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ORIGINAL RESEARCH

Non-invasive blood pressure measurement in conscious rabbits: A comparison of Doppler ultrasonic and oscillometric devices

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Abstract

Background: This study aimed to compare Doppler (the most commonly used technique for non-invasive indirect blood pressure [NIBP] measurement in rabbits) and oscillometric devices for NIBP measurements in conscious rabbits.

Methods: Blood pressure (BP) measurements were obtained for 49 conscious rabbits using the Doppler and oscillometric devices. Each measurement was repeated in triplicate. Three rabbits were excluded from the study because it was not possible to obtain BP measurements using the oscillometric device. The American College of Veterinary Internal Medicine (ACVIM) guidelines were followed to compare the results obtained with the two devices.

Results: A total of 164 systolic BP measurements were obtained with the Doppler device and 182 were obtained with the oscillometric technique. The mean of the three values obtained for each animal with each device was used for statistical analysis. The analysis demonstrated a poor level of agreement between the measurements obtained with the two devices.

Limitations: Oscillometric devices rely on built-in software algorithms to perform calculations and produce their measurements. However, the oscillometric devices currently available only have the software for dogs and cats installed. Therefore, these conclusions should be revised when a device with software specifically for rabbits is commercialised.

Conclusions: This study indicates that oscillometric devices should not be used as a substitute for the Doppler technique when measuring BP in rabbits.

KEYWORDS
Doppler, non-invasive blood pressure measurement, oscillometric technique, rabbit medicine

INTRODUCTION

Veterinarians have detected an increase in the life expectancy of pet rabbits over the past decade.[1–3] Nowadays, pet owners are more educated regarding the husbandry and diet of their animals, and veterinarians have more medical, surgical and diagnostic resources to treat them. Therefore, the lifespan of exotic species is slowly increasing every year, and it is increasingly common that 9 and 10-year-old rabbits are being presented at the clinic (even 14-year-old rabbits in the authors' experience). Thus, age-related pathologies are increasing among our rabbit patients.

Cardiovascular diseases are one of the less well-understood pathologies in rabbits that are now being diagnosed more frequently.[4] Among the complementary tests that are reliable for the assessment of cardiac functionality in lagomorphs (cardiac auscultation, radiography, echocardiography, electrocardiography and blood pressure [BP]), the present study focused on the evaluation of BP as a marker of the cardiorenal axis and vascular (atherosclerosis/vascular dystrophic calcifications) assessment.[5–8]

BP is defined as the pressure exerted by blood vessels when blood is expelled from the heart during

TABLE 1 Blood pressure risk levels for target organ damage

Risk level	SBP (mmHg)	DBP (mmHg)	Damage to target organs
I	<150	<95	Minimum
II	150–159	95–99	Light
III	160–179	100–119	Moderate
IV	≥180	≥120	Severe

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure.

contraction of the ventricles. Hence, it is considered an important regulator of cardiovascular function.[5,9–16] Reliable measurements of BP in rabbits have been used for cardiovascular disease studies and to understand the effect of different drugs on the cardiovascular system in human medicine.[7,8,17] In veterinary medicine, BP measurement in this species is vital, especially for older animals. As mentioned before, advances in internal medicine and pet owners' knowledge have led to a drastic increase in the average lifespan of these animals. This has resulted in a proportional increase in the diagnosis and treatment of age-related diseases. Among these, cardiovascular diseases (including hypertensive disorders) are one of the 'emerging pathologies' seen in rabbits.[1–2,5,7,8]

Systemic hypertension is defined as a persistent increase in systemic BP. Hypertension can be related to many pathologies, including eye damage, encephalopathy and renal and/or cardiovascular disorders. In other animal species (such as dogs and cats), there are published guidelines for the definition, diagnosis and management of systemic hypertension.[18] These guidelines propose four classifications for systemic BP, based on the risk of causing damage to target organs. According to these guidelines, there is a moderate risk of damage associated with a systolic blood pressure (SBP) of 160 mmHg or greater (category III), while an SBP of 180 mmHg or greater (category IV) indicates a severe risk. Various studies have proposed that SBP in lagomorphs is not significantly different from that in healthy dogs and cats.[3,4,10,18–22] Thus, in the absence of other studies on target organ damage in rabbits, we recommend the use of these guidelines for the control of hypertension-related pathologies in our patients (Table 1).

There are three methods available for indirect measurement of BP in veterinary medicine: Doppler, oscillometry and photoplestimography. According to the literature, the most commonly used technique for BP measurement in lagomorphs in veterinary clinics is the Doppler technique.[2,10,17,23]

Although invasive blood pressure (IBP) measurement is still considered the gold standard, non-invasive blood pressure (NIBP) measurement is generally used in routine veterinary practice due to the complexity of IBP measurement in the clinic – it must be measured in anaesthetised patients, with an artery catheterised and with technical equipment that is not available to every clinician.[4,5,10,24]

The Doppler technique is a universally used technique for NIBP measurement in rabbits and shows good correlation with the values obtained by gold standard IBP measurement.[3–5,10,17,25,26] There are several studies in which the oscillometric technique has been used in rabbits, but none of them compared the Doppler and oscillometric techniques in healthy and conscious rabbits.[26–30]

The way in which Doppler and oscillometric devices measure BP differs. While a Doppler device detects the blood flow using the Doppler effect on moving red blood cells, oscillometric devices rely on the detection of oscillations in the artery and built-in species-specific algorithmic calculations to measure SBP, diastolic blood pressure (DBP) and mean blood pressure (MBP). Theoretically, oscillometric devices are easier to use than Doppler machines. The Doppler method involves detecting blood flow using ultrasound, and the operator must complete a learning curve to use the machine reliably. However, this is not necessary when using an oscillometric device because it relies on the detection of oscillations in the cuff during the inflation and deflation processes. This oscillometric approach eliminates the need for precise ultrasonographic detection, significantly simplifying the measurement procedure. This could be a good reason to substitute the classic Doppler method for these oscillometric devices, as they also offer other advantages, such as obtaining SBP values easier and faster.[30–34]

The accuracy of NIBP measurements is an important prerequisite for their use.[20,31] NIBP measuring devices have been validated since the 1980s, and a consensus for device validation has been achieved and published due to a collaboration between the Association for the Advancement of Medical Instrumentation, the European Society of Hypertension and the International Organization for Standardization.[35] In veterinary medicine, standards for the validation of NIBP devices were established by the American College of Veterinary Internal Medicine (ACVIM) Consensus Statement.[18] This consensus statement was revised in 2018 and recommended that every NIBP measuring device should be validated.[20] These standards can be applied not only to compare a new technique with the gold standard (IBP method in our case) but also to compare one NIBP technique with another previously validated technique.[20,35]

The main objective of this study was to evaluate the agreement between the SBP values obtained with a Doppler device (SBPd; Dopplex, Huntleigh Vettex) and an oscillometric device (SBPo; SunTech Vet20, Braun) in healthy, conscious rabbits. The secondary objective was to determine the time necessary to obtain the measurements with both devices.

MATERIAL AND METHODS

Animals

A prospective clinical study was performed, which included rabbits presented to the Hospital Clínico Veterinario Complutense (Universidad Complutense Madrid) between September 2021 and June 2022.

This study was conducted using a diverse population of rabbits, comprising 26 females (53.06%) and 23 males (46.94%). No pathologies affecting BP values were detected in the animals, based on clinical history, physical examination and a basic blood test. Nine animals (18.36%) were intact, while the remaining 40 (81.64%) had undergone sterilisation.

The rabbits were classified into distinct age groups, following previously established criteria.[4] Group I included young animals up to 1 year of age ($n = 11$), group II consisted of adult animals aged between 1 and 5 years ($n = 19$) and group III included geriatric animals aged 5 years or more ($n = 19$). The youngest rabbit in the study was 4 months old, while the oldest was 12 years old. Additionally, the study included a variety of rabbit breeds, including Netherland dwarf ($n = 22$), Ibicenco ($n = 5$), Flemish giant ($n = 7$), lionhead ($n = 3$), Angora ($n = 4$) and Holland lop ($n = 8$). The individual weights of the rabbits ranged from 0.685 to 4.2 kg, with an average weight of 1.88 kg. The inclusion of a diverse and well-characterised population in the present study holds significant relevance for basic clinical understanding. In routine clinical consultations, healthcare professionals frequently encounter patients with varied demographic backgrounds, including differences in age, sex and health status. By mirroring this diversity in our study population, we aimed to provide insights that better reflect the real-world scenario of a mixed patient population typically seen in clinical practice.

In order to determine whether the measurements taken with the oscillometric equipment were in agreement with the measurements taken with the Doppler device, a Bland–Altman analysis was performed. The results were validated with the ACVIM consensus guidelines as well. The limits to be met for the ACVIM validation include:

1. The mean difference of paired measurements must be less than ±10 mmHg and the standard deviation (SD) must be less than ±15 mmHg.
2. The correlation between paired measurements treated separately should be 0.9 or more across the range of measured BP values.
3. Fifty percent of all measurements for SBP and DBP must be within 10 mmHg, and 80% must be within 20 mmHg of the invasive measurement.[20]

Protocol

For every animal, an identical BP measurement protocol was used based on the 'appropriate handling of pet rabbits' protocols.[36] The animals were received in the exotic animal consultation rooms at the Hospital Clínico Veterinario Complutense (Universidad Complutense Madrid) and kept in their carriers in a quiet environment for at least 5 minutes so that they could calm down before initiating the study. Throughout the procedure, every animal was handled smoothly and kept on the examination table with an adherent surface in a sternal decubitus position. Devices were used alternately as the first device, and the same sequence of techniques was used in all rabbits.

The guidelines of the ACVIM consensus statement on feline hypertension were used to standardise the results obtained, as no consensus on rabbit hypertension has been published to date. According to these guidelines, a single trained operator made all BP measurements with both devices, and three observers recorded the time taken to obtain the measurements.

Two methods were used to measure the blood pressure: (Figure 1)

1. For the SBP measurement using the Doppler technique, a paediatric blood pressure cuff with a width between 30% and 40% of the limb circumference[2,4,10,23,24,37] was placed on the front leg, proximal to the elbow joint and connected to a sphygmomanometer. A Doppler probe was used to locate the radial arterial pulse (medial/mediocranial face of the forearm distal to elbow joint) and used to measure systolic blood pressure by inflating the cuff until no pulse was recorded, and then slowly deflating it. The beginning of the equivalent of Korotkoff sounds during cuff deflation was recorded as the systolic blood pressure. At least three similar consecutive measurements (less than 10% difference) were necessary to calculate the mean SBP and to consider the measurement obtained acceptable.
2. For the measurement of tension using the oscillometric technique, a cuff was placed (same cuff diameter as with the Doppler technique for every patient) on the anterior extremity, proximal to the elbow or on the proximal radiocubital region, depending on the diameter of the limb, and it was connected to a tensiometer (SunTech Vet20, BRAUN). At least three similar consecutive measurements were considered necessary to calculate the mean BP values.

Statistical analysis

Statistical analysis was performed using SPSS.25 and SAS programmes. The data are expressed as the mean of SBP, DBP and MBP ± SD. Repeated measures for ANOVA were used to compare the means of the different devices. For statistical analyses, the mean SBP measurements derived from each rabbit were utilised.

To assess the agreement between SBP measurements obtained from the Doppler and the oscillometric devices, the Bland–Altman analysis was conducted. Additionally, a paired-sample *t*-test was employed to identify any statistically significant mean difference in SBPd and SBPo. Statistical significance was considered at a *p*-value of less than 0.05.

RESULTS

BP values were obtained from 46 of the 49 rabbits enrolled in the study. It was not possible to obtain

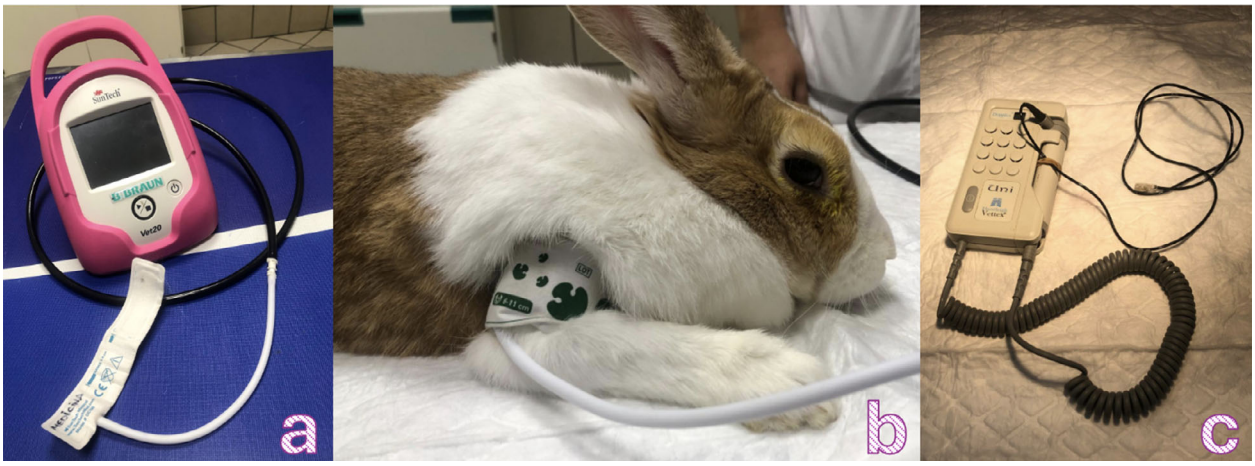

FIGURE 1 (a) SunTech Vet20, BRAUN, oscillometric device. (b) Paediatric blood pressure cuff positioning. (c) Dopplex, Huntleigh Vettex, Doppler device

correct pressure measurements with the oscillometric method in three rabbits. After a 15-minute attempt, three similar consecutive measurements were not acquired; thus, these animals were removed from the study (Table 2).

Out of the 346 readings obtained, 276 measurements (164 Doppler readings and 182 oscillometric readings) were selected for inclusion in the study based on the ACVIM criteria. This rigorous filtering process ensured that only consecutive blood pressure results with a difference of less than 10% between successive readings were included in the analysis. By adhering to these criteria, the study aimed to maintain a high standard of data quality and consistency in the analysed dataset. Only the systolic arterial pressure measurements were compared, as the Doppler technique does not report diastolic arterial pressure measurements.

The oscillometric method yielded a mean SBPo of 110.39 mmHg (ranging from a minimum of 71 mmHg to a maximum of 155 mmHg), while the Doppler method gave a mean SBPd of 111.88 mmHg (with a minimum of 67 mmHg and a maximum of 167 mmHg). Statistical analysis revealed no significant difference between the mean values obtained ($p = 0.56$). However, despite this lack of statistical difference, there was no correlation between the results obtained with the two methods ($p = 0.07$; interclass correlation of 0.3). The measured differences between the two methods ranged from 2 to 52 mmHg, with a mean difference of 17.56 mmHg.

Upon analysing the mean of SBPd and SBPo, a bias of 17.56 ± 14.71 mmHg was observed. Only 42.22% of the compared results exhibited a difference of less than 10 mmHg, and 71.11% were within a 20 mmHg limit (Table 3).

In addition to these comparative results, an adjustment for multiple comparisons was done using the Bland–Altman correction test (Figure 2), obtaining a positive bias (approximately 3). However, a statistically significative variability of SBP was obtained, thus demonstrating a poor agreement and precision between the two techniques.

There was no statistically significant difference observed in the results obtained based on breed, weight or sex ($p > 0.05$).

The average procedural time, encompassing the interval between cuff placement to the final measurement, varied significantly between the two techniques. The oscillometric method recorded a duration ranging from 105 seconds to 900 seconds, with a mean of 392 seconds. In contrast, the Doppler method demonstrated a narrower range, from 35 seconds to 430 seconds, with a mean procedural time of 137 seconds (Table 4).

DISCUSSION

Rabbit cardiology is still in its infancy, and cardiovascular issues in rabbits remain relatively uncommonly reported in the veterinary literature.[1,3,4,10] In fact, some studies relegate these alterations as anecdotal findings among the general rabbit population.[38] Nevertheless, recent publications suggest an increasing prevalence, nearing 2%, of cardiovascular problems within the general rabbit population.[39] However, rabbits are experiencing longer lifespans compared to a decade ago, and age-related conditions, including cardiovascular issues, are being diagnosed more frequently. Consequently, the demand for precise and straightforward BP measurement methods has become imperative. This study, therefore, addresses a critical need in advancing our understanding of BP measurement in rabbits, contributing to the evolving landscape of rabbit cardiology.

In the current investigation, we conducted a comparative assessment between an oscillometric device and a Doppler device, adhering to the validation guidelines for BP measurement devices outlined by ACVIM, as previously established for dogs and cats.[18] Notably, our review of the existing literature revealed a conspicuous absence of studies directly comparing these indirect techniques. As such, we assert that this study constitutes a pioneering effort, representing the

TABLE 2 Data on age, weight and systolic blood pressure (BP) measurements obtained using the oscillometric and Doppler devices, and the time taken to obtain the readings

			Oscillometric device		Doppler device	
Animal	Age (years)	Weight (Kg)	Systolic blood pressure (mmHg)	Time taken to obtain reading (seconds)	Systolic blood pressure (mmHg)	Time taken to obtain reading (seconds)
1	0.75	0.90	94	355	100	160
2	10	1.31	105	395	112	190
3	2	3.93	88	370	120	255
4	0.83	2.44	90	345	84	110
5	5	2.71	130	755	143	125
6	2	0.68	124	190	126	140
7	0.75	0.8	-	900	111	235
8	2	1.26	85	255	91	115
9	2	1.23	74	275	88	130
10	2	0.77	145	290	100	100
11	3	0.79	78	365	95	55
12	3	2.07	118	440	96	190
13	10	1.89	84	900	135	170
14	2	2.9	115	340	123	190
15	2	1.14	84	380	141	115
16	2	1.55	92	685	110	55
17	2	1.53	114	160	93	430
18	5	1.6	91	330	93	195
19	1	1.27	98	380	122	125
20	2	2.91	123	465	133	105
21	2	3.23	153	195	140	85
22	4	3.14	116	285	85	105
23	4	1.83	91	868	136	50
24	7	1.46	104	583	88	80
25	2	1.78	110	495	114	60
26	4	4.2	125	135	123	50
27	0.33	1.21	109	195	128	75
28	0.58	2.13	113	160	104	140
29	0.58	2.24	152	105	100	200
30	5	2.47	112	155	121	35
31	12	1.45	152	900	132	255
32	0.58	2.42	129	710	123	430
33	5	1.65	71	125	125	195
34	2	2.27	-	900	67	185
35	0.58	1.98	94	130	99	45
36	6	1.98	115	375	157	35
37	0.92	1.54	96	113	85	117
38	7	2.45	120	463	130	85
39	5	1.84	90	323	110	50
40	6	1.9	140	900	145	263
41	11	1.21	108	237	91	104
42	8	1.5	115	248	104	252
43	0.33	1.12	92	112	93	37
44	2	2.33	122	212	99	112
45	6	1.66	155	236	120	74
46	6	2.65	106	203	122	103
47	7	1.55	153	254	151	228
48	8	1.66	103	312	95	96
49	7	1.95	-	900	79	170

TABLE 3 Bias ± standard deviation (SD) and correlation of paired oscillometric and Doppler non-invasive indirect blood pressure measurements and its comparison with the American College of Veterinary Internal Medicine (ACVIM) guidelines

Variable	Bias[a] (mmHg)	SD (mmHg)	Correlation	≤10 mmHg (%)[b]	≤20 mmHg (%)[b]
SBP	17.56	14.71	0.3	42.22	71.11
ACVIM recommendations[c]	< ±10	< ±15	>0.9	≥50	≥80

Abbreviation: SBP, systolic blood pressure.
[a]Bias, average of all differences between the Doppler and oscillometric devices.
[b]Percentage of oscillometric SBP readings lying within ≤ ±10 or 20 mmHg of the corresponding Doppler pressure reading.
[c]ACVIM recommended limits for SBP values.

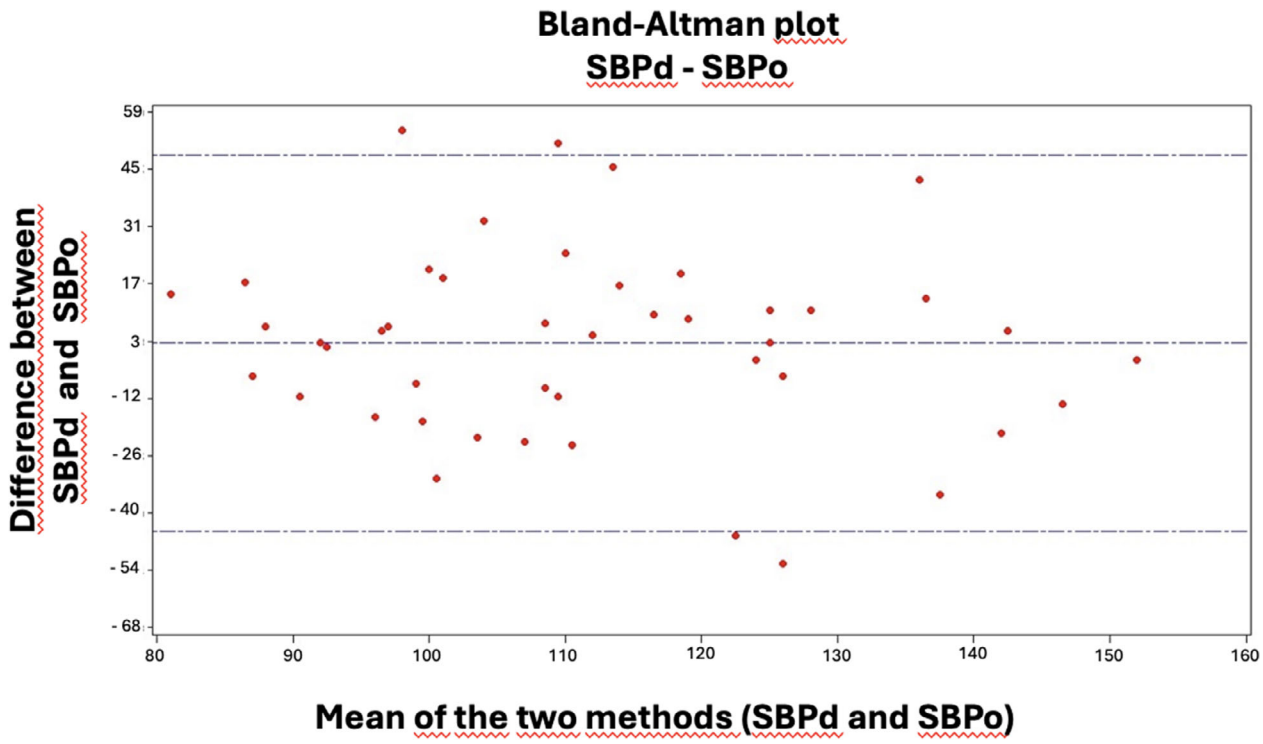

FIGURE 2 Bland–Altman plot showing the level of agreement between systolic blood pressure (SBP) measurements obtained with the oscillometric device (SBPo) and the Doppler device (SBPd)

TABLE 4 Time taken to achieve blood pressure measurements with the Doppler and oscillometric methods

Method	Minimum time (seconds)	Maximum time (seconds)	Mean (seconds)
Doppler	35	430	137
Oscillometry	105	15	392

inaugural examination of these indirect techniques in the context of BP measurement specifically in rabbits.

Doppler ultrasound and oscillometric machines are popular NIBP devices used worldwide, with studies demonstrating good correlation and accuracy between Doppler devices and direct BP assessment.[17,25,26] However, the use of oscillometric devices is not so widespread in rabbit medicine. Moreover, all the studies that compared the results of BP measurements with oscillometric devices and IBP used anaesthetised animals (movement, increased skeletal muscle tone and lability of measured parameters make indirect measurements in conscious animals substantially more problematic), and did not fully achieve the ACVIM minimal requirements.[15,25,28–32] In addition to this, achieving accurate BP measurements using oscillometric devices remains challenging across various species, as indicated by previous studies.[19,28,40,41] A similar outcome was obtained in this study, with an inability to obtain SBP measurements using the oscillometric method in 6.1% of animals.

Regarding the results obtained, only the systolic arterial pressure could be compared between devices, as the Doppler technique does not report diastolic arterial pressure. Analysing the mean of the SBPo and SBPd revealed that the bias was 17.56 ± 14.71 mmHg. Also, only 42.22% of the results showed less than 10 mmHg of difference between the paired measurements for the two techniques and 71.11% were within the 20 mmHg limit. For this reason, even though our results were close to the limits demanded by the ACVIM guidelines, these were not fully achieved (Table 3). In addition, the Bland–Altman analysis indicated a poor level of agreement between the two techniques (Figure 2). The findings of the present study align with outcomes observed in investigations involving diverse domestic species, where the application of oscillometric methods falls short

of meeting the stringent criteria set forth by the ACVIM.[15,18–20,26,29,30,37,40,42–44]

We did not observe any statistically significant difference in the outcomes based on sex, weight or breed. This observation is particularly relevant given the scarcity of literature addressing sex- or breed-specific variations in BP measurements using oscillometric and Doppler devices in rabbits and aligns with results observed in dogs and cats.[20]

From a technical point of view, we have been able to verify the possibility of measuring arterial BP using both technologies, as previously established.[17,25,27,29,30] The supposed technical complexity associated with the Doppler technique was ruled out based on the results obtained, with the average time required for sampling clearly shorter when using Doppler (137 seconds) compared to oscillometry (392 seconds). Furthermore, as we have already discussed, oscillometry yielded no results for BP measurements in 6.1% of the animals, whereas Doppler did not encounter this issue in any patient. These findings could translate into improvements in rabbit cardiovascular care via the following:

1. Streamlining clinical practices, particularly in busy veterinary settings where time is of the essence, and in emergency environments where prompt data collection is essential for swift and effective decision making.
2. Minimising stress levels experienced by animals, promoting their cooperation and facilitating precise measurements.
3. Facilitating early identification of cardiovascular issues and allowing for more effective monitoring of the impact of therapeutic interventions (not only to diagnose cardiovascular issues but also to stabilise critical patients).

According to the results obtained in this study, the oscillometric technique shows poor agreement with Doppler results when compared using the ACVIM guidelines and poor precision when compared using the Bland–Altman correction. The inability of oscillometric methods to consistently meet the ACVIM criteria raises critical questions about the reliability and accuracy of these devices, particularly in conscious animals.

With reference to the secondary objective of the study, we can conclude that the Doppler technique is faster 392 than the oscillometric method. Although it is true that the Doppler technique has a learning curve, once it is fulfilled, the measurements are more precise, and the time employed in the process is shorter when compared with oscillometric devices. This makes the Doppler method a more practical technique for use in day-to-day veterinary practice.

The representation of various age groups, sexes and health statuses in our study serves as a foundation, yet a more extensive and diverse sample would enhance the statistical robustness of our findings. Conducting additional studies with a larger number of participants is imperative to ensure the generalisability of our results and to establish more statistically significant trends applicable to the broader mixed patient populations commonly encountered in clinical settings. This will contribute to a more comprehensive understanding of BP variations across diverse demographics, ultimately informing evidence-based clinical practices.

CONCLUSIONS

Based on our results, we cannot currently recommend the use of an oscillometric device as a substitute for the Doppler technique when measuring BP in rabbits. Further research is warranted to explore alternative approaches or modifications to existing oscillometric techniques to enhance their reliability and accuracy, ultimately contributing to advancements in the field of veterinary cardiovascular care.

The main limitation of the study is that, to compare both methods, each rabbit had to undergo at least six individual BP measurements. The handling involved during this procedure can understandably cause some stress in the patients, which could lead to variations in the values obtained. To minimise this factor, the order in which the devices were used was alternated, and the ACVIM guidelines were strictly followed, requiring three consecutive measurements with less than a 10% difference for all subsequent calculations.

Another limitation of this study is that the oscillometric device used had software for dogs and cats installed, as species-specific software for rabbits does not exist at this time. Therefore, the comparison between techniques should be repeated when a device with software for rabbits is commercialised. Meanwhile, further studies are needed to determine whether a conversion calculation could be established between Doppler and newer oscillometric devices for the rabbit species.

AUTHOR CONTRIBUTIONS

Enrique González-González: contributed to the design of the study, performed the BP measurements, analysed the results and wrote and revised the manuscript. *Elisa González Alonso-Alegre*: contributed to the clinical observation of the animals during the procedures and revised the manuscript. *Andrés Montesinos Barceló*: contributed to the clinical observation of the animals during the procedures and revised the manuscript. *Alicia Caro Vadillo*: contributed to the design of the study, contributed to the clinical observation of the animals during the procedures, analysed the results and revised the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

FUNDING INFORMATION

The authors received no specific funding for this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Ethics committee approval was not required as every BP measurement was performed as a part of the routine clinical examination performed on every patient presented at the Hospital Clínico Veterinario Complutense (Universidad Complutense Madrid, Spain). Informed consent was obtained from the rabbits' owners before performing the measurements.

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