Oscillometric and Doppler arterial blood pressure measurement in conscious goats

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Abstract

The objective of this study was to characterize arterial blood pressure (BP) measurements obtained by using 2 indirect methods, oscillometry and Doppler ultrasonic sphygmomanometry, in conscious goats. Agreement between systolic BP yielded by these 2 methods was then assessed. Sixty female dairy goats aged from 1.5 to 11.8 y (median: 5.5 y) were examined in a standing position with a cuff placed on the tail. All goats had a severe arthritic form of caprine arthritis-encephalitis. Three to 5 repeated measurements of each BP type were averaged for each goat and considered as a final measurement. With oscillometry, systolic blood pressure (O-SBP), diastolic blood pressure, and mean blood pressure, as well as heart rate (HR) were measured, while only systolic blood pressure was measured with Doppler (D-SBP). The O-SBP did not correlate with D-SBP [correlation coefficient *(r)* = 0.24, *P* = 0.067]; the mean difference (± standard deviation) was 24.5 ± 26.3 mmHg and limits of agreement were from −27.2 mmHg [95% confidence interval (CI): −39.0, −15.4 mmHg] to 76.1 mmHg (95% CI: 64.3, 87.9 mmHg). No significant linear correlation was found between any BPs and HR (*r:* −0.10 to 0.22) or age (*r:* −0.26 to 0.07) of the goats. The study showed that, while BP could be measured in conscious goats using both oscillometry and Doppler ultrasonic sphygmomanometry, the results obtained were so inconsistent that these methods could not be used interchangeably.

Résumé

L'objectif de cette étude était de caractériser les mesures de pression artérielle (PA) obtenues en utilisant deux méthodes indirectes, l›oscillométrie et la sphygmomanométrie à ultrasons Doppler, chez des chèvres conscientes. L'accord entre la PA systolique produite par ces deux méthodes a ensuite été évalué. Soixante chèvres laitières âgées de 1,5 à 11,8 ans (médiane : 5,5 ans) ont été examinées en position debout avec un brassard placé sur la queue. Toutes les chèvres avaient une forme d'arthrite sévère de l'arthrite-encéphalite caprine. La moyenne de trois à cinq mesures répétées de chaque type de PA a été obtenue pour chaque chèvre et était considérée comme une mesure finale. Avec l'oscillométrie, la pression artérielle systolique (O-PAS), la pression artérielle diastolique et la tension artérielle moyenne, ainsi que la fréquence cardiaque (FC) ont été mesurées, seule la pression artérielle systolique a été mesurée par Doppler (D-PAS). L'O-PAS n'a pas de corrélation avec D-PAS [coefficient de corrélation (r) *= 0,24,* P *= 0,067]; la différence moyenne (± écart type) était de 24,5 ± 26,3 mmHg et les limites d'accord étaient de −27,2 mmHg [intervalle de confiance à 95 % (IC) : −39,0, −15,4 mmHg] à 76,1 mmHg (IC à 95 % : 64,3, 87,9 mmHg). Aucune corrélation linéaire significative n'a été trouvée entre les PA et les FC* (r : *−0,10 à 0,22) ou l'âge* (r : *−0,26 à 0,07) des chèvres. L'étude a montré que, bien que la PA puisse être mesurée chez des chèvres conscientes en utilisant à la fois l'oscillométrie et la sphygmomanométrie à ultrasons Doppler, les résultats obtenus étaient si incohérents que ces méthodes ne pouvaient pas être utilisées de façon interchangeable.*

(Traduit par Docteur Serge Messier)

Introduction

Systemic (arterial) blood pressure (BP) can be measured with direct (invasive) or indirect (noninvasive) methods. While the former is considered a gold standard, it requires a constant intra-arterial access, which precludes its use in conscious animals. Indirect methods consist of oscillometry and Doppler ultrasonic sphygmomanometry. Both can be done in conscious animals, but they easily unnerve animals as a compressive cuff has to be placed to apply pressure to a limb or the tail. In addition, a single examination lasts several to 15 min as 3 to 7 consecutive measurements are routinely taken and the first one is usually discarded as it is potentially most affected by the stress reaction (1). Oscillometry measures mean blood pressure (O-MBP), from which systolic blood pressure (O-SBP) and diastolic blood pressure (O-DBP) are then automatically derived, while Doppler only reliably measures the systolic blood pressure (D-SBP), since diastolic blood pressure using this method can vary greatly depending on the examiner (2).

Obviously, the 3 methods for measuring blood pressure do not yield identical results and evaluating agreement between them may

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Table I. Intra-measurement variability of oscillometric systolic (O-SBP), diastolic (O-DBP), and mean (O-MBP) blood pressure and Doppler systolic blood pressure (D-SBP) measurements in 60 adult female goats after removal of inconsistent measurements, i.e., 3 to 5 measurements included for each goat.

	Number (%) of goats with the following number of measurements retained			Coefficient of variation (CV)		
Blood pressure	5	4	3	Median	IQR	Range
D-SBP	60 (100%)	0	0	5.5	3.5 to 8.7	0 to 28.8
O-SBP	42 (70%)	16 (27%)	2 (3%)	5.5	3.4 to 8.0	0.4 to 21.8
DBP	47 (78%)	12 (20%)	1 (2%)	13.2*	7.4 to 20.0	1.2 to 37.7
MBP	43 (72%)	13 (22%)	4 (6%)	7.5	3.0 to 12.7	0.4 to 25.0

* Significantly higher at $\alpha = 0.05$; no other blood pressures differ significantly.
IQR — interquartile range.

lead to subjective conclusions. According to the guidelines of the American College of Veterinary Internal Medicine (1) and recommendations for humans (3), the mean difference (often called bias) and standard deviation (called precision) between invasive and noninvasive measurements should not be greater than 10 ± 15 mmHg, while the mean difference (standard deviation) between the 2 different noninvasive methods should not exceed 5 ± 8 mmHg.

Several studies have so far evaluated accuracy of the oscillometric method in anesthetized small ruminants (4-6) and, in general, these guidelines and recommendations were satisfied or nearly satisfied, which is in line with observations in dogs (7), cats (8), and horses (9). On the other hand, no study has directly assessed accuracy of the Doppler method in small ruminants or compared it with oscillometry. This issue needs to be clarified as results obtained in other animal species do not allow for a simple extrapolation. Although the Doppler method is generally considered reliable in companion animal practice (1), several studies have reported poor agreement between the 2 indirect methods in either anesthetized or conscious dogs (10,11) and cats (12,13). Moreover, the Doppler ultrasonic method seems to be unsuitable for horses (14).

The objective of this study was to characterize arterial BP measurements obtained by oscillometry and Doppler ultrasonic sphygmomanometry from conscious goats and to assess the agreement between systolic BP yielded by these 2 methods.

Materials and methods

Goats

Sixty female adult goats from a large dairy herd were enrolled. They belonged to the Polish White Improved and Polish Fawn Improved breeds and ranged from 1.5 to 11.8 y, with a median age of 5.5 y and interquartile range (IQR) of 3.7 to 7.1 y. All goats came from a single herd and were intended for sanitary culling due to a severe arthritic form of caprine arthritis-encephalitis (CAE), as confirmed by the positive result of an enzyme-linked immunosorbent assay (ELISA) (ID Screen MVV/CAEV Indirect Screening test, ID.vet; Innovative Diagnostics, Grabels, France) and the presence of the following clinical signs: lameness, uni- or bilateral swelling of carpal joints (carpal:metacarpal ratio of > 2), and emaciation (sternal and lumbar scores of 0 or 1) (15).

The goats were brought to the University Veterinary Clinic 2 to 7 d before BP measurement to allow for acclimatization to their new surroundings. During this time, they were kept in pairs in deep straw-bedded pens and fed with hay at will and oat grains and root vegetables in portion.

According to Polish legal regulations, no ethics committee approval was required as the study was not associated with a painful procedure. The owner granted informed consent for the goats to participate in the study.

Blood pressure and heart rate measurements

Blood pressure (BP) was measured on the tail in unsedated standing goats by 2 experienced examiners (OSJ, AŚ). Two methods were applied — oscillometry, with the use of a Cardell Veterinary Monitor, Model 9401 (Midmark, Dayton, Ohio, USA) and Doppler ultrasonic sphygmomanometry, with the use of an Ultrasonic Doppler Flow Detector, Model 811-B (Parks Medical Electronics, Las Vegas, Nevada, USA). In both methods, the width of the selected cuff was approximately 40% of the tail circumference and BP was measured 5 times in each goat. Systolic, diastolic, and mean BP, as well as heart rate were measured in oscillometry (O-SBP, O-DBP, O-MBP, and HR, respectively), while only systolic BP was measured in Doppler (D-SBP). In Doppler, skin in the area of probe placement was cleaned with alcohol and covered with coupling gel. The flat probe was positioned over the artery to obtain a clear audible signal from the Doppler device. The cuff was filled with air up to 30 mmHg over the point where the pulse signal was no longer audible and then gently deflated. The value at which the pulse signal was audible again was recorded as D-SBP.

Statistical analysis

Numerical values were given as the arithmetic mean ± standard deviation (SD) or median and interquartile range (IQR), depending on the normality of data distribution assessed with the Shapiro-Wilk W test. A range was presented every time.

In 5 measurements of any BP taken from a goat, extreme values were identified on the basis of the Tukey method (all values smaller

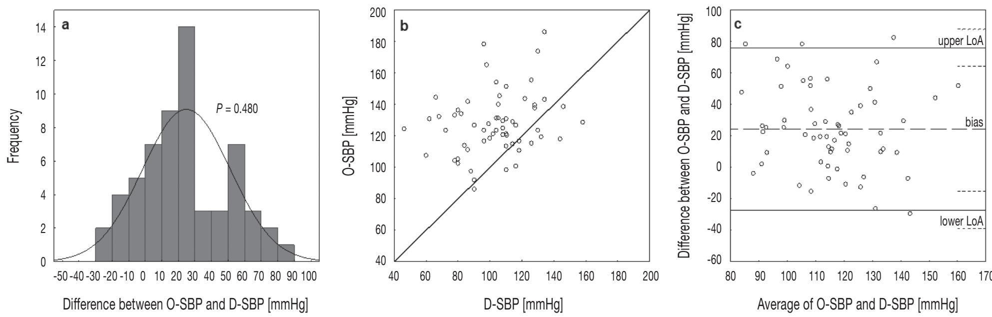

Figure 1. Histogram of differences with: a — theoretical normal distribution; b — scatter plot with the line of equality; and c — the difference against mean (Bland-Altman) plot for oscillometric systolic blood pressure (O-SBP) and Doppler systolic blood pressure (D-SBP). LoA — 95% limit of agreement [with 95% confidence interval (CI)]. *P*-value is the result of the Shapiro-Wilk test (α = 0.05).

than by 1.5 IQR from the lower quartile or larger than by 1.5 IQR from the upper quartile). The overall number of extreme values was compared between D-SBP and the 3 oscillometric BPs using Cohran's Q test. Variability among the 5 initial measurements of each BP type (before discarding inconsistent measurements) was assessed using a repeated-measure analysis of variance (ANOVA) with Greenhouse-Geisser correction for violation of sphericity (as shown by Mauchly's test).

If extreme values resulted in a coefficient of variation (CV) of above 20% for a patient's BP, the measurements were discarded as inconsistent (1). The remaining 3 to 5 values were averaged and used as the final BP measurement for a given goat.

In order to show discrepancies among BP measurements obtained in a single goat (intra-measurement variability), which still remained despite the fact that inconsistent measurements were discarded, the coefficient of variation (CV) was determined again by dividing the SD of the repeated measurements by their arithmetic mean. The CV was compared among all types of BP measurements using Friedman's test with the Dunn-Bonferroni *post-hoc* test (16).

Measurements of D-SBP and O-SBP were compared using a paired-sample Student's *t*-test and plotted on the scatter plots with the line of equality and the Bland-Altman plots. Mean (± SD) of differences between O-SBP and D-SBP measurements were used to compute limits of agreement (LoAs) with their 95% confidence interval (CI) (17). A Pearson's product-moment correlation coefficient *(r)* was used for evaluating linear correlation between O-SBP and D-SBP, as well as among all BPs and HR measurements or the age of the goat.

All statistical tests were 2-tailed. A *P*-value < 0.05 was considered statistically significant. Analyses were carried out in Statistica 12 (StatSoft, Tulsa, Oklahoma, USA).

Results

There were 23 extreme values identified in O-SBP, 20 in O-DBP, and 24 in O-MBP, whereas none were identified in D-SBP and this was a significant difference ($P < 0.001$). Before removing inconsistent measurements, as the first BP measurements did not differ from the remaining 4 in the repeated-measure ANOVA (O-SBP: $P = 0.455$; O-DBP: $P = 0.574$; O-MBP: $P = 0.660$; D-SBP: $P = 0.564$), the first BP measurements were not discarded by default. Out of all extreme values, 20 were discarded as inconsistent in O-SBP, 14 in O-DBP, and 21 in MBP.

After removal of inconsistent measurements, the coefficient of variation (CV) of O-DBP was significantly higher than CV of O-SBP, MBP, and D-SBP ($P < 0.001$) (Table I). The O-SBP was 128 ± 20 mmHg (86 to 186 mmHg), O-DBP 71 ± 19 mmHg (42 to 120 mmHg), O-MBP 96 ± 18 mmHg (54 to 138 mmHg), and D-SBP 103 ± 23 mmHg (46 to 158 mmHg). HR was 90 ± 21 bpm (59 to 143 bpm).

O-SBP did not correlate with D-SBP ($r = 0.24$, $P = 0.067$). Oscillometry significantly overestimated systolic BP compared to Doppler by the mean of 24.5 ± 26.3 mmHg (95% CI: 17.7, 31.3 mmHg; $P < 0.001$). Limits of agreement (LoAs) were from −27.2 mmHg (95% CI: −39.0, −15.4 mmHg) to 76.1 mmHg (95% CI: 64.3, 87.9 mmHg) (Figure 1).

No significant linear correlation was found between any BP measurement and HR ($r = -0.10$ to 0.22) or age ($r = -0.26$ to 0.07) of goats.

Discussion

Our study clearly shows that systolic blood pressure measured with oscillometry (O-SBP) differs substantially from that measured with Doppler (D-SBP) in conscious goats. Oscillometry tends to overestimate SBP compared with Doppler by roughly 25 mmHg and 95% of O-SBP measurements are expected to vary from up to 76 mmHg above D-SBP through up to 27 mmHg below D-SBP. This means that both bias and precision are much higher than what is accepted in veterinary and human medicine (1,3). These disparities preclude using the 2 methods interchangeably in goat clinical practice.

Our study does not indicate which method provides results that are most consistent with true BP. Given that oscillometry proved sufficiently accurate in previous studies on sheep (4–6), perhaps Doppler is less trustworthy. There are so many different factors affecting indirect BP measurement, such as the device used, the position of the patient, the site of cuff placement and fur clipping, and the width of the cuff (1,18–20), that any conclusions should be made with caution. Furthermore, data on the diagnostic performance of oscillometry have so far been collected in generally anesthetized small ruminants as part of perioperative monitoring, when the influence of stress and animal movements could be alleviated. It is widely known that stress or anxiety associated with the measurement process itself can interfere with BP measurement and usually leads to falsely elevated results (21–24). This is probably why the mean BPs we obtained in oscillometry are an average of 20 mmHg higher than results obtained in a previous study (4).

Blood pressure is measured in conscious animals in order to detect clinically significant hypertension or, less often, hypotension. It has found its place in companion animal medicine and large-scale epidemiological studies have provided reference intervals for these animals (24,25). Kidney failure, as well as various endocrine disorders, have been identified as primary causes of hypertension and proper BP control has proven to improve prognosis (1). No analogical diseases associated with abnormal BP are currently regarded as important health problems in goats. Nevertheless, goats are gaining popularity as pets and textbooks on goat medicine already dedicate chapters to health conditions in aging goats (15). Interest in the internal medicine of goats is growing and the attention of veterinarians will inevitably be directed to cardiovascular problems. As hypertension is one of the most recognizable conditions in human health (27), goat owners will also demand evidence-based health care, as is already the case with owners of dogs, cats, and horses (1).

From this standpoint, this is the first study carried out on a large group of conscious goats. The results of this study cannot be considered as indicators of normal BP in conscious goats, however, because at least 2 factors may have interfered with the BP values obtained. First, goats enrolled in the study were clinically ill with a severe arthritic form of CAE, which is usually associated with emaciation. Although nothing is known about the occurrence of hypertension in CAE, microscopic traits of degeneration and necrosis have been revealed in the kidneys of CAE-affected goats (28). As chronic kidney failure is one of the most important causes of secondary hypertension, pathological elevation of BP by CAE cannot be excluded. Second, and probably more important, goats that we examined had been taken away from the herd a few days before, kept in a totally different environment, and then examined by strangers who they had met only a few times before. This would have caused stress in the goats. Nevertheless, the BP values we obtained were similar to those previously observed in conscious dogs (24) and even lower than those obtained in unsedated cats (25) and horses (9). This may suggest that the role of so-called "white-coat syndrome" should not be overrated in goats.

Our study shows that both oscillometry and Doppler yield BP measurements of acceptable intra-measurement variability in conscious goats. By applying simple statistical procedures, we were able to identify extreme values and produce at least 3 (usually 4 to 5) consistent repeated measurements (1). As observed in other studies, O-DBP had the highest intra-measurement variability (4). On the other hand, Doppler was least likely to yield extreme measurements. Furthermore, our study does not seem to substantiate the recommendation of routinely discarding the first measurement, as BP measurements taken at first did not differ significantly from subsequent repetitions.

In conclusion, blood pressure can be measured in conscious goats using both oscillometry and Doppler ultrasonic sphygmomanometry. These methods cannot be used interchangeably, however, as the results obtained are very inconsistent. It remains to be clarified which of the 2 methods is the most accurate in conscious goats.

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