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Epidemiology of systemic hypertension in dogs

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ABSTRACT

The present study was designed with the objective to evaluate the systolic BP using Doppler sphygmomanometer in healthy and clinically ill dogs and to establish the association of BP with various factors like age, sex, breed and body weight/body condition score (BCS) as well as with different disease conditions. A total of 198 dogs (46 healthy and 152 clinically ill) were enrolled in the study and it was found that mean systolic BP of apparently healthy (n=46) and clinically ill dogs (n=152) varied significantly. The average systolic BP among the diseased dogs was significantly greater in the large breed dogs (n=124) than small-medium breeds (n=74). The Pearson's correlation coefficient revealed that age of the animals was positively correlated with BP along with a negative correlation of BCS with BP. The linear regression analysis also depicted that BCS had a significant effect on the systolic BP indicating that decreasing BCS had 13.52 times increasing systolic BP. The large breeds and male animals had more BP than the small breeds and females. The dogs affected with chronic kidney disease (CKD) had a highest prevalence of systemic hypertension indicating the more occurrence of secondary nature. Therefore, it was concluded that male dogs of large breeds affected with CKD and lower BCS had more prevalence of secondary systemic hypertension.

Keywords: Blood pressure, Body condition score, Chronic kidney disease, Dogs, Systemic hypertension

Systemic arterial blood pressure (BP) is the resultant of cardiac output and total peripheral resistance which is the total force exerted by blood on the walls of arteries (Williamson and Leone 2012, Sangwan and Saini 2023). Systemic hypertension also known as the silent killer in human medicine is a newly recognized and most under-diagnosed disease in veterinary that affects the essence and survivability of companion animals (Elliott and Brown 2020). The companion animals suffering from systolic BP of more than 140 mmHg presented with or without target organ damage (TOD) manifestations are considered to be systemically hypertensive (Acierno *et al.* 2018).

Hypertension in dogs can be classified into three types: primary, secondary and idiopathic hypertension. Secondary hypertension is the most common form in dogs which occurs due to the concurrent underlying disease in contrast to humans where primary form is predominant (Syme 2020). The clinical manifestations of systemic hypertension are undetectable in veterinary patients and more of subtle nature to veterinarian and dependent on underlying disease condition. Thus, systolic BP monitoring is indicated in the dogs with clinical signs consistent with TOD lesions and underlying diseases associated with hypertension (Acierno *et al.* 2018).

Systolic BP monitoring can be done by either direct arterial puncture or indirect non-invasive monitoring techniques like Doppler sphygmomanometry and oscillometry which are most commonly practiced. Doppler sphygmomanometry because of its irreplaceable advantages like portability, easy to use and audible signal along with economic feasibility, is the most commonly employed technique in routine clinical settings (Acierno *et al.* 2018, Lloyd 2018).

The prevalence of hypertension in companion animals is still in the infant stage. It has been depicted that BP is affected by various factors including patient related factors like age, breed, sex and body weight. No clear relationship with age, sex, body weight, breeds have been established yet with controversial findings. So, the present study was designed with the objective to evaluate the systolic BP in healthy and clinically ill dogs and to establish the association of BP with various factors and with different disease conditions to establish epidemiological presentation.

MATERIALS AND METHODS

Animals under study: A total of 198 dogs which were further classified in two groups, i.e apparently healthy (n=46) and clinically ill dogs (n=152) were part of this study. Group 1 (n=46) consisted of dogs presented for the routine health check-up, deworming, vaccinations without any history of heart or respiratory diseases. Group 2 (n=152) consisted of clinically ill dogs presented with signs of renal disease (polyuria, polydypsia, vomiting, halitosis, melena etc.), cardiac disease (heart murmurs, weight loss/cachexia,

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syncope, exercise intolerance, nocturnal coughing etc.), ocular abnormality (acute blindness), neurological disease (seizures, ataxia, paresis etc.), endocrinopathies (diabetes mellitus and hypothyroidism), ascites (cardiac/liver/renal origin), epistaxis and various tumorous conditions.

Signalment: The age, breed, sex, body weight and body condition score (BCS) were recorded in all dogs. The dogs were grouped on the basis of different parameters like age, breed, sex and BCS. Three age-groups were classified as <4 (young), 4-8 (middle aged) and ≥8 (senile dogs) years of age. The dogs were further grouped on the basis of breeds as large breeds (body weight ≥25 kg) and small-medium sized breeds (body weight <25 kg). Different breeds were individualized and taken into consideration. Number of male and female was noted in the whole study. The dogs were grouped as per BCS in three groups, i.e 1-2, 3 and 4-5.

Blood pressure monitoring: All the dogs (n=198) underwent systolic BP monitoring by Doppler method (Vet-dop2, Model BF2, Vmed technology, USA) as per the procedure specified by Sangwan *et al*. (2023). The dogs were classified into four categories on the basis of risk of target organ damage (TOD) and systolic BP as normotensive (<140 mmHg), pre-hypertensive (140-159 mmHg), hypertensive (160-179 mmHg) and severely hypertensive (≤180 mmHg) as per American College of Veterinary Internal Medicine (ACVIM) and Syme (2020).

Statistical analysis: The statistical analysis of the obtained data was done using Graphpad Prism statistical software version 8.0.1 (244). The normality of the obtained data was first tested using four tests (Anderson-Darling test, D'Agostino& Pearson test, Shapiro-wilk test, Kolmogorov-Smirnov test) using Graphpad Prism. The data was further analyzed only after passing the normality test (P>0.05) from at least one of these tests. The significant level of parameters was predicted at a 95% confidence interval (P<0.05) while, the tendency to be significant was evaluated at a P-value less than 0.10. The obtained values were expressed as Mean±standard error of Mean (SEM) and percentage (%) depending upon the type of data. One-way analysis of variance (ANOVA), student's T-test, Pearson's correlation coefficient (r) and linear regression analysis was used for the analysis of data.

RESULTS AND DISCUSSION

The demographics of all animals as per age (years), breed, sex, body weight and BCS with category-wise average systolic BP has been presented in Table 1. A

Table 1. Demographics of animals included in the study with category wise mean systolic BP (n=198)

Parameter		Mean systolic BP (mmHg)	
		Healthy (n=46)	Diseased (n=152)
Breed	Large Breeds (B. wt. ≥25 kg) (n=124)	117.4±1.53^{a} (n=26)	155.1±3.27^{bA} (n=98)
	Small-medium Breeds (B. wt. <25 kg) (n=74)	122.2±5.30^{a} (n=20)	140.7±4.66^{bB} (n=54)
Age group	<4 years (n=37)	117.0±3.54^{a} (n=20)	153.4±7.03^{b} (n=17)
	4-8 years (n=78)	119.2±3.26^{a} (n=17)	143.5±4.47^{b} (n=61)
	≥8 years (n=83)	129.5±9.47^{a} (n=09)	149.5±3.91^{b} (n=74)
Sex	Male (n=159)	118.3±2.41^{a} (n=34)	149.9±3.10^{bA} (n=125)
	Female (n=39)	121.6±7.05 (n=12)	135.3±7.01^{B} (n=27)
Body weight	<15 kg body weight (n=58)	114.4±4.23^{a} (n=15)	141.7±5.51^{b} (n=43)
	15-25 kg body weight (n=42)	132.0±10.43 (n=09)	148.4±5.80 (n=33)
	25-40 kg body weight (n=73)	122.9±6.30^{a} (n=18)	147.1±4.44^{b} (n=55)
	≥40 kg body weight (n=25)	131.1±14.62 (n=4)	157.5±9.17 (n=21)
BCS	1-2 (n=45)	95.00±15.0^{a} (n=2)	159.1±5.36^{aA} (n=43)
	3 (n=102)	122.0±4.67^{a} (n=29)	144.3±4.05^{bB} (n=73)
	4-5 (n=51)	127.4±6.32 (n=15)	139.3±5.69^{B} (n=36)
Total (n=198)		122.6±3.70^{a} (n=46)	147.3±2.86^{b} (n=152)

Mean±SEM with superscripts a, b differ significantly (P<0.05) within rows. Mean±SEM with superscripts A, B differ significantly (P<0.05) within columns for one parameter. Mean±SEM without superscripts differ non-significantly (P>0.05)

total 198 dogs were enrolled in the present study which comprised 46 healthy and 152 diseased dogs; 159 males and 39 females; 124 large breed dogs and 74 small-medium sized dogs. The average systolic BP of the healthy dogs in the present study was lower than the average BP readings monitored via Doppler method by other workers (Sanan and Arslan 2007, Rondeau *et al.* 2013). But, the systolic BP readings of present study were comparable and similar to studies conducted by Scansen *et al.* (2014) who used Doppler method for BP monitoring from foreleg and hindleg of dogs. Also, BP values matched to the various studies of systolic BP monitoring using other method (Hougland *et al.* 2012) in dogs.

Overall prevalence: The overall prevalence of hypertension in the present study was 44.44% (88/198). The prevalence of hypertension in different disease conditions with average systolic BP disease-wise is depicted in Table 2. The prevalence of systemic hypertension was higher (44.44%) in the current study than the previously reported prevalence by Scansen *et al.* (2014). The reason for the greater prevalence could be due to inclusion of a greater number of dogs with many different breeds in the study as compared to the small number of dogs with very few breeds inclusion in the previously conducted study. As secondary hypertension is the most common form in dogs, the prevalence of hypertension was described according to different underlying disease condition in veterinary literature (Acierno *et al.* 2018, Syme 2020).

Interbreed variations and breed-wise prevalence: The breed wise distribution of animals in the study has been presented in Supplementary Table 1. Also, the average systolic BP and prevalence of hypertension in different breeds of clinically healthy and ill dogs was monitored and calculated, respectively. It was found that the average systolic BP of diseased Labrador retrievers, pugs and other miscellaneous category dogs was significantly higher ($P<0.05$) than the control group of that breeds. Among the healthy dog breeds, Beagles had significantly higher BP ($P<0.05$) than healthy Golden retrievers and Pugs and among the diseased group, Pugs had significantly $P<0.05$) lower systolic BP as compared to other dog breeds. The average systolic BP among the diseased and healthy dogs with further comparison of large breed dogs to the small-medium sized breeds could not be comparable to any available study due to the lack of population wide studies in dogs. But Labrador retriever and Pug were the most common breeds affected with systemic hypertension in the present study because of more rearing of these breeds

Table 2. Prevalence of hypertension in different disease conditions in dogs

Disease	Average Systolic BP (mmHg)	Diseased				
		Normotensive (n=64)	Pre-hypertensive (n=31)	Hypertensive (n=32)	Severe hypertensive (n=25)	HT (n=88)
Chronic kidney disease (CKD) (n=67)	167.2±4.41^{aA}	10 (14.92%)	16 (23.88%)	21 (31.34%)	20 (29.85%)	57 (85.07%)
Acute kidney injury (AKI) (n=02)	159.8±20.60	01 (50.00%)	-	-	01 (50.00%)	01 (50.00%)
Cardio-renal syndrome (n=07)	142.2±7.25	02 (28.57%)	03 (42.85%)	02 (28.57%)	-	05 (71.42%)
Dilated cardiomyopathy (DCM)/ congestive heart failure (CHF) (n=22)	116.2±5.35^{b}	18 (81.81%)	04 (18.18%)	-	-	04 (18.18%)
Mitral valve degenerative disease (MVDD) (n=05)	143.3±10.15	03 (60.0%)	-	02 (40.0%)	-	02 (40.0%)
Hypertrophic cardiomyopathy (HCM) (n=08)	124.5±5.38^{B}	07 (87.50%)	01 (12.50%)	-	-	01 (12.50%)
Other cardiac abnormality (n=13)	118.0±5.51^{b}	10 (76.92%)	01 (7.69%)	-	02 (15.38%)	03 (23.07%)
Nervous syndrome (05)	125.0±14.05	03 (60.0%)	02 (40.0%)	-	-	02 (40.0%)
Diabetes mellitus (n=05)	139.5±10.48	03 (60.0%)	01 (20.0%)	01 (20.0%)	-	02 (40.0%)
Hepatic diseases (n=04)	123.6±18.27	03 (75.0%)	-	01 (25.0%)	-	01 (25.0%)
Miscellaneous conditions (n=14)	152.17±6.24			03 (21.42%)	05 (35.71%)	02 (14.28%)

HT: overall hypertensive dogs having systolic BP of ≥140 mm Hg. Mean±SEM with superscripts a, b, differ significantly ($P<0.05$) within columns.

in the surrounding areas thereby more presentation in the clinics. Similar to our findings, Bodey and Michell (1996) depicted the approximate variation of 10-15 mmHg among all breeds with the exception of Grey hounds in which the BP was 10-20 mmHg higher than mongrel breeds. The significantly higher BP in healthy Beagles was because Beagle breed dogs were less acclimatized with hospital surroundings and people even after providing sufficient time of acclimatization. Contrasting to the present study where small-medium sized breeds had comparatively lower BP, Hoareau *et al.* (2012) depicted the higher BP among the brachycephalic dogs as compared to other breeds. This could be because of the inclusion of different types of breeds (either brachycephalic or mesocephalic) among the small-medium breed group in the present study. Various breed specific studies (Sanan and Arslan 2007, Marino *et al.* 2011, Scansen *et al.* 2014) have been conducted on Shetland sheepdogs, Greyhounds, Kangal and Irish wolfhounds. But, data in the present study could not be comparable to any reference due to lack of population wide studies in dogs depicting BP among different breeds and because of heterogeneity among the dog breeds.

Diseases and clinical manifestations-wise prevalence: The distribution of animals' disease wise has been depicted in Supplementary Table 2. Out of all the dogs presented with different diseases, chronic kidney disease (CKD) was the most common disease associated with secondary hypertension with the highest prevalence followed by miscellaneous disease conditions like various carcinomas (renal), adrenal tumour, multi-organ failure and ocular disease and cardio-renal syndrome. Among the CKD affected dogs, the prevalence of systemic hypertension was 85.07% (57/67) which is in accordance with the other studies (Cortadellas *et al.* 2006, Buranakarl *et al.* 2007, Braga *et al.* 2015) where the prevalence of hypertension due to CKD varied from 9.5-93%. The range of systolic BP in renal disease affected dogs varying from normotensive category to severe hypertensive categories.

The highest prevalence of hypertension in CKD and cardio-renal diseases could be concluded by the fact that renal and its associated diseases causes failure of kidney to regulate body fluid volume and causes activation of RAAS (Renin-Angiotensin-Angiotensinogen System), over-activity of renal afferent nerves, decreased production of renalase enzyme and phosphate retention, all of which led to increased vascular tone. Also, failure to regulate fluid volume and high vascular tone causes high blood pressure (Elliott and Brown 2020).

The acute kidney injury (AKI) hypertension prevalence was in accordance with various studies who reported hypertension in 37-87% of AKI affected dogs (Francey and Cowgill 2000, Geigy *et al.* 2011). But, the less prevalence of hypertension caused by AKI in the present study was speculative due to a smaller number of AKI cases presented in the clinics. Such discrepancy in the prevalence of renal associated diseases in the previously conducted studies and present study might be due to the different etiologies of renal disease and different criterion of hypertension categorization (Cortadellas *et al.* 2006, Syme 2020).

Hypertensive dogs with MVDD (mitral valve degenerative disease) were in contradiction to the fact that with mitral valve diseases, due to decreased cardiac output the BP should decrease with increasing severity of heart failure (Borgarelli *et al.* 2008, Petit *et al.* 2013). The possible explanation for this could be the inclusion of higher number of aged dogs and thus subclinical renal affections and proteinuria can cause this hypertension in MVDD patient. With regard to diabetes mellitus, few studies (Herring *et al.* 2014, Marynissen *et al.* 2016) reported the prevalence of hypertension in diabetes mellitus (35-50%) to be an important disease after renal diseases in causing secondary hypertension.

Dilated cardiomyopathy (DCM)/Congestive heart failure (CHF), hepatic diseases and hypertrophic cardiomyopathy (HCM) were the diseases having least hypertensive prevalence. One study depicted the absence of marked hypertension in cardiac disease affected dogs with no significant difference in the systolic BP of healthy and cardiac disease affected dogs (Palanisamy 2021). The possible explanation for this could be decreased cardiac output with increasing severity of heart failure leading to decreased overall arterial BP (Borgarelli *et al.* 2008, Petit *et al.* 2013, Syme 2020). The normal BP in hepatic disease affected dogs could be due to concurrent hepatomegaly in cardiac diseases.

The clinical manifestations presented were related to the underlying disease condition in dogs which was causing secondary hypertension. As CKD was the most common underlying cause of hypertension, therefore the major clinical manifestations in hypertensive dogs were melena and vomiting (72.72%) along with cachexia (75.0%). This was followed by exercise intolerance (7.95%), ascites/limb edema (5.65%) and respiratory distress (5.68%). Epistaxis as the only clinical manifestation was observed in 4.54% of hypertensive dogs as hypertension due to subclinical and clinical CKD leads to epistaxis. Also, rubbery jaw (nutritional secondary hyperparathyroidism) associated with CKD was observed in 3.40% of hypertensive dogs. Polyuria and polydipsia as the clinical manifestations of endocrine diseases were observed in 3.40% of hypertensive dogs. Seizures due to nervous anomaly and hematuria due to cystitis and concurrent splenic tumour constituted only about 2.27% of cases. Syncope and acute blindness were the least common manifestations in the present study with only 1.14 % of hypertensive cases.

Correlation and regression of systolic BP with various factors: The Pearson's correlation coefficient (r), coefficient of determination (R^2), confidence interval and p-value for each factor was calculated to study the association of various factors like age (years), BCS, body weight (kg), breed (large/small) and sex (male/female) with systolic BP has been presented in Table 3. The multiple linear regressions were also calculated to study the cumulative effect of different factors on systolic BP. The Pearson's

Table 3. Correlation of blood pressure with various factors

Parameter	Pearson's coefficient (r)	Coefficient of determination (R^2)	Confidence interval	P-value
Age	0.120	0.0144	-0.02 to 0.25	0.047*
BCS	-0.197	0.0388	-0.33 to -0.06	0.003*
Body weight	0.074	0.0055	-0.07 to 0.21	0.149$
Breed	-0.131	0.0172	-0.27 to 0.008	0.033*
Sex	-0.111	0.0123	-0.25 to 0.03	0.061#

*, Significant (P<0.05); #, Significant (P<0.1); $, Non-significant (P>0.1).

correlation coefficient analysis depicted male dogs were found to be having greater systolic BP than females and the age of dogs (years) was positively correlated with systolic BP. No significant effect of body weight on systolic BP was noted in the present study of dogs. The body condition score (BCS) was found to be negatively correlated with systolic BP along with the regression coefficient of systolic BP on BCS was -13.52 (B= -13.52; P=0.003), indicating that lean and cachectic dogs have increased systolic BP. No other factor had significant effect in regression analysis.

The depiction of increased systolic BP with senility in the present study was similar to previous reports in dogs (Bright and Dentino 2002) as well as human beings (Bavishi *et al.* 2016). This increased systolic BP with age could be explained by the fact that aortic stiffening increases with age along with rapid returning of reflected pulse waves from periphery (Bavishi *et al.* 2016, Sangwan *et al*. 2023). Also, with the advancing age and maturity of body systems, low-resistance and high output cardiovascular system starts shifting to the high resistance and low output system ultimately leading to increased total peripheral resistance with resultant systemic hypertension (Bright and Dentino 2002). The positive correlation of male sex with high systolic BP was supported by Schellenberg *et al.* (2007) who depicted the higher BP in intact males as compared to females. The possible explanation is still unclear in veterinary literature. The non-association of body weight with systolic BP was supported by Willems *et al.* (2017) and Mooney *et al.* (2017) who depicted no association between body weight and BP readings. The association of lean BCS with high systolic BP was supported by a study conducted by Perez-Sanchez *et al.* (2015) who depicted that BP and body weight/BCS was associated in an indirect way with dependency on the underlying disease condition present in the dogs. Similarly, there was high number of CKD hypertensive dogs which were presented with cachexia in the present study, thereby supporting the positive association between lean and cachectic body condition with increased BP readings.

Therefore, it can be concluded that systemic hypertension is one of the most under-diagnosed disease because of its silent nature in clinical form. The clinical manifestations in the hypertensive dogs varied according to the underlying disease condition, as secondary hypertension was the most common form detected in the current study with chronic kidney disease as most common underlying cause. Thus, systolic blood pressure monitoring is indicated in the patients with clinical signs consistent with target organ damage lesions and dogs affected with diseases causally associated with hypertension.

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