Indian J Anim Health (2025), 64(2) : 372 - 378
DOI: https://doi.org/10.36062/ijah.2025.04125

Research Article

Evaluation of aortic and pulmonary artery flow by pulsed wave Doppler echocardiography in Indian mongrel dogs

A. Prashar[1], D. Bodh[1*], H. Prasad[1], A. Kumar[1] and S. P. Tyagi[1]

[1]Department of Veterinary Surgery and Radiology, Dr. G. C. Negi College of Veterinary and Animal Sciences, CSK HP Krishi Vishwavidyalaya, Palampur - 176 062, Himachal Pradesh, India

Abstract

The study focused on the evaluation of pulsed wave Doppler flow profile of aorta and pulmonary artery of sixty healthy Indian mongrel dogs, and determination of effect of age, body weight and heart rate on flow variables. Systolic Doppler echocardiographic blood flow profile of pulmonary artery and aorta showed significant differences. Peak velocity, ejection time, pre-ejection period, time to peak, acceleration rate and peak pressure gradient of aortic and pulmonary artery flows were: 1.15±0.02 m/s and 0.80±0.02 m/s, 197.08±3.92 ms and 200.99±7.22 ms, 44.41±1.29 ms and 40.26±1.30 ms, 50.21±2.75 ms and 90.05±2.45 ms, 22.52±0.99 m/s^2 and 10.26±0.54 m/s^2, 5.29±0.20 mm Hg and 2.90±0.17 mm Hg, respectively. Aortic flow peak velocity, pre-ejection period, acceleration rate and peak pressure gradient was significantly ($p<0.05$) greater than pulmonary artery flow. Aortic flow time to peak and time to peak to ejection time ratio was significantly ($p<0.05$) shorter than pulmonary artery flow. Aortic peak velocity showed significant positive correlation with heart rate (r=0.33; p=0.008), aortic pre-ejection period showed significant negative correlation with age (r=-0.25; p=0.05), pulmonary ejection time showed significant positive correlation with body weight (r=0.31; p=0.01) and pulmonary pre-ejection period showed significant negative correlation with heart rate (r=-0.28; p=0.02). Data obtained can be used as reference for cardiovascular disease diagnosis in mongrel dogs. Effect of age, heart rate and body weight on Doppler sonographic aortic and pulmonary artery flow variables should be considered for cardiovascular diseases diagnosis in Indian mongrel dogs.

Key words: Blood flow, Cardiac valve, Dogs, Echocardiography, Pulsed-wave Doppler

Highlights

- Aortic flow is asymmetrical while pulmonary artery flow is symmetrical
- Aortic PV, PEP and PPG is greater than pulmonary PV, PEP and PPG
- Aortic flow attains peak velocity in shorter time as compared to pulmonary artery flow
- Age, heart rate, body weight influences aortic and pulmonary artery flow in healthy dogs

INTRODUCTION

The ability of Doppler echocardiography to non-invasively estimate blood flow velocity and pressure gradient across cardiac valves has opened new areas of investigation for detection and quantification of cardiovascular diseases. Spectral Doppler waveform provides qualitative and quantitative information about blood flow across cardiac valves (Whey-Li et al., 2003). The blood flow of the aorta and pulmonary artery differs significantly, as has been specifically studied in small animal medicine (Kirberger et al., 1992a; Kirberger et al., 1992b)

Aortic and pulmonary artery flow obtained by pulsed-wave Doppler provide indirect estimation of pressures within the cardiac chambers and great vessels, and help in assessing diastolic function (Kellihan & Stepien, 2012). Altered blood flow in aortic or pulmonary artery may be seen in aortic stenosis, aortic insufficiency, and pulmonary hypertension. Doppler derived blood flow velocity across normal cardiac valves in mixed population of healthy dogs has already been documented (Brown et al., 1991; Yuill & O´Grady, 1991; Kirberger et al., 1992a; Petrus et al., 2010).

Mongrel dogs are not purebred, yet their value as pet in Indian households has increased due to their adaptability, low maintenance and affectionate nature. In mongrel dogs, M-mode (Singh et al., 2018), pulsed-wave Doppler (Bodhet al., 2020) and two-dimensional echocardiographic study (Bisht et al., 2024) have been done but there is only scant information about the blood flow of aorta and pulmonary artery in Indian mongrel dogs.

With this background, the aim of present study was to evaluate the blood flow across normal aortic and pulmonary valves using pulsed-wave Doppler echocardiography and to determine possible influences of different physiological parameters viz.

[*]Corresponding Author, E-mail: deeptibodh@yahoo.co.in

age, heart rate and body weight on aortic and pulmonary flow variables of healthy Indian mongrel dogs.

MATERIALS AND METHODS

Animals under study: A total of 60 client owned healthy mongrel dogs, aged 1-month to 3.5 years and weighing 3.5 to 28 kg (mean body weight =15.34±0.87 kg) presented for routine health check-up, vaccination and elective surgeries were enrolled for the study. The dogs were deemed clinically healthy after physical, haematological, radiographic, electrocardiographic, and echocardiographic evaluation.

Signalment: The age, breed, and body weight of all dogs were recorded. Dogs were randomly divided into three groups: group I (9.10±1.16; 3.5 to 10 kg), group II (18.0±0.67; 11.0 to 19.5 kg) and group III (20.6±0.74; 20 to 24 kg) (Table 1).

Patient preparation: Right and left lateral thoracic wall from 3rd to 7th rib and 1-5 cm lateral to sternum were prepared for Doppler echocardiographic study.

Doppler echocardiographic examination: Two-dimensional guided pulsed-wave Doppler echocardiographic images of aortic and pulmonary flow were obtained using a 4.0-8.0 MHz multi-frequency phased array transducer paired with a digital ultrasound system, ACUSON X300 Premium Edition Diagnostic Ultrasound System by Siemens Medical Solutions USA.

Imaging planes and sample volume position: The imaging planes, sample volume position, transducer position and echocardiographic image acquisition for recording aortic and pulmonary artery flow was done as per Prashar (2024). Aortic flow was recorded from the left caudal (apical) 5-chamber view by placing the sample volume in ascending aorta, at the distal end of the sinus of Valsalva (Fig. 1). Pulmonary artery flow was recorded from the right parasternal short axis view of right ventricular outflow tract at the level of aortic valve with sample volume placed in pulmonary artery just distal to the pulmonary valve (Fig. 2). The size of sample volume for recording aortic and pulmonary artery flow was 1-3 mm. Doppler cursor was kept as parallel as possible to direction of blood flow. No angle correction cursor was used. Gain settings and grayscale were optimized to enable enhanced visualization of aortic and pulmonary valves. The recorded images were reviewed subsequently and the measurements were done using the inbuilt electronic callipers of the ultrasound system. An informed consent was obtained from the pet owners, before starting the examination.

Measurement of the Doppler blood flow profile: Different echocardiographic parameters were measured.

Table 1. Comparison of aortic and pulmonary flow variables in healthy mongrel dogs

S. no.	Parameter	Cardiac valve	Pooled (n-60)	Group-I (n-24)	Group-II (n-16)	Group-III (n-20)	P value
1	PV (m/s)	Ao	1.15± 0.02[a]	1.18±0.04[a]	1.17±0.03[a]	1.11±0.02[a]	0.320
		Pul	0.80±0.02[b]	0.74±0.03[a]	0.87±0.04[ab]	0.80±0.02[b]	0.050
2	ET (ms)	Ao	197.08±3.92[a]	191.79±7.85[a]	192.50±4.94[a]	207.10±5.51[a]	0.197
		Pul	200.99±7.22[a]	210.67±5.92[a]	200.94±13.37[a]	189.41±17.57[a]	0.462
3	PEP(s)	Ao	44.41±1.29[a]	45.12±2.23[ab]	48.56±2.50[b]	40.25±1.67[a]	0.041
		Pul	40.26±1.30[b]	41.04±1.99[a]	39.06±1.80[a]	40.00±2.80[a]	0.836
4	TTP(s)	Ao	50.21±2.75[a]	51.58±4.77[a]	42.75±5.20[a]	54.55±4.09[a]	0.239
		Pul	99.05±2.45[b]	100.50±4.59[a]	93.12±3.17[a]	102.05±1.10[a]	0.339
5	Acc. rate (m/s²)	Ao	22.52±0.99[b]	20.35±1.36[a]	23.22±0.84[a]	24.57±2.33[a]	0.177
		Pul	10.26±0.54[a]	9.93±0.89[a]	9.75±0.72[a]	11.05±1.09[a]	0.585
6	TTP/ET	Ao	0.27±0.03[b]	0.32±0.07[a]	0.22±0.03[a]	0.25±0.01[a]	0.382
		Pul	0.43±0.01[a]	0.44±0.02[a]	0.42±0.01[a]	0.43±0.02[a]	0.821
7	PPG (mmHg)	Ao	5.29±0.20[a]	5.26±0.30[a]	5.61±0.56[a]	5.07±0.19[a]	0.596
		Pul	2.90±0.17[b]	2.83±0.37[b]	3.33±0.24[b]	2.63±0.15[b]	0.282

Values are expressed as mean±SE

n- number of dogs; Ao- aortic flow; Pul- pulmonary artery flow; PV- peak velocity; ET-ejection time; PEP-pre-ejection period; TTP-time to peak; Acc. Rate- acceleration rate; PPG-peak pressure gradient

p <0.05, statistically significant (S) at 95 %

Value with different superscript differed significantly (p<0.05) between groups

Value with same superscript differed non significantly (p>0.05) between groups

Peak velocity (PV, m/s) was recorded as the highest velocity in systolic Doppler flow spectrum. Ejection time (ET) or flow time (FT) in seconds (s) was calculated from the onset to the termination of flow. Pre-ejection period (PEP) in seconds (s) was recorded as the period from beginning of QRS complex to the opening of aortic or pulmonary valve. The shape of blood flow profiles of aorta and pulmonary artery were quantified by the determination of the time to peak (TTP) or acceleration time (AT) in seconds (s) recorded as the systolic time interval from beginning of systolic flow to peak flow, across the aortic or pulmonary valve. Acceleration rate (m/s^2) was recorded as the ratio of peak velocity and acceleration time. Peak pressure gradient (PPG) (mm Hg) was recorded by tracing the peak velocity of each flow and applying it in Bernoulli's equation.

Statistical analysis: The statistical analysis of the data was done by IBM SPSS Statistics 29.0 software. Values were expressed as Mean±standard error (SE). One-way analysis of variance (ANOVA) was used to compare mean between two flows. Bivariate Pearson's correlation test was used to estimate the correlation of aortic and pulmonary artery flow variables with age, body weight and heart rate. Linear regression equation (Y=bX+a) was utilized to quantify the relationship between dependent echocardiographic parameter (Y) and independent variables age, heart rate and body weight (X). The statistical analysis was performed at a confidence interval of 95% .

RESULTS

Mean±standard error (SE) values of aortic and pulmonary artery flow variables in healthy Indian mongrel dogs is displayed in Table 1. Correlation of aortic and pulmonary artery flow variables with age, body weight and heart rate is displayed in Table 2.

It was easier to scan the pulmonary valve from right parasternal location as compared to the left. Significant differences were observed between the systolic Doppler echocardiographic blood flow profiles of the aorta and pulmonary artery. The pulmonary blood flow profile was characterized by a round shape, with a similar acceleration and deceleration phase. In contrast to this, the blood flow profile of the aorta showed a short acceleration and a long deceleration phase. During systole, flow through both the valves was negative. Flow started near the end of QRS complex, and continued through the T wave of ECG. During acceleration phase, flow in aorta accelerated rapidly and smoothly, reaching peak velocity within first third of systole with little spectral broadening. Deceleration phase of aortic flow was slower, characterized by a dispersed spectrum, indicating wider variation in flow velocity (Fig. 1a). Pulmonary flow recorded similar duration of acceleration and deceleration phases, reaching peak velocity just before the mid-systole. Spectral width during acceleration phase was narrow indicating a well-defined and orderly flow pattern compared to spectral broadening during deceleration phase (Fig. 1b).

Aortic flow PV, PEP, acceleration rate and PPG was significantly ($p<0.05$) greater than pulmonary artery flow. Aortic flow TTP and TTP:ET ratio was significantly ($p<0.05$) shorter than pulmonary artery flow. Aortic PV showed significant positive correlation

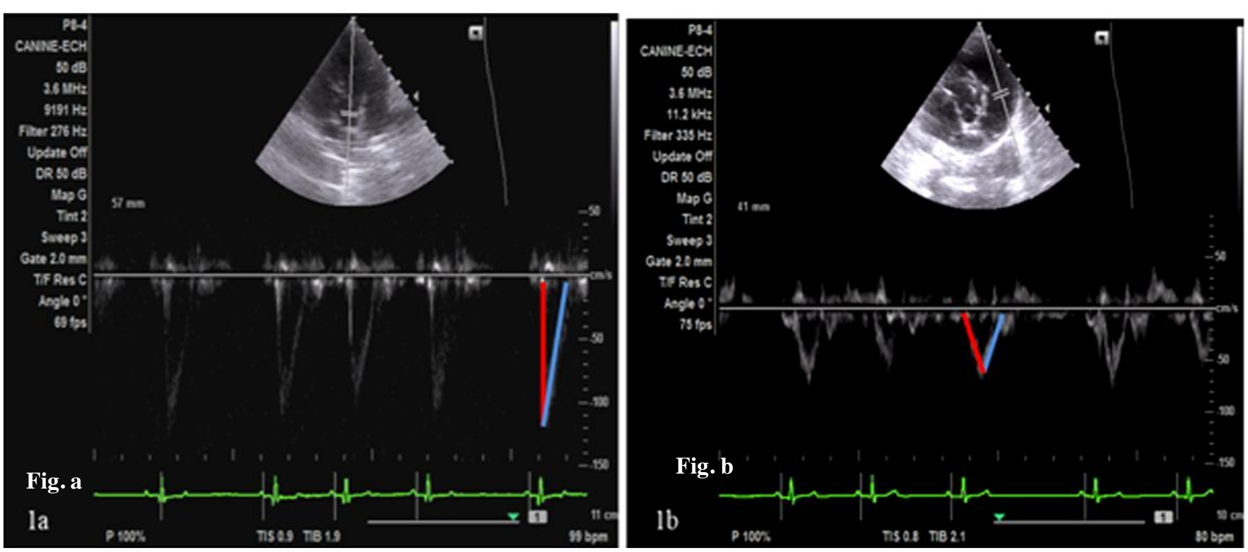

Fig. 1. Pulsed-wave Doppler echocardiography of blood flow profile of the aorta (a) and pulmonary artery (b). The acceleration phase of the blood flow is marked with a red line, and the deceleration phase with a blue line

Table 2. Correlation of pulsed-wave Doppler derived aortic and pulmonary valve flow variables with age, body weight and heart rate in healthy mongrel dogs (n=60)

Parameter	Cardiac Valve	Age(r)	p value	Body	P value weight (r)	Heart	p value rate (r)
PV	Ao	0.02	0.86	-0.02	0.82	0.33**	0.008*
	Pul	-0.15	0.23	0.29	0.24	-0.01	0.88
ET	Ao	0.01	0.97	-0.10	0.43	0.02	0.82
	Pul	0.90	0.49	0.31*	0.01*	-0.23	0.07
PEP	Ao	0.25*	00.05*	-0.04	0.73	-0.02	0.87
	Pul	0.12	0.92	-0.15	0.22	-0.28	0.028*
TTP	Ao	0.00	0.98	0.13	0.31	-0.06	0.15
	Pul	-0.09	0.46	-0.14	0.27	-0.01	0.16

n- number of dogs; Ao- aortic flow; Pul-pulmonary artery flow; PV- peak velocity; ET-ejection time; PEP-pre-ejection period; TTP-time to peak; r-correlation.
p <0.05, statistically significant (S) at 95 % level

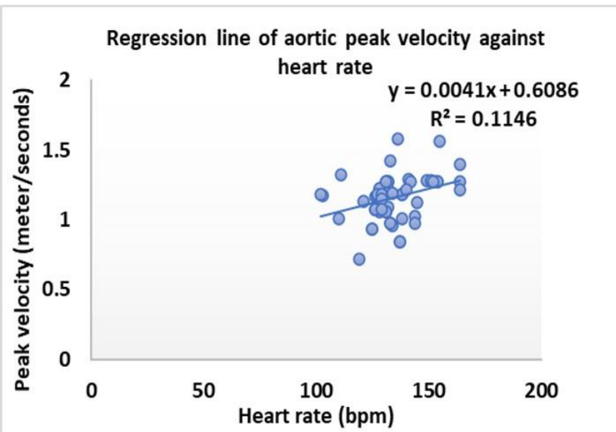

Fig. 2. Correlation of aortic peak velocity with heart rate

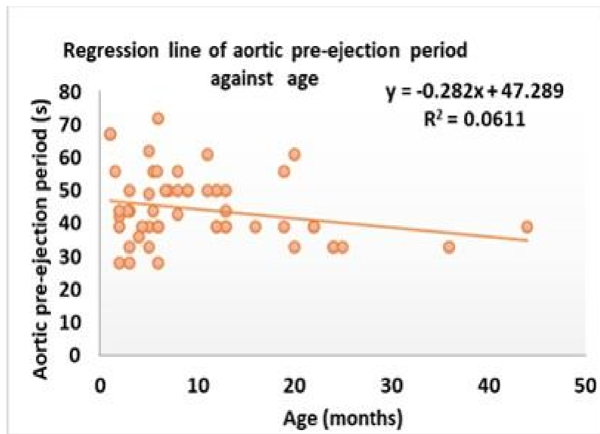

Fig. 3. Correlation of aortic pre-ejection period with age

with heart rate (r=0.33; p=0.008; Fig. 2). Aortic PEP showed significant negative correlation with age (r=-0.25; p=0.05; Fig. 3) but not with heart rate and body weight. Aortic ET and TTP did not show significant correlation with age, body weight and heart rate. Pulmonary artery PV did not show significant correlation with age, heart rate and body weight. Pulmonary PEP showed significant negative correlation with heart rate (r=-0.28; p=0.02; Fig. 4). Pulmonary artery ET showed significant positive correlation with body weight (r=0.31; p=0.01). Pulmonary artery PV was significantly (p<0.05) higher in group III as compared to group I. Aortic PEP was significantly (p<0.05) lower in group III as compared to group II (Table 1).

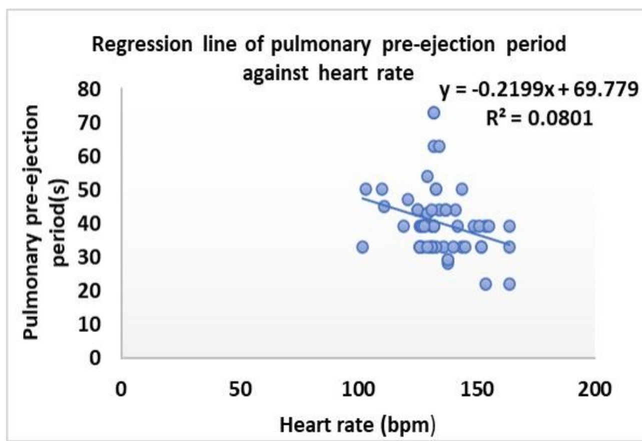

Fig. 4. Correlation of pulmonary artery pre-ejection period with heart rate

DISCUSSION

Normal values of pulsed-wave Doppler aortic and pulmonary artery flow variables and influence of age, heart rate and body weight on these variables in physiological condition must be known to identify hemodynamic changes in cardiac conditions involving aortic and pulmonary valves.

Difficulty was faced in obtaining optimal spectral Doppler recordings of pulmonary valve from left side of thorax due to interference from lung fields and from minor movements of either transducer or underlying cardiac structures (Brown et al., 1991; Yuill & O´Grady, 1991; Kirberger et al., 1992a). Difference in aortic and pulmonary artery waveforms might be attributed to the differences in acceleration time of aorta and pulmonary artery. Aortic flow profile had a shorter acceleration time than the pulmonary artery flow profile. This shorter acceleration time in aorta, coupled with a longer deceleration time imparts more triangular shape to Doppler flow profile of aorta compared to the pulmonary artery flow profile which appears more rounded due to comparable acceleration time and deceleration time (Girard et al. 2024)

Mild physiological regurgitation was detected across both the valves. Kostucki et al. (1986) reported that in humans, regurgitation across normal cardiac valve exceeding one centimetre above its closure with structural damage is considered pathological (Van Dijk et al., 1994). However, in canine patients, different opinions have been given with regards to regurgitation across normal valves. Brown et al. (1991) in their study reported 54% cases of pulmonary regurgitation, 11 % cases of aortic regurgitation and 1.4% cases of pulmonary and aortic regurgitation. Yuill and O'Grady (1991) reported 70 % cases of pulmonary regurgitation and 50 % cases of tricuspid regurgitation while Kirberger et al. (1992b) reported mild mitral regurgitation. Petrus et al. (2010) reported that in absence of right heart enlargement and audible murmur on auscultation, pulmonary regurgitation may be considered physiological in dogs. Variation in the definition of valve regurgitation among researchers and use of different Doppler techniques to detect regurgitant flows might have contributed to differences in above observations.

Aortic and pulmonary artery peak velocities were within the range reported for healthy dogs (Brown et al., 1991) but lower than values reported in Indian mongrel dogs by Bodh et al. (2020). Lower vascular resistance in pulmonary circulation and drop in peak pressure of pulmonary flow during early systole (Isobe et al., 1986) might have contributed to lower peak velocity of pulmonary artery compared to aorta. Higher aortic peak velocity was in line with findings of Brown et al. (1991), and Kirberger et al. (1992a). Increased aortic peak velocity is associated with higher transvalvular pressure gradients and a greater risk of adverse events in dogs with severe aortic stenosis. Similarly, fall in aortic peak velocity below normal is associated with severe systolic dysfunction as observed in dilated cardiomyopathy (Bodh, 2014).

Aortic and pulmonary artery peak velocity did not correlate with body weight in accordance with findings of Brown et al. (1991) and Kirberger et al. (1992b) in healthy dogs, Sharma et al. (2021) in small breed dogs and Bodh et al. (2022) in Indian Spitz dogs. Aortic peak velocity showed statistically significant correlation with heart rate, contrary to findings of Brown et al. (1991). Increased heart rate can lead to a higher aortic peak velocity due to a shorter time for blood to flow through the aorta during each cardiac cycle. In cases of severe aortic stenosis, the peak velocity of aorta is often used to assess the severity of condition, and it is affected by heart rate. Statistically non-significant correlation between pulmonary artery peak velocity and heart rate was in line with findings of Brown et al. (1991).

Aortic and pulmonary artery ET were lower than values reported by Brown et al. (1991). Although, statistically non-significant but longer ET of pulmonary artery compared to aorta corroborated findings of Brown et al. (1991). Longer ET of pulmonary artery could be due to lower resistance and pressure in the pulmonary circulation compared to systemic circulation, leading to a slower ejection of blood from the right ventricle into the pulmonary artery. In general, ET in inversely related to heart rate, however, the relationship between heart rate and ET is complex and involves a dynamic interplay of several physiological factors. Different breeds, ages and even individual dogs show variations in body weight, heart size, muscle strength, and blood volume, all of which can affect ET independently of heart rate. This could be the reason for non-significant correlation of ET (aortic and pulmonary artery) with heart rate of dogs in our study.

Larger dogs have lower PV, however, higher PV in larger dogs of group III compared to smaller dogs of group I might be due to the influence of other factors (pulmonary artery pressure, cardiac function and individual variation among dogs) besides body weight that might have led to variation in peak velocity. Significantly ($p<0.05$) lower aortic PEP in large sized dogs of group III as compared to small sized dogs of group II can be explained by the fact that aortic PEP is negatively correlated with body weight i.e. as body weight increases, the PEP tends to decrease (Rajabioun et al., 2008)

Aortic TTP was similar but pulmonary artery TTP was greater than values reported for normal dogs (Kirberger et al., 1992a; Darke et al., 1993). Time taken by blood flow to reach its peak velocity (TTP) was significantly longer in the pulmonary artery compared to the aorta, corroborating findings of Kirberger et al.

(1992b), and Petrus et al. (2010) in healthy dogs. This difference in time to peak is related to different characteristics of systemic and pulmonary circulation. Blood flowing through systemic circulation i.e. aorta accelerates rapidly, attaining maximum velocity in shorter time while blood flowing through pulmonary circulation accelerates much slowly taking longer time to reach maximum velocity.

Acceleration rate of aorta and pulmonary artery was lower than values reported in healthy dogs (Kirberger et al., 1992b; Darke et al., 1993). Acceleration rate of blood flow in aorta was significantly ($p<0.05$) greater than in the pulmonary artery in line with findings of Kirberger et al. (1992b). This difference might have resulted from higher pressure and resistance in the aorta compared to lower pressure and resistance in the pulmonary artery. Rapid acceleration rate and shorter acceleration time of aortic flow resulted in a significantly ($p<0.05$) lower aortic TTP: ET ratio compared to pulmonary TTP: ET ratio.

Pulmonary artery flow pattern may mimic aortic flow pattern in cases of pulmonary hypertension which causes rapid early rise to peak velocity giving the pulmonary artery flow wave a more eccentric apex, like the aortic flow (Kitabake et al., 1983; Isobe et al., 1986). Pulmonary artery TTP also depends on the pressure within the pulmonary arteries (Kitabake et al., 1983). Rapid increase in mean pulmonary artery pressure causes a gradual and proportional shortening of acceleration time (Uehara 1993). Contrary to findings of Petrus et al. (2010), non-significant correlation of aortic and pulmonary TTP with heart rate might be due to fact that aorta is a high-pressure system, so its acceleration time is minimally affected by heart rate while pulmonary artery is a low-pressure system with similar acceleration and deceleration phases, therefore change in heart rate may lead to change in ejection time and other variables. The study included relatively small number of mongrel dogs, so some potentially interesting but non-significant correlations may point to lack of statistical power due to small number.

Alteration in transvalvular flow velocities and pressure gradients provide early and confirmatory diagnosis of cardiac diseases before structural changes become apparent. Rapid rise and drop in the peak velocity and pressure gradient across aortic and pulmonary valve indicates stenosis and insufficiency of valves, respectively (Bussadori et al., 2000). Aortic PPG was within the range of values reported in Indian Spitz and Labrador retrievers (Reetu et al., 2022) while pulmonary PPG was greater than values reported in Taiwanese dogs (Whey-Li et al., 2003).

The aortic flow profile differs significantly from pulmonary artery flow profile in mongrel dogs. The low dependence of many aortic and pulmonary artery flow variables on physiological parameters viz. age, body weight and heart rate could also enable the use of Doppler echocardiographic aortic and pulmonary artery flow profiles for assessment of heart disease in mongrel dogs.

Conflict of interest: The authors have disclosed no conflict of interest in this study.

Author's contribution: AP, HP: Involved in investigation, data generation, preparing original draft; DB: Engaged in conceptualization, data curation, supervision, and final editing; AK, SPT: Involved in statistical analyses, methodology and editing.

Data availability statement: All the data supporting the research findings have been presented in this paper. The corresponding author is willing to provide the raw data upon reasonable request.

Ethical approval: The study was performed on healthy dogs presented for health check-ups and elective procedures as a part of their routine clinical examination. An informed client-consent was obtained from the pet owners prior to echocardiography.

Use of artificial intelligence tools: No artificial intelligence tools were used for preparation of the manuscript. The author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

ACKNOWLEDGEMENTS

The authors would like to thank Department of Veterinary Medicine and Veterinary Clinical Complex for the referrals.

REFERENCES

Bisht, S. S., Bodh, D., Kumar, A., Tyagi, S. P., Kumar, A., Sharma, D., & Kumar, R. (2024). Echocardiographic quantitation of left ventricular size and function in Indian mongrel dogs. *Indian Journal of Animal Research*. https://doi.org/10.18805/IJAR.B5331

Bodh, D. (2014). *Evaluation of cardiac function in Spitz, Labrador Retriever and non-descript dogs with special reference to Doppler parameters* (PhD dissertation). Deemed University, Indian Veterinary Research Institute, Izatnagar, India.

Bodh, D., Hoque, M., & Saxena, A. C. (2020). Pulsed wave Doppler echocardiographic evaluation of mitral, tricuspid and aortic valve flow in healthy Indian mongrel dogs. *Indian Journal of Veterinary Surgery, 41*(1), 6–10.

Bodh, D., Hoque, M., & Saxena, A. C. (2022). Studies on pulsed-wave Doppler echocardiographic parameters of blood flow through mitral, tricuspid, and aortic valves in healthy Indian Spitz dogs. *Indian Journal of Animal Research, 56*(10), 1246-1251. https://doi.org/10.18805/IJAR.B-4256

Brown, D. J., Knight, D. H., & King, R. R. (1991). Use of pulse-wave Doppler echocardiography to determine aortic and pulmonary velocity and flow variables in clinically normal dogs. *American Journal of Veterinary Research, 52*(4), 543–550. https://doi.org/10.2460/ajvr.1991.52.04.543

Bussadori, C., Amberger, G., Le Bobinnec, C., & Lombard, W. (2000). Guidelines for the echocardiographic studies of suspected subaortic and pulmonic stenosis. *Journal of Veterinary Cardiology, 2*(2), 15–22. https://doi.org/10.1016/S1760-2734(06)70007-8

Darke, P. G. G., Fuentes, V. L., & Champion, S. R. (1993). Doppler echocardiography in canine congestive cardiomyopathy. *Proceedings of the 11th ACVIM Forum*, 531–534.

Girard, C., Koy, L., Kummerfeld, N., Pees, M., Fehr, M., & Legler, M. (2024). Shape of the Doppler sonographic systolic blood flow profile of the pulmonary artery of healthy racing pigeons and the influence of anesthesia. *Veterinary Sciences, 11*(12), 679. https://doi.org/10.3390/vetsci11120679

Isobe, M., Yazaki, Y., & Takaku, F. (1986). Prediction of pulmonary arterial pressure in adults by pulsed Doppler echocardiography. *American Journal of Cardiology, 57*(4), 316-321. https://doi.org/10.1016/0002-9149(86)90911-2

Kellihan, H. B., & Stepien, R. L. (2012). Pulmonary hypertension in canine degenerative mitral valve disease. *Journal of Veterinary Cardiology, 14*(1), 149–164. https://doi.org/10.1016/j.jvc.2012.01.001

Kirberger, R. M., van den Berg, P. B., & Darazs, B. (1992a). Doppler echocardiography in the normal dog: Part I. Velocity findings and flow patterns. *Veterinary Radiology & Ultrasound*, *33*(6), 370–379. https://doi.org/10.1111/j.1740-8261.1992.tb00162.x

Kirberger, R. M., van den Berg, P. B., & Grimbeek, R. J. (1992b). Doppler echocardiography in the normal dog: Part II. Factors influencing blood flow velocities and a comparison between left and right heart flow. *Veterinary Radiology & Ultrasound, 33*(6), 380–386. https://doi.org/10.1111/j.1740-8261.1992.tb00163.x

Kitabatake, A., Inoue, M., Asao, M., Masuyama, T., Tanouchi, J., Morita, T., Mishima, M., Uematsu, M., Shimazu, T., Hori, M., & Abe, H. (1983). Noninvasive evaluation of pulmonary hypertension by a pulsed Doppler technique. *Circulation*, *68*(2), 302–309. https://doi.org/10.1161/01.cir.68.2.302

Kostucki, W., Vandenbossche, J. I., Friart, A., & Englert, M. (1986). Pulsed Doppler regurgitant flow patterns of normal valves. *American Journal of Cardiology, 58*(3), 309-313. https://doi.org/10.1016/0002-9149(86)90068-8

Petrus, L. C., Oliveira, V. M. C., Pereira, G. G., & Larsson, H. M. A. (2010). Evaluation of aortic and pulmonary valve flow with pulsed Doppler echocardiography in clinically healthy dogs. *Pesquisa Veterinária Brasileira*, *30*(7), 586-592. https://doi.org/10.1590/S0100-736X2010000700013

Prashar, A. (2024). *Pulsed wave Doppler echocardiographic evaluation of cardiac function in dogs* (MVSc dissertation). Dr. G. C. Negi College of Veterinary and Animal Sciences, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India.

Rajabioun, M., Vajhi, A., Masoudifard, M., Ghaffari, M. S., Sadeghian, H., & Azizzadeh, M. (2008). Echocardiographic measurement of systolic time intervals in healthy Great Dane dogs. *Iranian Journal of Veterinary Surgery, 3*(4), 57–64.

Reetu, Hoque, M., Saxena, A. C., Verma, N. K., & Kalaiselvan, E. (2022). Doppler-assisted evaluation of velocities and pressure gradient across mitral and aortic valves in healthy Spitz and Labrador Retriever dogs. *Indian Journal of Veterinary Surgery, 41*(1), 11–14.

Sharma, P., Purohit, S., Singh, A., Singh, P. R., & Pandey, R. P. (2021). Studies on pulsed-wave Doppler echocardiography in small breed dogs. *Journal of Animal Research, 11*(6), 983-988. https://doi.org/10.30954/2277-940X.06.2021.5

Singh, P. R., Malik, V., & Pandey, R. P. (2018). M-mode echocardiography in Indian mongrel dogs. *Indian Journal of Veterinary Surgery, 39*(2), 86–91.

Uehara, Y. (1993). An attempt to estimate the pulmonary artery pressure in dogs by means of pulsed Doppler echocardiography. *Journal of Veterinary Medical Science*, *55*(2), 307–312. https://doi.org/10.1292/jvms.55.307

Van Dijk, A. P., van Oort, A. M., & Daniels, O. (1994). Right-sided valvular regurgitation in normal children determined by combined colour-coded and continuous-wave Doppler echocardiography. *Acta Paediatrica*, *83*(2), 200–203. https://doi.org/10.1111/j.1651-2227.1994.tb13051.x

Whey-Li, S., Kimehiko, T., & Ming-Jeng, P. (2003). Spectral Doppler echocardiographic indices in normal Taiwanese dogs. *Advances in Animal Cardiology, 36*(2), 92–109. https://doi.org/10.11276/jsvc.36.92

Yuill, C. D. M., & O'Grady, M. R. (1991). Doppler-derived velocity of blood flow across the cardiac valves in the normal dog. *Canadian Journal of Veterinary Research, 55*(2), 185–192.

Received - 31.03.2025, Accepted - 16.11.2025, Published - 22.11.2025 (Online), 01.12.2025 (Print)

Section Editor: Dr. Joydip Mukherjee, Editorial Board Member