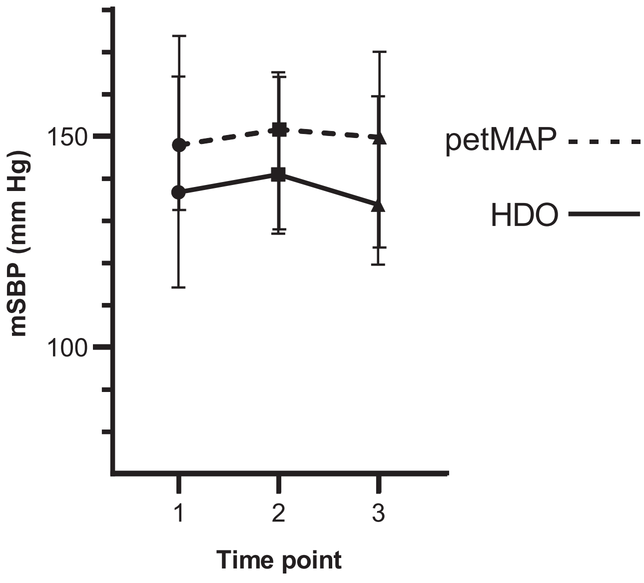

FIGURE 2 Median mSBP of all (n = 37) dogs at 3 standardized time points during a clinical visit, as measured by HDO or petMAP. Bars indicate the interquartile range. HDO, high-definition oscillometry; mSBP, mean systolic blood pressure

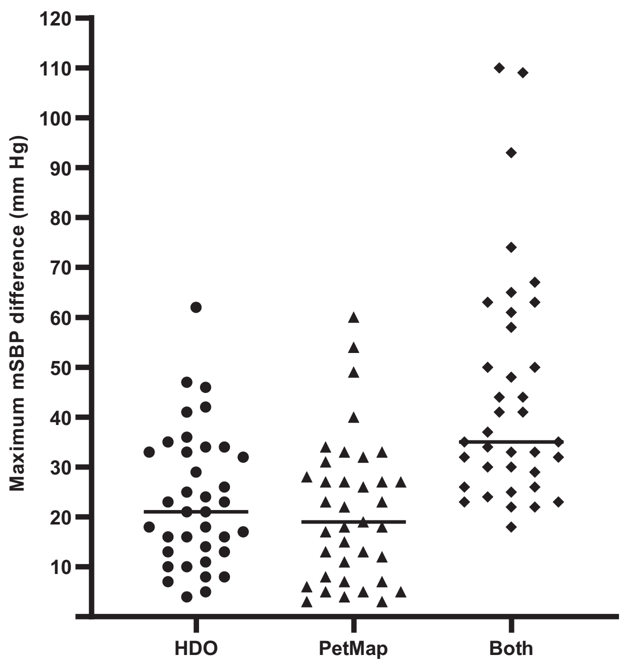

FIGURE 3 Maximum differences in mSBP among the 3 different time points of blood pressure measurement in individual dogs. Values are shown for HDO and petMAP separately and for both devices together (maximum difference among all 6 calculated values for mSBP during the day). HDO, high-definition oscillometry; mSBP, mean systolic blood pressure

Mean SBP measurements obtained with petMAP were 14 (95% CI: 8-20) mm Hg higher than those obtained with the HDO. The difference between devices increased with increasing mSBP (Figure 4).

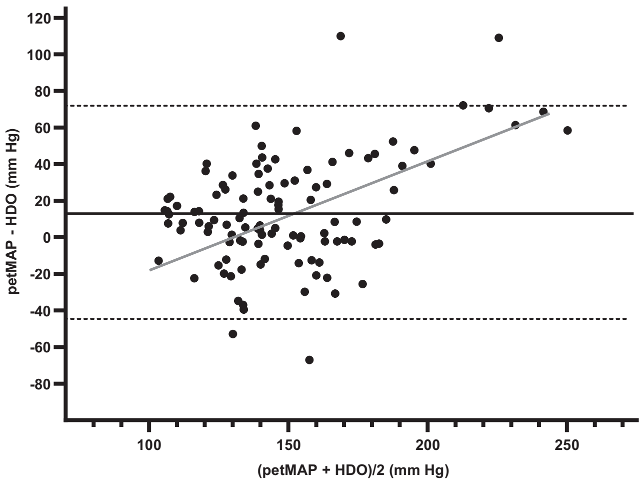

FIGURE 4 Bland-Altman plot for calculated mean systolic blood pressure in all dogs (n = 37) in part A of the study at all 3 time points measured by HDO and petMAP (109 comparisons). The solid black line indicates the mean difference (bias, 14 mm Hg) and dotted lines indicate the mean difference ± 1.96 SD (limits of agreement, −45 to 72 mm Hg). The solid gray line represents the line of best fit (least squares method)

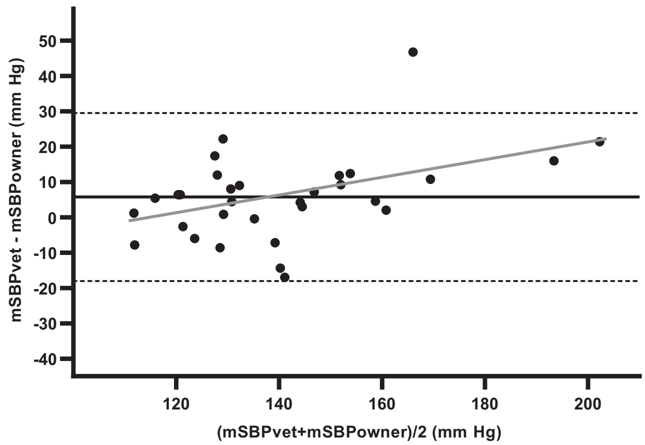

FIGURE 5 Bland-Altman plot for calculated mean systolic blood pressure in all dogs (n = 30) in part B of the study, measured by a trained veterinary student or the owner alone (30 comparisons). The solid black line indicates the mean difference (bias, 7 mm Hg) and the dotted lines indicate the mean difference ± 1.96 SD (limits of agreement, −18 to 30 mm Hg). The solid gray line represents the line of best fit (least squares method)

The mixed model analysis confirmed a significant effect (*P* < .0001) of device on mSBP values, but not time point or the interaction factor [time point × device].

3.2 | Part B

3.2.1 | Dogs

Thirty (17 female and 13 male) dogs were included in part B. Median age was 4.9 (1-13.5) years, and median bodyweight was 16.2 (6.3-46.2) kg. The study sample comprised 6 mixed breed dogs and ≤2 individuals of 20 other breeds. Using only the lowest mSBP of the day for each dog (either mSBPvet or mSBPowner), the median (IQR) mSBP of dogs with a confirmed diagnosis of CKD (n = 10) was 145 (118-169) mm Hg, and for dogs without a diagnosis of CKD (healthy or inconclusive; n = 20), the median mSBP was 130 (120-143) mm Hg. The mSBP values for all dogs and operators are provided in Supplementary Table S2.

3.2.2 | Operator

There was strong correlation between mSBPvet and mSBPowner (*r* = 0.84; *P* < .0001). Measurements obtained by EA were 7 (95% CI: 2-11) mm Hg higher than measurements obtained by the owner (Figure 5). Differences between mSBPvet and mSBPowner in individual dogs varied from 0 to 47 mm Hg and increased with increasing mSBP (Figure 5). In dogs with a mean ([mSBPvet+mSBPowner]/2) mSBP of >143 mm Hg, mSBPowner was consistently lower than mSBPvet. The mixed model analysis showed a significant (*P* = .004) effect of operator on mSBP.

3.2.3 | Software

The HDO software was used for 56 of 60 sets of measurements. The software was unavailable on the day of inclusion for 1 dog (2 sets of measurements), and no graph could be obtained by the software despite several attempts at 1 of the 2 sets of measurements in 2 other dogs. Replacement of nonreliable measurements with reliable measurements based on visual examination of graphs was possible for all other measurements. For 29 (52%) of the 56 sets of measurements with acceptable graphs, the new calculated mSBP (mSBPvet_adjusted or mSBPowner_adjusted, respectively) was identical with the original mSBPvet or mSBPowner value. Consequently, the adjusted values differed from the originally calculated values in less than half (n = 27) of all sets of measurements. In 24 (89%) of these 27 sets of measurements, the difference between the original and the recalculated values (between mSBPvet and mSBPvet_adjusted or between mSBPowner and mSBPowner_adjusted, respectively) was <10 mm Hg. In the remaining 3 sets of measurements, the differences between the original and recalculated measurements were 14, 15, and 19 mm Hg, respectively.

4 | DISCUSSION

In the present study, the time point of BP measurement during a clinical visit did not affect values on a group level, although large differences in mSBP for individual dogs were documented between time points. Type of oscillometric device and operator affected BP measurement results. Use of the HDO graphical software to identify and exclude unreliable measurements resulted in markedly (>10 mm Hg) different calculated mSBP values for only 3 of the 56 measurement sessions performed in part B.

This study did not detect a difference in mSBP on a group level among the 3 time points of BP measurement (TP1, TP2, TP3) regardless of type of device used. It is often advised that BP measurements should take place before other procedures in order to minimize stress that potentially could influence measurements.[18-20] However, the results of the present study indicate that the chosen time point of BP measurement during a clinical visit might not be overly important in dogs, provided that the dog is allowed sufficient acclimatization time before measurements. Specifically, this study did not detect that the time of arrival at the clinic (before any other interventions are performed) provides the optimal time point of BP measurement. This suggests that demeanor of the dog and technical aspects of how measurements are performed are more important.

Comparably large individual differences in mSBP values between time points were common (median difference close to 20 mm Hg for both devices). There are individual variation in systolic BP within and between days in both dogs and cats.[2,19,22,30-33] For example, within- and between-day coefficients of variation in SBP are 9.0% to 10.1% and 12.8% to 16.4%, respectively, in healthy Beagle dogs using the petMAP device.[32] There are diurnal fluctuations in SBP in healthy mixed breed dogs using a direct method (telemetry).[22] In that study, systolic BP was on average 7.7 mm Hg higher during periods of activity compared to periods of rest. In the present study, the time point that resulted in the lowest mSBP during the day varied between dogs (Table S1), possibly representing different degrees of stress at different time points during the clinical visit in individual dogs.

Measurements obtained with the petMAP device were on average 14 mm Hg higher than those obtained with HDO. The difference between devices in obtained values for mSBP increased with increasing mSBP. This increase persisted despite expressing mSBP differences between devices as percentages (data not shown). This finding reinforces existing recommendations to always use the same device when BP is monitored over time in individual dogs.[18] The results also, unfortunately, indicate that measurements by at least 1 machine (petMAP or HDO or both) probably did not satisfactorily represent the true BP of the dogs, especially in the higher ranges of mSBP. The HDO and the petMAP both have been evaluated in several studies with varying results. The use of HDO for SBP measurements in healthy awake cats is validated according to American College of Veterinary Internal Medicine (ACVIM) consensus panel.[34] To the authors' knowledge, validation of HDO according to the ACVIM consensus panel has not been performed in conscious dogs. There is no consensus regarding the conformity of SBP measurements for HDO compared to the direct method in conscious dogs.[35,36] In anesthetized dogs, the HDO meet the ACVIM criteria for mean and diastolic arterial pressures but not for systolic BP.[37] In anesthetized dogs, the HDO overestimates SBP compared to the direct method.[38] The situation is similarly unclear for petMAP.[39,40] Differences between results obtained with different devices in different scenarios indicate a need for validation of BP devices for specific clinical scenarios (eg, screening for hypertension in conscious dogs). However, even with the exclusive use of validated devices in the future, development of device-specific BP target intervals (and IRIS substage intervals) could be relevant. At the authors' University Animal Hospital, it is recommended to extend the duration of BP measurements if the routine procedure results in SBP values indicative of systemic (or situational) hypertension. The goal of performing continuous measurements (for up to 1 hour if needed) is to evaluate if the SBP gradually decreases over time in dogs and cats suspected to experience situational hypertension.[18] In current guidelines and on the International Renal Interest Society (IRIS) website, the difference between the highest SBP suggestive of normotension (139 mm Hg) and the lowest SBP suggestive of hypertension (160 mm Hg) is only 21 mm Hg.[18,41] This underscores the importance of reliable BP estimates in dogs.

Mean SBP was in average 5.8 mm Hg higher when measured by the trained veterinary student compared to measurements recorded by the owner. In dogs with an mSBP value suggestive of hypertension, mSBP was consistently lower when the owner performed the measurements. This was interpreted as a result of decreased stress in the dogs when they were alone with the owner(s) in the room. Stress affects BP in dogs as well as humans.[2,6,18,20,21,24,42] Although the clinical importance of the detected mean difference of 5.8 mm Hg is debatable, the difference between results obtained by the veterinary student and the owner increased with increasing BP up to a maximum of 46 mm Hg. The advantage of leaving owners alone in the consulting room during BP measurement represents an advantage of the use of oscillometric devices compared to Doppler devices, which are unlikely to be reliably operated by owners without considerable training.

According to the manufacturer, the graphic software belonging to the HDO can contribute to a qualitative and quantitative assessment and help minimize the risk of errors.[43] In almost 50% of the sets of measurements performed in part B, the calculated values for mSBP after visual inspection of the graphs (mSBPvet_adjusted and mSBPowner_adjusted, respectively) was different from the original values (mSBPvet and mSBP owner, respectively). However, in 89% of cases where the values differed, the difference between original and adjusted values was small and probably not clinically significant (<10 mm Hg). These results suggest that use of the HDO without the software, if not available, is reasonable. If BP measurements are extended in time and continued until a plateau is reached in dogs with suspected situational hypertension, the necessity of the software to exclude unreliable readings could potentially be even lower. Further studies are needed to investigate the value of the HDO software for interpretation of BP measurement results in dogs. In dogs that are difficult to restraint, when values differ greatly between readings, or when only a few measurements are possible to obtain, the value of using the software could be substantial.

5 | LIMITATIONS

For ethical and logistic reasons, results of indirect BP measurement in this study were not compared to values obtained with direct measurement techniques (considered gold standard). Therefore, it was not possible to draw any conclusions regarding which of the 2 devices (petMAP and HDO) resulted in the most representable BP measurements.

In the comparisons of devices and operators, measurements were made directly after one another. Considering that BP can change momentarily, this is a source of potential error. To minimize this error, the order of measurements was systematically altered. Furthermore, [device × time point] was not associated with BP results in the mixed model analysis, which showed that the difference in mSBP obtained with the 2 oscillometric devices was not influenced by time point of measurement.

Visual inspection of graphs of the HDO software is a subjective assessment. The interpretation, performed by 1 individual (E. Ahlund) in this study, could possibly have been different if a group of people had taken part in the inspection of graphs. Also, adjustment of BP measurement results using the HDO software was not performed in study A, which might be considered a limitation. Considering the result of study B however, the authors conclude that any adjustments would probably have had only minor consequences for the results of study A.

ACKNOWLEDGMENTS

No funding was received for this study. The authors thank all owners of included dogs.

CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Uppsala Ethics Committee approved this study.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Lyberg M, Ljungvall I, Häggström J, Ahlund E, Pelander L. Impact of equipment and handling on systolic blood pressure measurements in conscious dogs in an animal hospital environment. *J Vet Intern Med*. 2021;35:739–746. https://doi.org/10.1111/jvim.16062