FULL PAPER *Internal Medicine*

Systolic Blood Pressure of Clinically Normal and Conscious Cats Determined by an Indirect Doppler Method in a Clinical Setting

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ABSTRACT. The purposes of the present study were to determine the systolic blood pressure (SBP) of clinically normal and conscious cats, and to set up reference values of feline SBP for subsequent clinical application. SBPs were measured in 53 healthy cats using an ultrasonic Doppler device. The mean SBP was 133.6 ± 16.0 mmHg (range, 110.0–180.0 mmHg). The distribution of SBP values was not significantly affected by factors such as breed, body condition score, or age (P>0.05), but SBP values of female cats were significantly lower and more variable than those of males (t test, P=0.004; F test, P<0.001). Feline SBP between 114.3 mmHg and 149.5 mmHg was considered indicative of normotension. SBP values higher than 159.3 mmHg were defined as hypertension, and those less than 104.5 mmHg were determined as hypotension.

KEY WORDS: clinically normal, Doppler, feline reference value, systolic blood pressure.

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Blood pressure (BP) is an important dynamic measurement of cardiovascular system function and is affected by physical and pathological conditions [5, 7, 9, 12, 13, 27]. In feline medicine, various medical disorders, such as chronic renal failure, hyperthyroidism, retinopathy, and left ventricular hypertrophy, are associated with abnormal BP [4, 7, 16, 17, 20, 22–23]. Although BP measurements are not routinely performed in general feline practice, numerous clinical studies and case reports provide technical and diagnostic information [4, 11, 16, 19, 23, 25]. Indirect BP measurements can be obtained by either Doppler or oscillometric methods, since both are noninvasive and suitable for clinical use. In conscious patients, the indirect Doppler technique has a better successful measurement rate, shows less sensitivity to respiration or movement of the animals, and has a shorter operating duration than oscillometric methods [14, 21, 28]. To date, only a few studies have surveyed feline BP distribution or generated reference ranges with the Doppler method, and there are some conflicting opinions on criteria for feline hypertension [15, 16, 20, 25].

The aims of the present study were to assess the distribution of systolic blood pressure (SBP) in clinically normal and conscious cats with an indirect Doppler method, and to establish reference values for feline SBP in clinical settings.

MATERIALS AND METHODS

Fifty-three clinically normal cats at the National Taiwan University Veterinary Hospital were enrolled for this survey. All cats were assessed by physical examinations, clinical signs, chest radiographs, and routine blood profiles to exclude renal disease, cardiorespiratory diseases, heartworm infestation (Feline Heartworm Antigen Test Kit, IDEXX Laboratories, Maine, U.S.A.), or other conditions that might affect blood pressure directly. Breeds included 30 domestic shorthairs; 11 Persians; Himalayan and Persian-crossed (3 each); Siamese and domestic longhairs (2 each); and 1 American shorthair and 1 Siamese-crossed. Of these 53 cats, 32 were female and 21 were male. The mean age was 3.7 ± 2.8 years, and ranged from 7 months to 14 years. A 5-point body condition score (BCS) system was used to evaluate all cats [6]. Over half of cats (n=29, 54.7%) were in fit body condition (BCS=3); 18.9% (n=10) were mildly overweight (BCS=4); 17.0% (n=9) were mildly underweight (BCS=2); 5.7% (n=3) were obese (BCS=5), and 3.8% (n=2) were excessively underweight (BCS=1). The obese or excessively underweight cats in the present study otherwise were in good healthy condition and free of detectable diseases.

To minimize stress, cats were allowed to assume a comfortable position with only gentle restraint by their owners, and remained in the same position throughout SBP measurement. Cats that were too anxious (eg, cats that need strict restraint, cats that attacked people, or cats that were not able to take a comfortable position and were assessed to be too nervous by owners and clinicians) to allow BP measurement were excluded from the study. SBP was measured by an indirect Doppler method. An ultrasonic Doppler flow detector (Model 811-B, Parks Medical Electronics, Inc, Oregon, U.S.A.) with 1.9-cm, 2.5-cm, or 3-cm width inflatable cuffs were used, depending on the circumference of the antebrachium. The cuff was wrapped around the middle part of the antebrachium, and a Doppler probe coated with ultrasonic transmission gel was positioned over the palmar area to detect blood flow from the digitalis palmaris communis artery. The cuff then was inflated and deflated to obtain SBP readings through an aneroid pressure gauge. During BP measurements, the antebrachium was maintained at the level of the heart. A series of 5 readings was obtained

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from each cat, with intervals of 10 to 20 seconds between consecutive readings, and all measurements were completed within 6 min. After excluding maximal and minimal readings, the final SBP value was calculated as the mean of 3 readings.

Statistical analyses were performed with the Statistical Products of Services Solution (SPSS software, Statistical Package for the Social Sciences, version 10.0, SSPS Inc, Illinois, U.S.A.). Comparisons of the SBP of 2 or more subgroups were performed by independent sample *t* tests or one-way ANOVA with Tukey HSD Post Hoc test. The relationships between age, BCS, and SBP were evaluated by Pearson correlation and Kendall's tau-b correlation. The reference values of feline SBP were determined with statistical methods that have been previously applied to humans and dogs [18, 28]. Values represent mean ± standard deviation (SD). A value of $P<0.05$ was considered statistically significant.

RESULTS

The mean SBP for 53 cats was 133.6 ± 16.0 mmHg (range, 110.0–180.0 mmHg). There was no significant difference among different breeds ($P=0.62$) (Fig. 1). Blood pressure distribution was not significantly different between males and females, ($P=0.20$), but SBP distribution seemed more variable in female cats (Fig. 2). After deleting outlying and extreme outlying values (Fig. 2), SBP distribution between the 2 sexes was significantly different (*t* test, $P=0.004$; F test, $P<0.001$). No significant correlation was found between SBP and age ($P=0.30$, coefficient of correlation=0.15) (Fig. 3). SBPs among cats with different BCS were not significantly different ($P=0.67$) (Fig. 4), and there was no significant correlation between SBP and BCS ($P=0.96$, coefficient of correlation = –0.006).

A normal Q-Q plot of SBP for all 53 cats (Fig. 5) showed that there were 2 outlying values. To calculate reference values for SBP, these 2 outlying data were excluded to generate a normal distribution. The mean SBP of these 51 cats was 131.9 ± 13.7 mmHg (range, 110.0–158.5 mmHg) (Fig. 6). A normal SBP range includes the mean ± 1.282 SD, meaning between 114.3 mmHg and 149.5 mmHg (Table 1). Hypertension was defined by the mean plus 2 SD, or greater than 159.3 mmHg, and hypotension by the mean minus 2 SD, or less than 104.5 mmHg. A border zone of suspected hypertension included values of 149.5 mmHg to 159.3 mmHg, and a border zone of suspected hypotension included values of 104.5 mmHg to 114.3 mmHg.

These 53 cats were further categorized into 3 groups: group 1, BP measurements ranged between 114.3 mmHg and 149.5 mmHg (n=38); group 2, BP measurements were lower than 114.3 mmHg (n=8); and group 3, BP measurements were higher than 149.5 mmHg (n=7). The ages, BCSs, and sexes of these 3 subgroups were then compared. There were no significant differences for age ($P=0.34$) or BCS distribution ($P=0.80$), but group 2 had an obviously higher female-to-male ratio (3:1) than did group 1 (1.375:1) and group 3 (1.33:1).

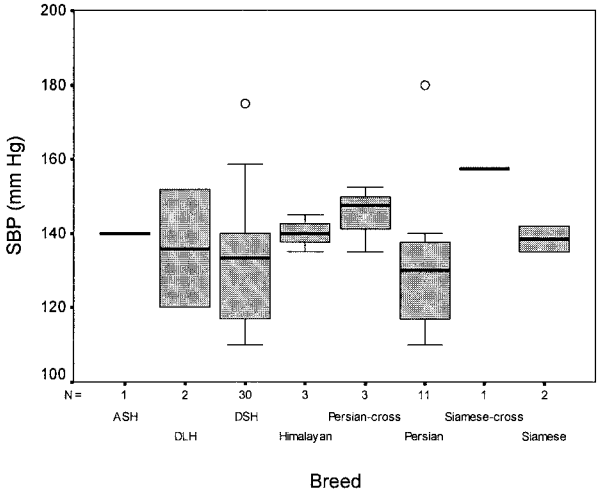

Fig. 1. There was no significant difference in systolic blood pressure (SBP) distribution among different breeds ($P=0.62$). The box represents the 25th and 75th percentiles; whiskers represent 10th and 90th percentiles; line represents median value for each group. ASH = American short haired; DLH=Domestic long haired; DSH = Domestic short haired.

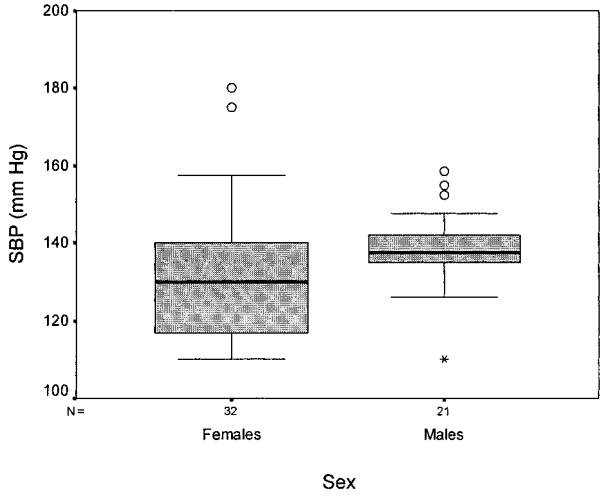

Fig. 2. Systolic blood pressure (SBP) distribution was not significantly different between males and females (P=0.20). After deleting outlying and extreme outlying values, there is a significant difference between sexes (*t* test, $P=0.004$; F test, $P<0.001$). The box represents the 25th and 75th percentiles; whiskers represent 10th and 90th percentiles; line represents median value for each group.

DISCUSSION

Blood pressure is a product of cardiac output and total peripheral resistance. The importance of maintaining normal BP and the consequences of abnormal BP are well known [5, 9, 12, 27]. In cats, abnormal BP is associated

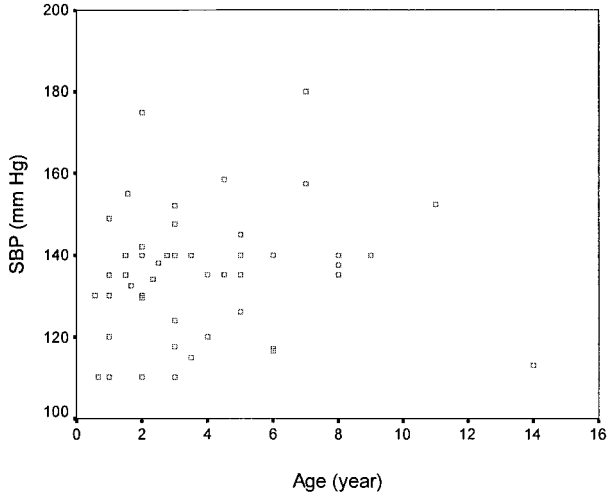

Fig. 3. Scatter diagram of systolic blood pressure (SBP) and age in 53 cats. There was no correlation between SBP and age (P=0.30, coefficient of correlation=0.15).

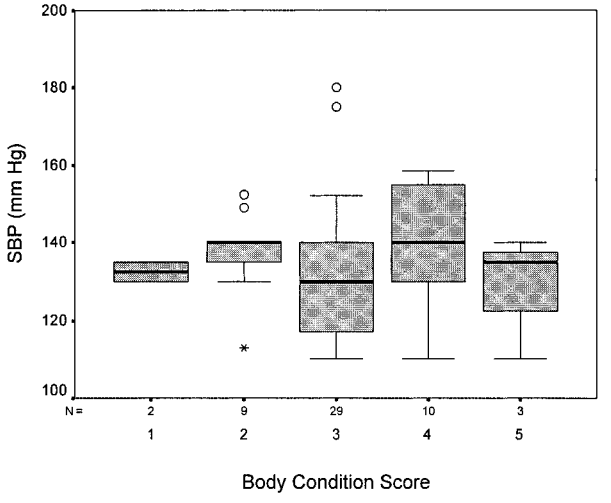

Fig. 4. Systolic blood pressures (SBPs) among cats with different body condition scores (BCSs) were not significantly different (P=0.67), and there was no correlation between SBP and BCS (P=0.96, coefficient of correlation = –0.006). The box represents the 25th and 75th percentiles; whiskers represent 10th and 90th percentiles; line represents median value for each group.

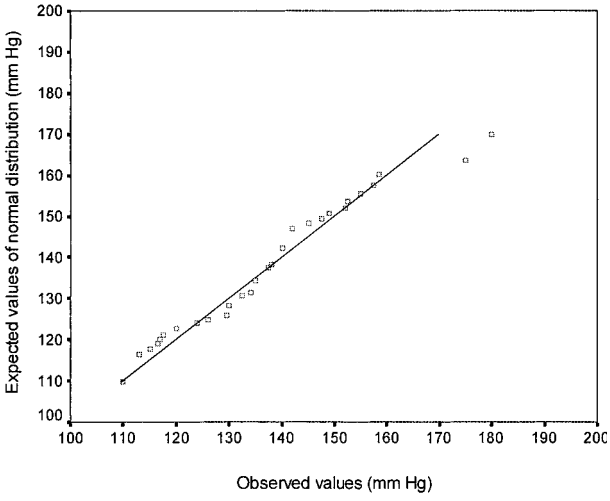

Fig. 5. Normal Q-Q plot of systolic blood pressures (SBP) in 53 cats. There were 2 outlying values noted.

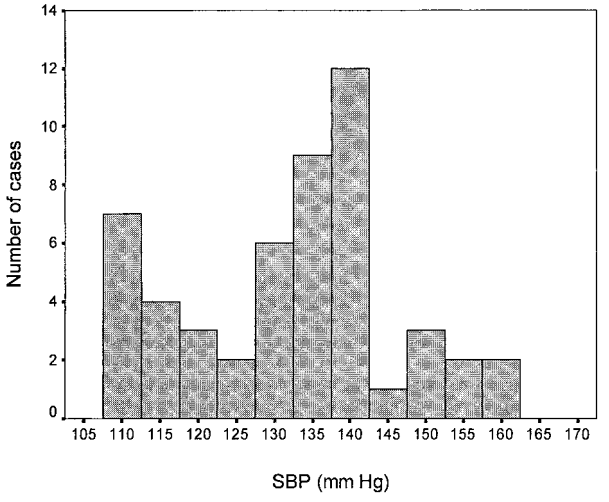

Fig. 6. Systolic blood pressure (SBP) distribution of cats (n=51) after excluding 2 outlying values from normal distribution. The mean SBP of these 51 cats was 131.9 ± 13.7 mmHg.

Table 1. Criteria for normal and abnormal systolic blood pressure of cats

Definition	Systolic blood pressure
Hypertension	>159.3 mmHg
Suspected hypertension	149.5~159.3 mmHg
Normotension	114.3~149.5 mmHg
Suspected hypotension	104.5~114.3 mmHg
Hypotension	<104.5 mmHg

with a variety of disease states, such as renal, cardiovascular, endocrine, and ocular diseases [5, 9, 15, 19]. Although BP measurement is important, it is not routinely performed partially owing to a lack of sufficient evidence for adequate references in a clinical setting. Blood pressure measurements in human have been practicing for nearly 100 years, but the clinicians have been still working on updating and adjusting their reference values [8, 10]. However, this information is relatively lacking in veterinary medicine.

The ultrasonic Doppler technique is a convenient, inexpensive, rapid, and accurate method for indirect BP measurement in conscious cats. When performed by an experienced clinician or technician, SBP can be measured quickly and accurately with minimal stress to the cat.

Table 2. Studies of SBP in conscious and healthy cats using an indirect Doppler method

Author	N	Age	SBP (mean ± SD)	Site of cuff wrapping	Environment	Origin of cats
Klevans *et al.* (1979)	5	Adult cats	139 ± 8 mmHg to 146 ± 9 mmHg	Hind limb	Lab	Colony cats in a laboratory
Kobayashi *et al.* (1990)	33	Mean: 8.7 ± 5.6 yrs (2–20 yrs)	118.4 ± 10.6 mmHg	Hind limb	A quiet room	Colony cats in a laboratory + client-owned
Sparkes *et al.* (1999)	50	Mean: 5.4 yrs (1.5–16 yrs)	162 ± 19 mmHg	Antebrachium	An unfamiliar room (to mimic a clinical setting)	Specific-pathogen-free-derived cats
Nelson *et al.* (2002)	15	Mean: 10.1 ± 2.3 yrs (all > 8 yrs)	145.5 ± 18.3 mmHg	Hind limb	Hospital	Client-owned + cats owned by VTH staff & students
The present study	53	Mean: 3.7 ± 2.8 yrs (0.6 –14 yrs)	133.6 ± 16 mmHg	Antebrachium	Hospital	Client-owned

Table 3. Variable criteria for feline hypertension measured by the indirect Doppler method

Determined by statistical method			
Study	Criteria for hypertension (SBP) (mmHg)	N	Statistical method
Lesser *et al.* (1992)	SBP > 141 mmHg	33	Based on Kobayashi & coworkers (1990) (by the mean SBP plus 2 SD of 33 clinically normal cats)
Sparkes *et al.* (1999)	SBP ≥ 200 mmHg: Strongly suggestive of hypertension SBP ≥ 185 mmHg: Viewed with suspicion & monitored further	50	Determined by the mean SBP plus 2 SD of 50 clinically normal cats Determined by the mean SBP plus 1.282 SD of 50 clinically normal cats
Not determined by statistical method			
Study	Criteria for hypertension (SBP) (mmHg)	N	References
Morgan (1986)	SBP > 170 mmHg	–	Chosen subjectively based upon previous reports in both dogs and cats
Sansom *et al.* (1994)	SBP > 170 mmHg	–	Unknown (no references given in their materials & methods)
Stiles *et al.* (1994)	SBP > 160 mmHg	–	Based upon work with normal & hypertensive cats in the University of Minnesota Veterinary Teaching Hospital
Henik *et al.* (1997)	SBP > 170 mmHg	–	According to the criteria built by Morgan (1986)
Snyder *et al.* (2001)	SBP > 170 mmHg	–	Unknown (no references given in their materials & methods)
Nelson *et al.* (2002)	SBP > 180 mmHg	–	Chosen subjectively based upon previous reports in cats
Chetboul *et al.* (2003)	SBP > 170 mmHg	–	According to the criteria built by Morgan (1986)

Numerous studies and case reports of hypertensive cats have used this technique for SBP measurement [7, 11, 13, 15–17, 19, 20]. However, there are few studies of BP distribution in nonanesthetized normal cats, and the reported SBP values vary widely (Table 2) [15, 16, 20, 25]. Klevans and coworkers determined that SBP in 5 healthy cats varied from 139 ± 8 to 146 ± 9 mmHg when measured hourly over a 5-hr period [15]. In 1990, Kobayashi and coworkers reported a mean SBP of 118.4 ± 10.6 mmHg from 33 clinically normal cats [16]. Sparkes and coworkers determined a mean SBP of 162 ± 19 mmHg from 50 healthy cats, which was much higher than that of previous reports [25]. Based on these results, they claimed that previous estimates for the upper limit of normal BP were too conservative [25]. In a recent study, Nelson and coworkers reported a mean SBP of 145.5 ± 18.3 mmHg in 15 healthy and senile cats [20]. The mean SBP from this study was not as high as Sparkes reported, but higher than Kobayashi's results. In short, the previous reference values for feline BP are still inconsistent and lack of agreement between studies.

To set up SBP references for normal, conscious cats in a clinical setting, we measured SBP in cats attending our hospital for routine health care or other purposes (eg, castration or ovariohysterectomy). Our mean SBP from 53 cats was 133.6 ± 16.0 mmHg, which was not as high as Sparkes and coworkers reported, but was closer to other results. As a

result, we support a stricter limit for the definition of hypertension in cats. Master and coworkers described a statistical technique for defining normal and abnormal BP ranges in the early years of human studies, and others have applied this method to canine and feline BP studies [17, 18, 21, 25, 28]. In the present study, the reference range of normal SBP was defined as the mean ± 1.282 SD, which includes 80% of a normally distributed population. Hypertension was defined as the mean plus 2 SD, which represents 2.5% of the population at high extreme; hypotension was defined as the mean minus 2 SD, which represents 2.5% of the population at low extreme.

The criteria for feline hypertension varies from 141 mmHg to 200 mmHg (Table 3) [7, 13, 17, 19, 20, 22, 24–26], but the most common definition is about 170 mmHg [7, 13, 19, 22, 24]. However, this criterion was often chosen subjectively based upon previous reports or on observations in both dogs and cats. Only 2 reports defined the parameters of their statistical analyses, and the results of these 2 studies were quite different (141 and 200 mmHg) because of considerable differences in the mean SBP [17, 25]. Therefore, we sought to determine the criteria for normal and abnormal SBP based on clearly defined statistical analyses. Our criterion for feline hypertension was an SBP of over 160 mmHg, a value consistent with the recent literature.

Factors such as breed, BCS, and age did not affect feline SBP distribution significantly in our study. In an epidemiological study of BP measured by oscillometric methods, there were no significant relationships noted between SBP and breed or BCS [4]. Obesity is associated with higher BP in human beings, and possibly in dogs, but this has not been shown for cats [3, 4, 9, 27]. Compared with dogs, cats tend to have more consistent body weight and shape. Feline BP might not be affected by body weight or shape. Age-related increases in BP have been described extensively in humans [2], and recently were shown for dogs [28]. However, the relationship between feline SBP and age has been inconsistent [4, 16, 23, 25]. The results of the present study only showed that factors such as breed, BCS, and age had no impact on SBP distribution among the included 53 cats, and the actually effects of these factors on SBP should be assessed separately and properly in the future.

In the present study, female cats had significantly lower SBP values and greater variability in their SBP distribution than males. The role of sex on feline SBP is unknown. One study showed no effect of sex on SBP, whereas another report found female cats to be at a markedly increased risk for developing hypertensive retinopathy [23, 25]. The degree of socialization, hormones, and lifestyles could all contribute to sex-related differences in SBP.

The stress associated with the white-coat effect was the most important confounding factor to identify a truly hypertensive state in cats, but the impact of this effect appeared to decrease over the time of the measurement [1]. However, in our experience, prolonging the measurement time can lead to some cats becoming more stressed and anxious, leading to higher BP readings over time in these cats. Based upon our finding, we excluded the extreme readings in a series of SBP values in the present study, other than deleting the first few readings. Since the Doppler method allows rapid assessment of BP (all of our measurements could be completed within 6 min), we suggest that this technique could improve animals' tolerance to the procedure, and therefore make it more useful in the clinical settings. In conclusion, BP monitoring should be performed routinely in feline practice to allow the benefit or efficacy of BP control to be evaluated more extensively.

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