Received: 14 July 2020 | Accepted: 19 February 2021

DOI: 10.1111/jvim.16096

STANDARD ARTICLE

Journal of Veterinary Internal Medicine Open Access

ACVIM American College of Veterinary Internal Medicine

Influence of clinical setting and cat characteristics on indirectly measured blood pressure and pulse rate in healthy Birman, Norwegian Forest, and Domestic Shorthair cats

Sofia Hanås[1,2] | Bodil S. Holst[1] | Ingrid Ljungvall[1] | Anna Tidholm[1,3] | Ulf Olsson[4] | Jens Häggström[1] | Katja Höglund[5]

[1]Department of Clinical Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden

[2]Evidensia Specialist Animal Hospital Strömsholm, Strömsholm, Sweden

[3]Anicura Albano Animal Hospital, Stockholm, Sweden

[4]Unit of Applied Statistics and Mathematics, Swedish University of Agricultural Sciences, Uppsala, Sweden

[5]Department of Anatomy, Physiology and Biochemistry, Swedish University of Agricultural Sciences, Uppsala, Sweden

Correspondence
Sofia Hanås, Department of Clinical Sciences, Swedish University of Agricultural Sciences, Box 7054, 750 07 Uppsala, Sweden.
Email: sofia.hanas@slu.se

Funding information
Agria and Swedish Kennel Club's Research Fund; Foundation Strömsholms Djursjukvård; Michael Forsgren Foundation; Sveland Research Fund; The research bursary fund within IVC and Evidensia; The SLU Companion Animals Research Fund

Abstract

Background: Measured indirect blood pressure (BP) results in cats in a clinical environment might be affected by stress and characteristics of the cats.

Hypothesis: To investigate the influence of clinical setting, cat characteristics, and life situation on BP and pulse rate (PR) in healthy cats.

Animals: Ninety-four healthy Domestic Shorthair, Birman and Norwegian Forest cats.

Methods: Blood pressure measured by high-definition oscillometry in 3 settings: cat placed in its own carrier with veterinarian present; cat placed in carrier with owner alone present; and cat placed on table with veterinarian present. Statistical analyses were performed using mixed linear models.

Results: Systolic BP (SBP) did not differ among settings. Higher mean arterial pressure (MAP), diastolic BP (DBP), and PR were found when measurements were performed with cat placed on table, rather than in carrier. Coefficients of variation (CVs) higher for SBP, MAP, DBP, and PR when measured with cat placed on table than in carrier. Birman cats had lower BP than other breeds. Systolic BP, MAP, DBP, and PR increased with age. Cats allowed outdoors had lower PR than cats living strictly indoors.

Conclusion and Clinical Importance: No difference in SBP was found among settings, but measuring BP with the cat placed on the examination table gave higher MAP, DBP, PR, and CV than measuring BP with the cat in its carrier. Breed affected BP, with lower BP in Birman cats than other breeds. Blood pressure

Abbreviations: APPW, arterial pulse pressure wave; BCS, body condition score; BP, blood pressure; BW, body weight; Carrier-O, carrier-owner; Carrier-VO, carrier-veterinarian-owner; CI, confidence interval; CV, coefficient of variation; DBP, diastolic blood pressure; DSH, non-purebred Domestic Shorthair; FS, fractional shortening; HDO, high-definition oscillometry; HR, heart rate; IVSd, interventricular septum diastole; $IVSd_{inc\%}$, percentage increase interventricular septum diastole; LA, left atrium; LA/Ao, left atrial-to-aortic root diameter ratio; LV, left ventricular; LVFWd, left ventricular free wall diastole; $LVFWd_{inc\%}$, percentage increase left ventricular free wall diastole; LVIDd, left ventricular internal diameter diastole; $LVIDd_{inc\%}$, percentage increase left ventricular internal diameter diastole; LVIDs, left ventricular internal diameter systole; MAP, mean arterial blood pressure; NF, Norwegian Forest; PR, pulse rate; SBP, systolic blood pressure; Table-VO, table-veterinarian-owner; TOD, target organ damage; TT4, total thyroxine.

increased with age. Pulse rate was lower in cats allowed outdoors than cats living strictly indoors.

KEYWORDS
Birman, breed, oscillometry, pulse rate

1 | INTRODUCTION

Regulation of blood pressure (BP) is complex, involving the cardiovascular, nervous, renal, and endocrine systems. Excitement, stress, and anxiety in a clinical environment might increase BP by sympathetic activation (ie, situational hypertension[1]) in cats,[2] dogs,[3,4] and humans,[5] impairing the reliability of indirect BP measurements. The clinical setting has been shown to affect BP measurements in dogs, with higher systolic BP (SBP) and diastolic BP (DBP) results when performed by the veterinarian alone, compared to when the owner was present.[3] Few published studies have investigated how different clinical settings might affect measurements of BP and pulse rate (PR) in healthy cats.[6,7]

Breed differences have been identified for BP and PR in dogs,[3,8] whereas to the authors' knowledge, no studies have been specifically designed to investigate breed differences for these parameters in cats. Previous studies on other cat characteristics and their association with BP and PR measurements in healthy cats show variable results.[9-16]

In the clinical environment, BP measurements in cats are performed routinely by oscillometric or Doppler methods.[10,11,13,15,17] Indications for BP measurement in cats might be to identify and monitor systemic hypertension and hypotension in cats with primary disease processes that might affect BP, and potentially to screen for idiopathic hypertension in older cats.[1,18] Measurement of BP is indicated when evidence of target organ damage (TOD), such as hypertensive ocular TOD and left ventricular (LV) hypertrophy, is present, and hypertension thus might be suspected.[1,19]

Our primary aims were to investigate how different clinical settings (cat in a carrier with the owner and veterinarian present, cat in carrier with only the owner present, cat on the table with the owner and veterinarian present) and cat characteristics (breed, age, sex, body weight, and body condition) affect indirectly measured BP and PR in healthy cats. A secondary aim was to evaluate the potential influence of life situation (eg, single cat household, multi-cat household, being allowed outdoors, living strictly indoors) on BP and PR in healthy cats. We hypothesized that indirect BP and PR results would be affected by the clinical setting during measurement, cat characteristics, and life situation.

2 | MATERIALS AND METHODS

This prospective observational randomized study was approved by Uppsala Animal Experiment Ethics Board, Sweden (C137/13). Client-owned cats were recruited for the study by information distributed to cat owners on webpages, at seminars for owners, or at the recruiting clinic. Cats were examined at Evidensia Animal Clinic in Västerås in Sweden between September 2014 and June 2017. Informed written consent was obtained from the owner of each cat. The population has in part been described in a previous study.[20]

2.1 | Study design

Each cat was examined between 9:00 AM and 1:00 PM by a Swedish national veterinary specialist in internal medicine and cardiology (SH), according to a standardized protocol. Cats were brought directly to a quiet examination room upon arrival to the clinic, case history was obtained, and the cat was gently removed from the carrier and weighed on a digital scale. After an acclimatization period, BP measurements were performed in different clinical settings, followed by physical examination including assessment of body condition score (BCS; 1-9),[21] echocardiography, and blood sampling, in the same manner, and in the order described. All examinations were performed without sedation of the cats. Some cats had urinalysis performed.

2.2 | Inclusion criteria

Healthy Domestic Shorthair (DSH), Birman, and Norwegian Forest (NF) cats, aged 1-14 years, were included in the study. Cats were considered healthy if their physical examination did not identify any clinically relevant abnormalities, and if echocardiogram, hematology, and biochemistry results were within normal reference intervals. Where urine was available, urinalysis was performed and results were required to be within normal reference ranges for the cat to be included.

2.3 | Exclusion criteria

If findings indicating clinically relevant organ-related, or systemic diseases were detected, or if hematology or blood biochemistry results were outside reference intervals, the cat was excluded. Cats receiving medical treatment were excluded. If the BP protocol was not followed, the cat was excluded.

2.4 | Indirect blood pressure measurement

For acclimatization, all cats were allowed to adapt to the clinical environment for at least 10 to 15 minutes in the presence of their owners

(ie, allowed to roam freely) before BP measurement was performed.[1,18] Indirect BP was measured using high-definition oscillometry (HDO) device (Vet Memodiagnostic HDO monitor, S+B medVET, Babenhausen, Germany) with the C1 cuff applied to the base of the tail. Measurements were taken in 3 different clinical settings: 2 with the cat placed in its own carrier (a covered pet carrier) and 1 with the cat placed on the examination table (with rubber matting). The clinical settings were as follows: (a) cat placed in its carrier with the owner and veterinarian present in examination room. The veterinarian performed 6 measurements (setting carrier-veterinarian-owner [Carrier-VO]); (b) cat placed in its carrier and after instructing the owner on use of the device, the veterinarian left the room, and the owner performed 6 measurements (setting carrier-owner [Carrier-O]); and (c) cat placed on the examination table, with both the owner and veterinarian present. The veterinarian performed 4 measurements (table-veterinarian-owner [Table-VO]).

At least 10 seconds were allowed to elapse between all cuff inflations. The sequence of settings was randomized for all cats using Microsoft Excel. For practical reasons, the 2 settings with the cat placed in the carrier were always carried out sequentially, but in randomized order, whereas the setting with the cat placed on the table was randomized to be performed either first or last. In settings Carrier-VO and Carrier-O, the cuff was placed on the tail after the acclimatization period, and the cat was gently placed in the carrier, which then was closed. The cat had the cuff on the tail for 5 minutes before the measurement started. In setting Table-VO, the cat was gently placed on the table after the acclimatization period, the cuff was placed on the tail and the cat was gently held by the owner during measurements. The cat was allowed to settle and when it was still on the table, standing or resting in sternal recumbency, BP measurement started. For all settings, SBP, MAP, DBP, and PR were recorded using the HDO device. No readings were excluded at the time of measurement. If the HDO device failed to obtain a reading and a new cuff inflation had to be performed, it was noted as an error by the veterinarian in settings Carrier-VO and Table-VO. Errors could not be noted by the veterinarian in the setting Carrier-O, with the owner only present.

In some cats, subjective evaluation of the arterial pulse pressure wave (APPW) form was performed by the veterinarian after each measurement in settings Carrier-VO and Table-VO. The APPW form was assessed as "adequate" if the pulse waves generated a bell curve pattern, and "inadequate" if the waveform had substantial distortion (Supplement 1).[22]

2.5 | Echocardiography

Echocardiographic examination was performed using an ultrasound unit (IE33, Philips Ultrasound, Bothell, Washington) with a 4 to 12 MHz phased-array probe, and continuous ECG monitoring.[23] Left atrial-to-aortic root diameter ratio (LA/Ao) was measured from the right 2-dimensional (2D) short-axis view.[24] End-diastolic and systolic LV dimensions (interventricular septum diastole [IVSd], LV internal diameter in diastole [LVIDd], LV free wall diastole [LVFWd], LV internal diameter in systole [LVIDs], and fractional shortening [FS]) were measured from M-mode and 2D images.[23,25] Expected body weight (BW)-dependent values for IVSd, LVIDd, and LVFWd were calculated according to previously generated formulas for cats.[26] Mitral, tricuspid, aortic, and pulmonic valves were interrogated using spectral and color flow Doppler.[23,25]

2.6 | Blood and urine analyses for health assessment

Blood sampling was performed by venipuncture for analyses of selected hematology (hematocrit, hemoglobin, white blood cell count), and biochemistry tests (alanine aminotransferase [ALT] activity, and serum creatinine, glucose, total protein concentrations) at Evidensia Animal Clinic in Västerås using the ProCyte (IDEXX ProCyte Dx, IDEXX Laboratories, Inc., Westbrook, Maine) and Catalyst (Catalyst Dx Chemistry Analyzer, IDEXX Laboratories, Inc., Westbrook, Maine) systems. Serum samples for total thyroxine (TT4) and fructosamine concentrations were analyzed by chemiluminescence at the Clinical Pathology Laboratory at the University Animal Hospital of the Swedish University of Agricultural Sciences, using the Immulite (IMMULITE 2000, Siemens Healthcare GmbH, Erlangen, Germany) and Abbott Architect (Abbott Architect c4000, Abbott Park, Illinois) systems, respectively.

A voided urine sample from the cat was collected by the owner at home, if possible. Urine samples were examined by urine dipstick analysis (Siemens Multistix 10SG, Erlangen, Germany). Urine specific gravity was measured using a digital refractometer (Pocket refractometer, Atago, Tokyo, Japan).

2.7 | Statistical analyses

Statistical analyses were performed using commercially available software (SAS 2017, SAS Institute Inc., Cary, North Carolina),[27] (JMP Pro 12.2.0, SAS Institute Inc., Cary, North Carolina). Data on SBP, MAP, DBP, and PR are presented as mean ± SD. Coefficient of variation (CV) is presented as mean in percentage. Group comparisons for cat characteristics and echocardiographic variables were made using 1-way analysis of variance (ANOVA). Significance level was set at $P < .05$ and multiple comparisons were adjusted using Tukey's method.

When analyzing the effect of clinical setting on obtained indirect BP and PR results, readings for the first 4 measurements per setting initially were included to obtain a balanced data set (ie, the 2 last measurements for Carrier-VO and Carrier-O were excluded). In the next step, measurements with PR < 75 or > 300 pulses/min, regarded as outliers, were excluded.[28-30] Mean values, SD, and CV for SBP, MAP, DBP, and PR were determined for each cat in each setting. These summary statistics were subjected to analysis without transformation by mixed linear models using the mixed

TABLE 1 Cat characteristics, echocardiographic data, and laboratory variables in 94 healthy cats

Group	All cats	Birman	Domestic Shorthair	Norwegian Forest	*P*-value
Number	94	34	27	33	
Sex (F/M)	54/40	21/13	12/15	21/12	
Neuter status (F/NF/M/NM)	22/32/9/31	12/9/6/7	0/12/0/15	10/11/3/9	
Indoor/Outdoor	68/26	30/4	9/18	29/4	
Age (y)	5.4 ± 3.8	4.7 ± 3.9[a]	6.7 ± 4.3[a]	5.0 ± 3.0[a]	.11
BCS normal 4–5/ Overweight 6–7	48/46	23/11	11/16	14/19	
BW (kg)	4.6 ± 1.4	3.6 ± 0.7[a]	4.8 ± 1.0[b]	5.4 ± 1.6[b]	.0003
HR ausc (bpm)	158 ± 26	158 ± 20[a]	151 ± 28[a]	165 ± 27[a]	.11
LA/Ao	1.1 ± 0.1	1.1 ± 0.1[a]	1.1 ± 0.1[a]	1.1 ± 0.1[a]	.68
IVSd (mm)	3.8 ± 0.4	3.6 ± 0.4[a]	3.9 ± 0.4[b]	4.0 ± 0.4[b]	.0032
$IVSd_{inc}$ (%)	−0.5 ± 9.1	−1.1 ± 9.4[a]	0.4 ± 8.7[a]	−0.6 ± 9.4[a]	.82
LVIDd (mm)	16.2 ± 2.1	15.1 ± 1.6[a]	16.5 ± 1.8[b]	17.1 ± 2.3[b]	.011
$LVIDd_{inc}$ (%)	2.5 ± 10.3	1.1 ± 9.0[a]	3.4 ± 12.4[a]	3.3 ± 10.0[a]	.62
LVFWd (mm)	3.7 ± 0.5	3.5 ± 0.4[a]	3.8 ± 0.5[b]	3.9 ± 0.4[b]	.015
$LVFWd_{inc}$ (%)	−0.9 ± 9.6	−2.0 ± 9.5[a]	−0.2 ± 10.7[a]	−0.5 ± 8.8[a]	.74
FS (%)	50 ± 7	49 ± 7[a]	52 ± 8[a]	50 ± 7[a]	.15
Creatinine (mg/dL)	1.68 ± 0.3	1.80 ± 0.32[a]	1.58 ± 0.27[b]	1.64 ± 0.26[a,b]	.011
Hematocrit (%)	35 ± 5	35 ± 7[a]	35 ± 4[a]	37 ± 4[a]	.28
TT4 µg/dL (nmol/L)	2.4 ± 0.5 (30.6 ± 7.0)	2.3 ± 0.6[a] (28.9 ± 7.3)	2.7 ± 0.6[b] (34.3 ± 7.4)	2.3 ± 0.4[a] (29.4 ± 5.2)	.016
USG	1.053 ± 0.01 (N = 38)	1.057 ± 0.01[a] (N = 19)	1.053 ± 0.01[a] (N = 9)	1.047 ± 0.01[a] (N = 10)	.10

Note: The mean ± SD are shown for continuous variables. Within each row, values with different superscripts are statistically different between breeds. Tukey's adjustment for multiple comparisons was performed and a *P*-value of <.05 was considered significant. For urine-specific gravity (USG), results were available for a proportion of cats, and the number of cats is stated in the table.
Abbreviations: BCS, body condition score; BW, body weight; F, female; FS, fractional shortening; Indoor, indoor only; HR ausc, heart rate auscultation; IVSd, interventricular septum diastole; $IVSd_{inc}$, percentage increase interventricular septum diastole; LA/Ao, left atrial-to-aortic root diameter ratio; LVFWd, left ventricular free wall diastole; $LVFWd_{inc}$, percentage increase left ventricular free wall diastole; LVIDd, left ventricular internal diameter diastole; $LVIDd_{inc}$, percentage increase left ventricular internal diameter diastole; M, male; N, number of cats for which results were available; NF, neutered female; NM, neutered male; Outdoor, allowed outdoors; TT4, total thyroxine; USG, urine specific gravity.

TABLE 2 Blood pressure and pulse rate values in the different clinical settings

	SBP	MAP	DBP	PR
Setting	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Carrier-VO	138 ± 18[a]	94 ± 11[a,b]	70 ± 10[a]	152 ± 26[a]
Carrier-O	136 ± 18[a]	93 ± 12[a]	70 ± 11[a]	151 ± 25[a]
Table-VO	138 ± 19[a]	97 ± 14[b]	75 ± 13[b]	161 ± 32[b]
P-value	.21	.002	.011	.007
All	137 ± 18	95 ± 13	72 ± 12	155 ± 28

Note: Obtained SBP, MAP, and DBP and PR measurements in 94 healthy cats in the different clinical settings. Values are given as mean ± SD. Blood pressure is measured in mmHg, and PR in pulses per minute. Obtained BP and PR values were included for the first four measurements of each setting (in total 12 missing values), and thereafter measurements with PR <75 or >300 pulses/min, regarded as outliers, were excluded (in total 18 measurements). Within each column, values with different superscripts were statistically different between settings. Tukey's adjustment for multiple comparisons was performed and a *P*-value of <.05 was considered significant. The *P*-values presented are the highest of the pairwise comparisons within each column.
Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; Carrier-O = cat placed in carrier with cuff on tail, owner alone performed the measurements; Carrier-VO = cat placed in carrier with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements; MAP, mean arterial blood pressure; mmHg, millimeters of mercury; mmHg, millimeters of mercury; PR, pulse rate; SBP, systolic blood pressure; Table-VO = cat placed on examination table with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements.

procedure in SAS.[27,31] Models included setting, sequence, and the interaction setting × sequence as fixed factors. Cat was set as random factor. If significant interactions were found, subsequent comparisons of least squares mean values were performed to investigate in which sequences the BP, PR, and CVs differed. Assumptions underlying analysis were checked by preparing

diagnostic plots. Post hoc comparisons were adjusted for multiplicity using Tukey's method. Although sample estimates of SD and CV are not expected to follow normal distributions, sample size was large enough to allow analyses using similar models as for mean values, and residual plots did not suggest extreme distributions.

Randomization of BP settings gave the following possible sequences: (Carrier-VO; Carrier-O; Table-VO); (Carrier-O; Carrier-VO; Table-VO); (Table-VO; Carrier-VO; Carrier-O); and (Table-VO; Carrier-O; Carrier-VO). Each of the 94 cats was subjected to each of the 3 clinical settings, resulting in 282 sessions.

Because of the high CVs for BP and PR measurements in setting Table-VO, only settings Carrier-VO and Carrier-O were included in evaluation of the effect of cat characteristics and life situation on measured BP and PR. Six measurements per setting were available. After discarding the first BP measurement in settings Carrier-VO and Carrier-O, measurements with >20% variation in SBP[1,18,22] and measurements with PR < 75 or > 300 pulses/min,[28-30] 1 mean value for SBP, MAP, DBP, and PR, respectively, was determined for each cat. Models then were built using stepwise procedures for general linear models, using the GLMselect procedure.[27] The models included the following variables and all 2-way interactions between them: breed, age, sex, BW, BCS, and life situation (ie, indoor only or allowed outdoor, number of cats in household). Age, BW, and number of cats in household were assessed as continuous variables. Body condition score was divided into 4 classes (4–7), sex into 4 classes (male, female, neutered male, neutered female), and breed was set as a classification variable. The first analyses were performed using the Lasso method,[32] because comparisons based on simulations indicated that the prediction power was slightly better for Lasso than for traditional methods, such as stepwise selection.[33] These analyses suggested that breed and age were associated with all BP

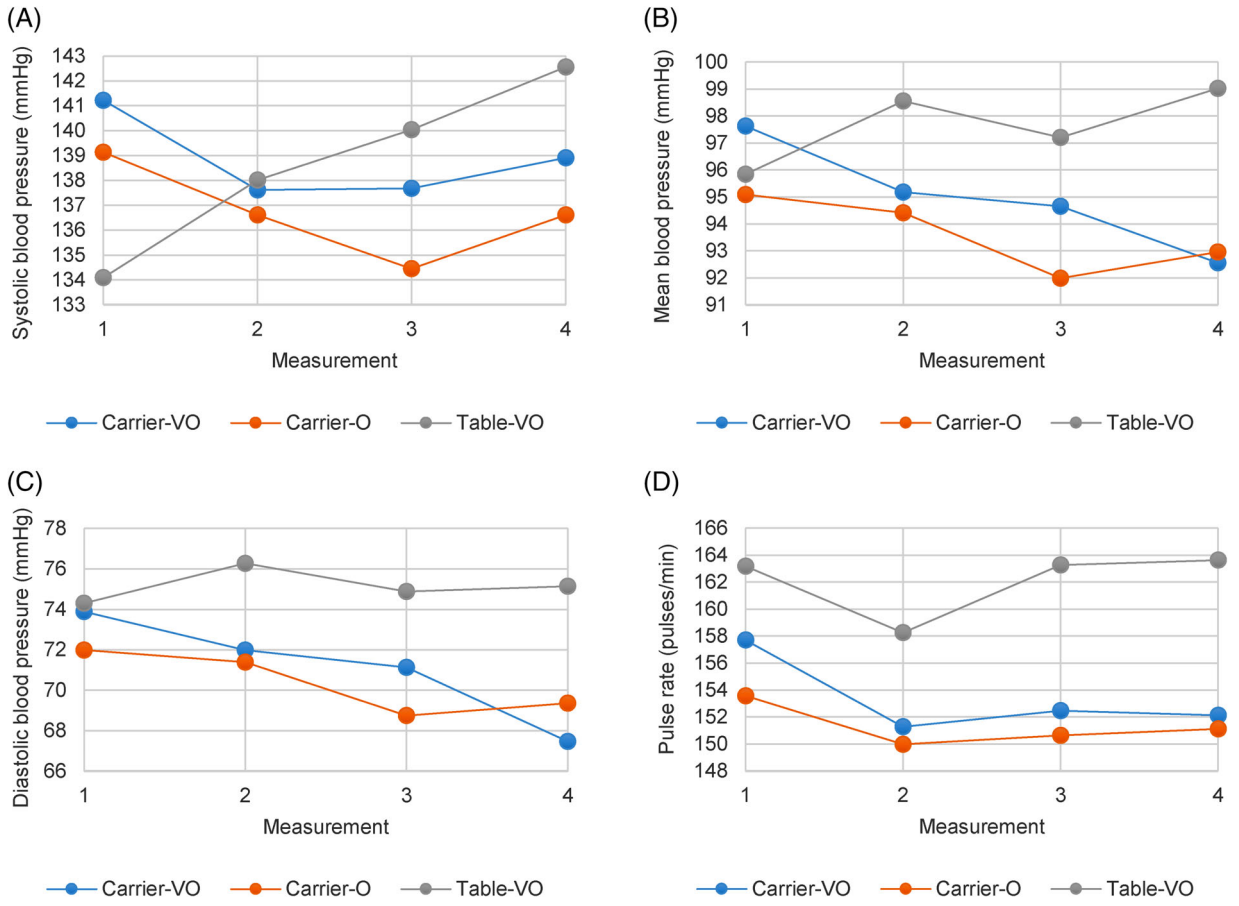

FIGURE 1 Arterial systolic (A), mean (B), and diastolic (C) indirect blood pressures, and pulse rate (D) in all cats (n = 94) in three different clinical settings by the number of measurement. Mean values are presented at each measurement. Obtained BP and PR values were included for the first four measurements of each setting. There were 12 missing values, one in the setting Carrier-O in the second measurement, and the others in the setting Table-VO in the second (N = 1), third (N = 3), and fourth (N = 7) measurement. Measurements with PR <75 or >300 pulses/min (N = 18) were regarded as outliers and excluded. Two of these were in the setting Carrier-VO in the fourth measurement: in the setting Table-Carrier-O they were in the first (N = 3) and fourth (N = 1) measurements, and in the setting Table-VO in the first (N = 4), second (N = 4), third (N = 1), and fourth (N = 3) measurements. Carrier-O = cat placed in carrier with cuff on tail, owner alone performed the measurements; Carrier-VO = cat placed in carrier with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements; Table-VO = cat placed on examination table with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements

variables and PR. Therefore, new stepwise analyses for SBP, MAP, DBP, and PR in which breed and age were forced into the model were performed to determine if any other variables contributed. The assumptions underlying the analyses were checked using diagnostic plots. Post hoc pairwise comparisons were adjusted for multiplicity using Tukey's method.

TABLE 3 Coefficients of variation for blood pressure variables and pulse rate

	Coefficient of variation (%)			
Settings	**SBP**	**MAP**	**DBP**	**PR**
Carrier-VO	7.3[a]	8.4[a]	12.8[a]	8.3[a]
Carrier-O	9.1[a]	8.6[a]	12.2[a]	7.4[a]
Table-VO	13.4[b]	14.3[b]	18.7[b]	12.7[b]

Note: Coefficient of variation (CV) for obtained SBP, MAP, and DBP variables and pulse rate (PR) in the three different clinical settings for the first four blood pressure measurements per setting in 94 healthy cats (in total 12 missing values, of these, one was in setting Carrier-O, and 11 in setting Table-VO). Measurements with PR <75 or >300 pulses/min, regarded as outliers, were excluded (in total 18 measurements, of these, two were in setting Carrier-VO, four in setting Carrier-O, and 12 in setting Table-VO). The CVs are given as mean values in percent. Within each column, values with different superscripts were statistically different between clinical settings. Tukey's adjustment for multiple comparisons was performed and a *P*-value of <.05 was considered significant.
Abbreviations: Carrier-O = cat placed in carrier with cuff on tail, owner alone performed the measurements; Carrier-VO = cat placed in carrier with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; PR, pulse rate; SBP, systolic blood pressure; Table-VO = cat placed on examination table with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements.

3 | RESULTS

3.1 | Study population

Of 117 examined healthy cats, 23 were excluded. Five cats had kidney disease, 5 heart disease, 2 severe gingivitis, 2 congenital defects (diaphragmatic hernia and peritoneal-pericardial diaphragmatic hernia), 2 increased ALT activity, 1 hyperthyroidism, 2 treated with deslorelinacetate, and in 4 cats BP was not measured according to study protocol. Blood glucose concentration was mildly increased in 6 cats. However, serum fructosamine concentration, hematology, and other serum biochemistry variables were within normal limits, and thus these cats were included. Urine was available in 38 of 94 cats and results of urinalyses were within normal limits in all cats (Table 1).

Of the 94 included cats, 33 were NF, 34 Birman, and 27 non-purebred DSH. Cat characteristics, echocardiographic, and laboratory variables are presented in Table 1.

3.2 | Indirect blood pressure and pulse rate

In the data for analysis of effect of clinical setting on obtained BP and PR results, there were 12 missing BP values (11 in setting Table-VO; cats did not cooperate, and 1 in Carrier-O; owner missed 1 measurement). Because each of the 94 cats was subjected to each clinical setting, there were 1116 measurements. Of these, 18 measurements from 13 cats were identified as outliers and excluded (2 in setting Carrier-VO, 4 in Carrier-O, and 12 in Table-VO). The HDO device failed to obtain a reading and a new cuff inflation had to be performed in 55/94 cats. These errors occurred 46 times in setting Carrier-VO and 65 times in Table-VO.

TABLE 4 Blood pressure and pulse rate values divided per breed

Breed		**SBP**	**MAP**	**DBP**	**PR**
Domestic Shorthair	27	146 ± 14[a] (116-180)	98 ± 10[a] (77-123)	72 ± 9[a] (48-97)	141 ± 28[a] (90-215)
Birman	34	125 ± 12[b] (107-159)	85 ± 9[b] (68-106)	63 ± 8[b] (44-84)	159 ± 22[b] (104-193)
Norwegian Forest	33	141 ± 17[a] (109-170)	96 ± 10[a] (78-117)	72 ± 9[a] (58-92)	152 ± 25[a,b] (97-207)
P-value		<.0001	<.0001	.001	.02
All cats	94	136 ± 17 (107-180)	93 ± 11 (68-123)	69 ± 10 (44-97)	151 ± 26 (90-215)

Note: SBP, MAP, and DBP blood pressure and PR values in 94 healthy cats. Values are given as mean ± SD and (range), and are based on the clinical settings Carrier-VO and Carrier-O. Outliers have been discarded. Blood pressure was measured in mmHg and PR in pulses per minute. Within each column, values with different superscripts are statistically different between breeds. Tukey's adjustment for multiple comparisons was performed and a *P*-value of <.05 was considered significant. The *P*-values presented are the highest of the pairwise comparisons within each column.
Abbreviations: Carrier-O = cat placed in carrier with cuff on tail, owner alone performed the measurements; Carrier-VO = cat placed in carrier with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; PR, pulse rate; SBP, systolic blood pressure.

Systolic BP did not differ between settings (P = .21). Clinical setting had an impact on MAP, DBP, and PR (overall P = .003). Mean arterial BP, DBP, and PR were higher in setting Table-VO than Carrier-O (P = .002). Furthermore, DBP and PR were higher in setting Table-VO than Carrier-VO (P = .007). Sequence alone did not significantly affect BP variables or PR. The combined effect of setting and sequence was significant for SBP, MAP, and DBP (all P = .02). Subsequent comparisons among settings, within sequences, showed lower results for MAP in setting Carrier-O compared to Table-VO, when the owner measured BP last in the sequence (Table-VO; Carrier-VO; Carrier-O; P = .02).

Mean results for SBP, MAP, DBP, and PR in different settings for the first 4 measurements are presented in Table 2. Plots of SBP, MAP, DBP, and HR in different settings by measurement number are presented in Figure 1A-D.

3.3 | Variation in obtained indirect blood pressure and pulse rate measurements

The CVs for SBP, MAP, DBP, and PR in the different settings are presented in Table 3. Clinical setting had an impact with higher CVs for SBP, MAP, DBP, and PR results in setting Table-VO compared to both settings in the carrier (all P < .0001). Neither sequence nor the combined effect of setting and sequence affected the CV for BP values. The combined effect

TABLE 5 Association between indirect blood pressure and pulse rate, and cat characteristics and life situation in 94 healthy cats

Mean	Variable	Estimate	*P* value	95% confidence interval	
				Lower limit	Upper limit
SBP (mmHg)	Breed		<.0001		
	DSH	3.839		−3	11
	Birman	−16.029		−23	−9
	NF	Baseline breed			
	Age	1.006	.01	0.2	1.8
MAP (mmHg)	Breed		<.0001		
	DSH	−0.044		−5	5
	Birman	−11.358		−16	−7
	NF	Baseline breed			
	Age	0.769	.0031	0.3	1.3
DBP (mmHg)	Breed		.0001		
	DSH	−1.948		−6	2
	Birman	−8.592		−13	−5
	NF	Baseline breed			
	Age	0.687	.0039	0.2	1.1
PR (pulses/min)	Breed		.02		
	DSH	−4.596		−19	10
	Birman	7.488		−4	19
	NF	Baseline breed			
	Age	1.458	.036	0.1	2.8
	Life situation		.016		
	Indoor	16.462		4	29
	Outdoor	Baseline life situation			

Note: The effect of cat characteristics and life situation on indirect SBP, MAP, DBP, and PR using multivariable analysis in 94 healthy cats. A mean value from the measurements from settings Carrier-VO and Carrier-O was used for each variable. The final multiple regression model, including cat characteristics (breed, age, sex, BW, and BCS), and life situation (indoor only/allowed outdoor, and number of cats in household) had an adjusted R^2 of 0.32 for SBP, 0.32 for MAP, 0.23 for DBP, and 0.14 for PR. In this table, variables that remained significant in the final model are reported. A P-value of <.05 was considered significant.

Abbreviations: Carrier-O = cat placed in carrier with cuff on tail, owner alone performed the measurements; Carrier-VO = cat placed in carrier with cuff on tail, both owner and veterinarian present, veterinarian performed the measurements; DBP, diastolic blood pressure; DSH, Domestic Shorthair; Indoor, indoor only; MAP, mean arterial blood pressure; NF, Norwegian Forest; Outdoor, allowed outdoor; PR, pulse rate; SBP, systolic blood pressure.

of setting and sequence affected the CV for PR results (P = .04). Subsequent comparison among settings, within sequences, showed lower CV for PR in settings Carrier-O and Carrier-VO compared to setting Table-VO, when the owner measured BP first in sequence Carrier-O; Carrier-VO; Table-VO; P = .02). The APPW was available for evaluation in 43/94 cats (Supplement 1, Figure S1A-C). The percentage values of adequate and inadequate APPWs were 90% and 10%, respectively, in setting Carrier-VO, and 62% and 38%, respectively, in setting Table-VO.

3.4 | Effect of cat characteristics and life situation on indirect blood pressure and pulse rate measurements

Because each of the 94 cats was subjected to each carrier setting with 6 measurements per setting, and there was 1 missing result, there were 1127 measurements (Supplement Figure S2A-D). After discarding the first measurement in each setting, there were 939 measurements. Of these, 88 measurements from 39 cats were identified as outliers and excluded, leaving 4 to 10 included measurements per cat. Mean BP and PR measurements for each breed are shown in Table 4. Ten cats had mean SBP > 160 mmHg, of which 6 were NF cats and 4 were DSH cats. Of these 10 cats, 9 of 10 cats had a BP recording of <150 mmHg in 1 of the settings during the study.

Results of multivariable analyses of BP and PR vs cat characteristics (breed, age, sex, BW, BCS) and life situation (indoor only, allowed outdoor, number of cats in household) are presented in Table 5. All indirect BP variables were lower in Birmans than in NF and DSH cats (SBP, MAP, DBP; adjusted R^2 = 0.28, 0.26, 0.16, respectively). The PR was higher in Birman than DSH cats (adjusted R^2 = 0.06). With increasing age, all indirect BP variables (SBP, MAP, DBP; adjusted R^2 = 0.32, 0.32, 0.23; P = .01, .0003, .004, respectively), as well as PR (adjusted R^2 = 0.10; P = .04) increased. Cats allowed outdoors had lower PR (adjusted R^2 = 0.14; P = .02) as compared with cats living indoors only. Mean PR (pulses/min) ± SD was 157 ± 24 (= 68) for cats living strictly indoors, and 137 ± 26 (=26) for cats allowed outdoors.

4 | DISCUSSION

In this group of healthy cats, MAP, DBP, and PR were higher when indirect BP was measured with the cat placed on the examination table (Table-VO) compared to 1 or both settings in the cat's own carrier (Carrier-VO and Carrier-O). The CVs for SBP, MAP, and DBP as well as PR were higher in setting Table-VO compared to both settings with the cat placed in the carrier. Breed and age had an effect on BP and PR variables, with lower BP in the Birman cats than in NF and non-purebred DSH cats, and increasing BP and PR with increasing age.

The variation in recorded results was higher for all BP variables, as well as PR, when measurements were performed with the cat placed on the table compared to both settings with the cat in its own carrier (Table 3). In the first part of the study, our focus was to evaluate performance of the oscillometric system under clinical conditions in different clinical settings, and therefore the first measurement was not discarded. A higher percentage of inadequate APPWs in setting Table-VO than in setting Carrier-VO (Supplement 1, Figure S1A-C) might contribute to the higher variation in setting Table-VO. Moreover, the HDO device failed to obtain readings more often in the setting Table-VO than in the setting Carrier-VO and additional cuff inflations had to be performed, which could have had an impact on the stress of the cat. Inadequate APPWs with following high CVs could be attributed to movement or anxiety, which may have been exacerbated by failure to obtain readings and requirement for more cuff inflations during measurements on the table.[22,34,35] Overall, these factors indicate that results from setting Table-VO were less reliable in our study. A potentially more stressful situation also might explain the higher results of MAP and DBP in setting Table-VO compared to 1 or both settings in the carrier (Table 2). However, albeit statistically significant, differences in recorded values among settings were small and likely not of relevance to the individual cat in a clinical situation.

In contrast to MAP and DBP, no difference was found among settings for SBP. Although MAP and DBP showed a decreasing pattern by measurement number for both settings in the carrier, but not for setting Table-VO, this difference in pattern was not as evident for SBP, which might explain the lack of difference among settings (Figure 1A-C). Hence SBP, the most commonly assessed variable in clinical practice,[1] did not differ among settings in our study of healthy cats. Because the degree of situational hypertension has been reported to be larger in cats with hypertension than in healthy cats,[2] investigation of the effects of different clinical settings on BP recordings in cats with hypertension would be of interest.

For PR, recorded results were lower in both settings in the carrier compared to setting Table-VO and a decreasing pattern similar to observations for MAP and DBP was evident in the carrier settings, but not in setting Table-VO (Figures 1B-D). The first measurement had a higher percentage of inadequate APPW, which might be caused by cuff inflation surprising the cat, leading to movement (Figure S1B- S1C). Again, situational stress might initiate early pressor and tachycardic responses, thereby causing early increases in BP and PR, which is in accordance with previous studies in cats[2] and humans.[5] This observation emphasizes the importance of performing multiple measurements over a period of time and to exclude the first measurement as recommended.[1,2]

No significant effect of the sequence of measurements (created by randomization of settings) was found on BP measurements or PR. However, the interaction between setting and sequence was significant for SBP, MAP, and DBP, complicating interpretation of these findings. Subsequent evaluation showed lower MAP when the owner alone measured BP last with the cat in the carrier in sequence (Table-VO, Carrier-VO, Carrier-O) than with the cat placed on table first. An explanation might be that placing the cat on the table, after the acclimatization period, entails a change in the cat's situation, leading to increased BP.[2,7] The first set of measurements then was performed—a new event for the cat. The cat then was placed in the carrier,

potentially perceived as a secure place, before further measurements were performed. Cats often respond to confrontation by hiding, and the carrier might be considered a safe place to hide for many cats.[36,37] Finally, the veterinarian, who together with the owner had been present in both of the above settings, an unfamiliar person to the cat, left the room and final measurements were performed by the owner, a familiar person to the cat.[36,37] The order of these changes for the cat in the 3 settings in this specific sequence might explain the lower MAP in setting Carrier-O compared to Table-VO. In the clinical environment, being placed in the cat's own carrier, with its familiar smell, might thus cause less stress than being placed on the table.[36,37]

A significant interaction was found between setting and sequence for the CV of PR, with lower CV in both settings in the carrier than the setting on the table in sequence (Carrier-O, Carrier-VO, Table-VO). An explanation might be that the first measurements were performed by the owner alone, a familiar person, and that the cat had the possibility to hide in the carrier, leading to less perceived stress in this setting.[36,37] Thereafter, the veterinarian entered the room, and further measurements were performed by the veterinarian (setting Carrier-VO), but the cat remained in the carrier. The measurement procedure was already known to the cat, presumably inducing less anxiety for the cat in this setting.[2,36,37] The third setting, Table-VO, led to a change in the cat's situation (ie, being removed from carrier), which might lead to increased stress and the possibility for movement.[2,7]

The Birman breed had lower SBP, MAP, and DBP than NF and DSH cats (Table 4). In previous studies, no effect of breed was found for BP.[9,10,16] The Birman cats also had higher PR than DSH cats in our study. In dogs, breed differences have been reported for both BP and PR.[3,8] A previous study showed that women had comparatively lower BP and higher HR than men.[38] Studies indicate that lower BP in women might be caused by shorter length of the arterial tree and smaller LV diameter, giving a lower stroke volume in comparison with men.[38,39] In our study, standard cuff size for cats (cuff C1) was used. In the multivariable model, including breed, BW and the 2-way interaction between them, breed was associated with BP variables, whereas BW was not, indicating that the lower BP in the Birman cats was mainly a breed effect, and less dependent on smaller body size. However, breed and BW are highly covariate, and a smaller tail circumference in Birmans, relative to the cuff size, might have contributed to lower results in this breed.[15,18]

In all 3 breeds, mean SBP was within previously published reference ranges for cats obtained using oscillometric devices,[10,13,17] whereas mean DBP was under or at the lower end of previously published reference ranges.[10,17] The HDO performs a real-time analysis of the arterial oscillations to obtain pulse amplitudes and measures SBP, MAP, and DBP.[40] The lowest mean DBP was found in Birmans. This breed has a relatively low risk of being overweight[41] and also had the lowest proportion of overweight cats in our study. In people, it is important to measure DBP in relation to simultaneous magnitude of SBP. Diastolic hypertension occurs predominantly with obesity, insulin resistance, and hyperlipidemia and might evolve into systolic-diastolic hypertension, a potential increased risk for future diabetes.[42] Obesity is a risk factor for diabetes mellitus in cats and is an important health problem facing domestic cats.[43] Future studies on DBP in overweight and obese cats would be of interest, and for such studies, our results using healthy cats could serve as a foundation.

In our study, including cats of a wide range of ages, all BP variables increased with increasing age, in accordance with previous studies in cats,[9-12] dogs,[8] and humans.[38] However, this is not a consistent finding in the literature and some studies of cats have shown no effect of age on indirect BP measurements.[13-15] These variable results might be caused by different cat populations, use of different BP devices, and different handling techniques of cats during measurements. Kidney disease can be a cause for hypertension in both cats and humans. Alterations in renal vasculature, such as fibrointimal hyperplasia and hyperplastic arteriolosclerosis, are found both in healthy cats and in cats with chronic kidney disease.[44] In people and in cats,[45] aging leads to progressive stiffening of arteries caused by vascular remodeling with progressive intimal thickening, which can lead to an increase in SBP with age,[46] although these changes were found to be indistinguishable from similar lesions of aging in normotensive patients.[47] In 1 study, hypertensive cats were not more likely to be affected by fibrointimal hyperplasia than normotensive cats.[44] The process of vascular aging in cats and people is associated with vascular remodeling and inflammatory processes,[44,45,47] which might be an explanation for increasing BP with age. Pulse rate also increased with increasing age, which is in accordance with a previous study.[28] Heart rate also has been shown to increase with age in dogs.[8,48]

Pulse rate was lower in cats allowed outdoors than in cats living strictly indoors, possibly explained by cats allowed outdoors being more physically fit or more comfortable with different situations than cats living strictly indoors. However, this association was weak and should be interpreted with caution.

4.1 | Study limitations

Our study included healthy cats of 3 genetically distant breeds,[49] with relatively large group sizes. All cats were specifically recruited for the study. Cats visiting veterinary clinics for BP measurements comprise a great variety of breeds, including healthy cats as well as those with extra-cardiac diseases that might lead to hypertension. Therefore, our study population cannot be considered representative of the general population, and results cannot be extrapolated to a general cat population or to cats with hypertension.

Kidney disease is common in cats and might cause hypertension.[11,14,17] For practical reasons, urine samples were only available in 38/94 cats. Although serum creatinine concentration and hematocrit were within reference ranges in all cats, subclinical kidney disease might have been present in some cats, causing increased BP results.[11,18] In accordance with previous studies, Birman cats had serum creatinine concentrations in the upper end of normal reference ranges, which might have masked subclinical kidney disease.[50,51] Of the 94 cats, 10 had mean SBP > 160 mmHg, which might have been caused by situational stress or subclinical kidney disease. None of these cats were Birmans.

To limit the number of measurements for the individual cat and minimize the handling of each cat, 6 measurements were performed in each setting in the carrier (Carrier-VO, Carrier-O) and 4 measurements in the setting on the table (Table-VO). In the first part of the study, focusing on the performance of the oscillometric system under clinical conditions, measurements 5 and 6 in the carrier settings were excluded to obtain a balanced data set. The first measurement of each setting was included, again to evaluate the oscillometric device under clinical conditions. Thus, the protocol deviated from current *American College of Veterinary Internal Medicine* guidelines.[1] Because a large CV might affect findings by masking results, setting Table-VO was excluded in statistical analysis of effect of cat characteristics and life situation on SBP, MAP, DBP, and PR. However, exclusion of measurements might affect the data.

Inspection of the APPW form was not performed in all cats, which is a limitation, considering that if the APPW was deemed inadequate, the result from that measurement should have been excluded.[22] Thus artifacts, such as motion disturbances, that might have affected measurements could not be evaluated in these cats.[22,40]

Another potential limitation is the slight difference in time from cuff placement to measurement between carrier and table settings. In carrier settings, the cat had the cuff on the tail for 5 minutes in the carrier before measurements started, whereas on the table measurement started when the cat had settled and was still on the table. This procedure was chosen to avoid unnecessary handling of the cats on the table.

A few results in our study had weak associations, and these should be interpreted with caution.

5 | CONCLUSIONS

In our study of healthy cats, CVs were higher for indirect BP variables, as well as PR, when measurements were performed with the cat on the table compared to in the carrier. The SBP did not differ among the 3 clinical settings, whereas MAP, DBP, and PR were higher when measurements were performed on the table compared with the cat in its own carrier. The differences in recorded results for MAP, DBP, and PR among settings were small and likely not of clinical relevance for the individual cat. There was a higher percentage of inadequate APPW forms (evaluated by the veterinarian in some of the cats), when BP was measured on the table compared to in the carrier. Thus, measuring BP with the cat placed in its own carrier, thereby giving the cat the possibility to hide, might result in less variable BP. Blood pressure increased with increasing age and was lower in Birman cats than in both other breeds. Pulse rate was lower in cats allowed outdoors than in cats living strictly indoors.

ACKNOWLEDGMENT

Funding provided by the Foundation Strömsholms Djursjukvård, Agria and Swedish Kennel Club's Research Fund, SLU Companion Animals Research Fund, Sveland Research Fund, Michael Forsgren Foundation, and The research bursary fund within IVC and Evidensia. Presented in part at the 29th ECVIM congress in Milan, 2019, as a short abstract. The authors thank dedicated veterinary technicians at Evidensia Animal Clinic in Västerås for their important role in completing this study. Special thanks to all participating cats and their owners.

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

Approved by the Uppsala ethical committee for animal research, Uppsala, Sweden C137/1.

HUMAN ETHICS APPROVAL DECLARATION

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

ORCID

Sofia Hanås https://orcid.org/0000-0002-6758-8190
Bodil S. Holst https://orcid.org/0000-0001-7623-7141
Anna Tidholm https://orcid.org/0000-0002-6277-3936
Jens Häggström https://orcid.org/0000-0003-3402-023X
Katja Höglund https://orcid.org/0000-0002-7486-0420

REFERENCES

1. Acierno MJ, Brown S, Coleman AE, et al. ACVIM consensus statement: guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats. *J Vet Intern Med*. 2018;32:1803-1822.
2. Belew AM, Barlett T, Brown SA. Evaluation of the white-coat effect in cats. *J Vet Intern Med*. 1999;13:134-142.
3. Hoglund K, Hanas S, Carnabuci C, et al. Blood pressure, heart rate, and urinary catecholamines in healthy dogs subjected to different clinical settings. *J Vet Intern Med*. 2012;26:1300-1308.
4. Marino CL, Cober RE, Iazbik MC, Couto CG. White-coat effect on systemic blood pressure in retired racing greyhounds. *J Vet Intern Med*. 2011;25:861-865.
5. Mancia G, Bertinieri G, Grassi G, et al. Effects of blood-pressure measurement by the doctor on patient's blood pressure and heart rate. *Lancet*. 1983;2:695-698.
6. Nibblett BM, Ketzis JK, Grigg EK. Comparison of stress exhibited by cats examined in a clinic versus a home setting. *Appl Anim Behav Sci*. 2015;173:68-75.
7. Quimby JM, Smith ML, Lunn KF. Evaluation of the effects of hospital visit stress on physiologic parameters in the cat. *J Feline Med Surg*. 2011;13:733-737.
8. Bodey AR, Michell AR. Epidemiological study of blood pressure in domestic dogs. *J Small Aim Pract*. 1996;37:116-125.
9. Payne JR, Brodbelt DC, Luis Fuentes V. Blood pressure measurements in 780 apparently healthy cats. *J Vet Intern Med*. 2017;31:15-21.
10. Bodey AR, Sansom J. Epidemiological study of blood pressure in domestic cats. *J Small Aim Pract*. 1998;39:567-573.
11. Bijsmans ES, Jepson RE, Chang YM, Syme HM, Elliott J. Changes in systolic blood pressure over time in healthy cats and cats with chronic kidney disease. *J Vet Intern Med*. 2015;29:855-861.
12. Sansom J, Rogers K, Wood JL. Blood pressure assessment in healthy cats and cats with hypertensive retinopathy. *Am J Vet Res*. 2004;65:245-252.

13. Hori Y, Heishima Y, Yamashita Y, et al. Epidemiological study of indirect blood pressure measured using oscillometry in clinically healthy cats at initial evaluation. *J Vet Med Sci*. 2019;81:513-516.
14. Kobayashi DL, Peterson ME, Graves TK, Nichols CE, Lesser M. Hypertension in cats with chronic renal failure or hyperthyroidism. *J Vet Intern Med*. 1990;4:58-62.
15. Sparkes AH, Caney SM, King MC, Gruffydd-Jones TJ. Inter- and intra-individual variation in Doppler ultrasonic indirect blood pressure measurements in healthy cats. *J Vet Intern Med*. 1999;13:314-318.
16. Lin CH, Yan CJ, Lien YH, et al. Systolic blood pressure of clinically normal and conscious cats determined by an indirect Doppler method in a clinical setting. *J Vet Med Sci*. 2006;68:827-832.
17. Mishina M, Watanabe T, Fujii K, et al. Non-invasive blood pressure measurements in cats: clinical significance of hypertension associated with chronic renal failure. *J Vet Med Sci*. 1998;60:805-808.
18. Brown S, Atkins C, Bagley R, et al. Guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats. *J Vet Intern Med*. 2007;21:542-558.
19. Telle MR, Betbeze C. Hyphema: considerations in the small animal patient. *Top Companion Anim Med*. 2015;30:97-106.
20. Hanas S, Holst BS, Hoglund K, et al. Effect of feline characteristics on plasma N-terminal-prohormone B-type natriuretic peptide concentration and comparison of a point-of-care test and an ELISA test. *J Vet Intern Med*. 2020;34:1187-1197.
21. Laflamme D. Development and validation of a body condition score system for cats: a clinical tool. *Feline Pract*. 1997;25:13-18.
22. Taylor SS, Sparkes AH, Briscoe K, et al. ISFM consensus guidelines on the diagnosis and Management of Hypertension in cats. *J Feline Med Surg*. 2017;19:288-303.
23. Thomas WP, Gaber CE, Jacobs GJ, et al. Recommendations for standards in transthoracic two-dimensional echocardiography in the dog and cat. Echocardiography Committee of the Specialty of cardiology, American College of Veterinary Internal Medicine. *J Vet Intern Med*. 1993;7:247-252.
24. Hansson K, Haggstrom J, Kvart C, Lord P. Left atrial to aortic root indices using two-dimensional and M-mode echocardiography in cavalier King Charles spaniels with and without left atrial enlargement. *Vet Radiol Ultrasoun*. 2002;43:568-575.
25. Sahn DJ, DeMaria A, Kisslo J, Weyman A. Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. *Circulation*. 1978;58:1072-1083.
26. Haggstrom J, Andersson AO, Falk T, et al. Effect of body weight on echocardiographic measurements in 19,866 pure-bred cats with or without heart disease. *J Vet Intern Med*. 2016;30:1601-1611.
27. SAS/Stat User's Guide. *Version 9.4*. Cary, NC: SAS Institute Inc.; 2017.
28. Hanas S, Tidholm A, Egenvall A, et al. Twenty-four hour Holter monitoring of unsedated healthy cats in the home environment. *J Vet Cardiol*. 2009;11:17-22.
29. Jackson BL, Lehmkuhl LB, Adin DB. Heart rate and arrhythmia frequency of normal cats compared to cats with asymptomatic hypertrophic cardiomyopathy. *J Vet Cardiol*. 2014;16:215-225.
30. Abbott JA. Heart rate and heart rate variability of healthy cats in home and hospital environments. *J Feline Med Surg*. 2005;7:195-202.
31. Littell RC, Milliken GA, Stroup WW, Wolfinger RD. *Schabenberger, Oliver. SAS for Mixed Models*. Second ed. Cary, NC: SAS Inst; 2006.
32. Tibshirani R. The lasso method for variable selection in the cox model. *Stat Med*. 1997;16:385-395.
33. Hastie T, Tibshirani R. Extended comparisons of best subset selection, forward stepwise selection, and the lasso. *arXiv: Methodology*. 2017.1–19. https://arxiv.org/abs/1707.08692.
34. Slingerland LI, Robben JH, Schaafsma I, Kooistra HS. Response of cats to familiar and unfamiliar human contact using continuous direct arterial blood pressure measurement. *Res Vet Sci*. 2008;85:575-582.
35. Mishina M, Watanabe N, Watanabe T. Diurnal variations of blood pressure in cats. *J Vet Med Sci*. 2006;68:243-248.
36. Ellis SL, Rodan I, Carney HC, et al. AAFP and ISFM feline environmental needs guidelines. *J Feline Med Surg*. 2013;15:219-230.
37. Rodan I, Sundahl E, Carney H, et al. AAFP and ISFM Feline-Friendly Handling Guidelines. *J Feline Med Surg*. 2011;13:364-375.
38. Smulyan H, Asmar RG, Rudnicki A, London GM, Safar ME. Comparative effects of aging in men and women on the properties of the arterial tree. *J Am Coll Cardiol*. 2001;37:1374-1380.
39. Elzinga G, Westerhof N. Matching between ventricle and arterial load. An evolutionary process. *Circ Res*. 1991;68:1495-1500.
40. Schmelting B, Niehoff M, Egner B, Korte SH, Weinbauer GF. High definition oscillometry: a novel technique for non-invasive blood pressure monitoring in the cynomolgus monkey (*Macaca fascicularis*). *J Med Prim*. 2009;38:293-301.
41. Öhlund M, Palmgren M, Holst BS. Overweight in adult cats: a cross-sectional study. *Acta Vet Scand*. 2018;60:5.
42. Franklin SS. The importance of diastolic blood pressure in predicting cardiovascular risk. *J Am Soc Hypertens*. 2007;1:82-93.
43. Chandler M, Cunningham S, Lund EM, et al. Obesity and associated comorbidities in people and companion animals: a one health perspective. *J Comp Pathol*. 2017;156:296-309.
44. McLeland SM, Cianciolo RE, Duncan CG, et al. A comparison of biochemical and histopathologic staging in cats with chronic kidney disease. *Vet Pathol*. 2015;52:524-534.
45. McLeeland SM, Histologic Assessment of the Aging Feline Kidney in Cats Without Kidney Disease. 2019 ACVIM forum research abstract program. *J Vet Intern Med*. 2019. https://doi.org/10.1111/jvim.15597.
46. Fleg JL, Strait J. Age-associated changes in cardiovascular structure and function: a fertile milieu for future disease. *Heart Fail Rev*. 2012;17:545-554.
47. Martin JE, Sheaff MT. Renal ageing. *J Pathol*. 2007;211:198-205.
48. Hezzell MJ, Dennis SG, Humm K, et al. Relationships between heart rate and age, bodyweight and breed in 10,849 dogs. *J Small Anim Pract*. 2013;54:318-324.
49. Lipinski MJ, Froenicke L, Baysac KC, et al. The ascent of cat breeds: genetic evaluations of breeds and worldwide random-bred populations. *Genomics*. 2008;91:12-21.
50. Reynolds BS, Concordet D, Germain CA, Daste T, Boudet KG, Lefebvre HP. Breed dependency of reference intervals for plasma biochemical values in cats. *J Vet Intern Med*. 2010;24:809-818.
51. Paltrinieri S, Ibba F, Rossi G. Haematological and biochemical reference intervals of four feline breeds. *J Feline Med Surg*. 2014;16:125-136.

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: Hanås S, Holst BS, Ljungvall I, et al. Influence of clinical setting and cat characteristics on indirectly measured blood pressure and pulse rate in healthy Birman, Norwegian Forest, and Domestic Shorthair cats. *J Vet Intern Med*. 2021;35:801–811. https://doi.org/10.1111/jvim.16096