

Echocardiographic assessment of right heart indices in dogs with elevated pulmonary artery pressure associated with chronic respiratory disorders, heartworm disease, and chronic degenerative mitral valvular disease

T.C. TAI, H.P. HUANG

Institute of Veterinary Clinical Science, National Taiwan University, Taipei City, Taiwan

ABSTRACT: The aim of this study was to evaluate right ventricular (RV) remodeling and right heart failure associated with different causes of elevated pulmonary arterial pressure (PAP) in dogs. In total, 169 client-owned dogs with tricuspid regurgitation (TR) and 40 client-owned clinically healthy dogs were included. Dogs with TR were further categorised as suffering from chronic respiratory disorders (CRD), heartworm disease (HWD), mild/moderate chronic degenerative mitral valvular disease (CDMD), and severe CDMD. Among the echocardiographic indices of the right heart, no significant difference in the tricuspid annular plane systolic excursion to aortic root diameter ratio was found among the clinical healthy controls and the four different TR categories. No significant differences in TR peak velocity and pulmonic regurgitation peak velocity were found among dogs in the four different TR categories. The ratio of the right to left ventricular basal diameter in the right ventricular-focused view was significantly higher in dogs with chronic respiratory disorders and dogs with heartworms. Left ventricular compression quantified using the eccentricity index and the ratio of the main pulmonary artery to aortic root diameter were significantly higher in dogs with HWD. Their right ventricular acceleration to ejection time (AT/ET) was significantly lower in dogs with HWD. Based on these findings, we conclude that right heart indices are affected by CRD, HWD, and moderate to severe CDMD. However, right heart indices derived from left heart measurements might be underestimated in dogs with CDMD.

Keywords: left ventricular eccentricity indices; mean electrical axis; pulmonary hypertension; right heart remodelling; tricuspid annular plane systolic excursion

List of abbreviations

Ao = aortic root diameter, AT = acceleration time, CDMD = chronic degenerative mitral valvular disease, CRD = chronic respiratory disorders, CV = coefficient of variation, ECG = electrocardiography, ET = ejection time, HWD = heartworm disease, LA/Ao = left atrial/aortic root ratio, LVD = left ventricular basal diameter, LV-EI = left ventricular eccentricity index, MEA = mean electrical axis, MPA = main pulmonary artery, PAP = pulmonary arterial pressure, PH = pulmonary hypertension, PR = pulmonic valve regurgitation, RVD = right ventricular basal diameter, SBP = systemic blood pressure, SD = standard deviation, TAPSE = tricuspid annular plane systolic excursion, TR = tricuspid regurgitation, VHS = vertebral heart scale

Pulmonary hypertension (PH) is defined by high diastolic or systolic PAP and may lead to right ventricular concentric or eccentric hypertrophy, right atrial enlargement, and right-sided heart failure (Serres et al. 2006). High PAP values above the reference range indicate PH, which can

result from pre- and post-capillary haemodynamic changes (Kellihan and Stepien 2012). PH is a well-recognised clinical condition in human patients and can be primary or secondary to various diseases of the pulmonary vasculature (Galie et al. 2009). Primary pulmonary artery hypertension in

dogs has rarely been studied. Common secondary causes of PH in dogs include left-sided heart failure, increased pulmonary blood flow, increased pulmonary vascular resistance caused by conditions such as obstructive pulmonary vascular disease, thromboembolic disease, pulmonary parenchymal disease, and chronic hypoxia (Glaus et al. 2004; Schober and Baade 2006; Serres et al. 2006). CDMD can lead to left heart dilation and increased left atrial pressure, causing elevated pulmonary venous pressure (post-capillary PH), pulmonary oedema and chronic post-capillary hypoxia. (Kelliham and Stepien 2012). HWD infested by *Dirofilaria immitis* and associated thromboembolism is the most commonly reported cause of severe pre-capillary PH in dogs (Sasaki et al. 1992). CRD, such as tracheobronchial disease, brachycephalic syndrome, and interstitial lung diseases, lead to chronic hypoxia, mechanical stress, and inflammation, which may cause pre-capillary PH (Schober and Baade 2006).

In recent years, Doppler echocardiography assessment of TR and pulmonic valve regurgitation (PR) have allowed non-invasive estimates of PAP and the evaluation of right heart function and structure (Johnson et al. 1999; Serres et al. 2006). In this study, we assessed echocardiographic indices of the right heart in dogs with elevated PAP associated with different causes.

MATERIAL AND METHODS

Case selection. Medical records of dogs with TR (> 1.5 m/s) (based on colour flow and continuous Doppler examinations) from September 2009 to April 2012 at the National Taiwan University Veterinary Hospital (NTUVH) were reviewed. Dogs were excluded if a right bundle branch block was evident in their electrocardiogram, primary/secondary lung tumours were detected on their chest radiography, or if standard echocardiography detected pulmonary stenosis.

Medical records review. Data obtained from the records included signalment, clinical signs in their medical history, heartworm antigen test results, systolic blood pressure measurements, chest radiography, electrocardiography (ECG), and echocardiography (2D, M-mode, and Doppler). Systemic blood pressure (SBP) was measured with a Doppler flow detector using a 9.5-MHz probe and an inflatable cuff attached to a sphygmomanometer (Ultrasonic Doppler Flow Detector, Parks Medical Electronics,

Inc., Aloha, Oregon). A standard 6-lead ECG (CardiovitTMAT-1, Schiller AG, Switzerland) was recorded in right lateral recumbency. The vertebral heart scale (VHS) was measured using electronic callipers in the right lateral recumbent view of digital thoracic radiographs (Buchanan and Bucheler 1995).

All included cases required thoracic radiographs (both lateral and ventrodorsal views) and echocardiography (2D, M-mode, and Doppler) for enrolment of this study.

Diagnostic criteria. PH diagnoses were based on non-invasive predictions of systolic or diastolic PAP, which were estimated using the modified Bernoulli equation based on the maximal velocity of TR or PR, respectively (Berger et al. 1985). Elevated systolic PAP was defined using the affirmative identification of TR velocity > 1.5 m/s in both colour flow and continuous Doppler modes. TR velocities of < 2 m/s and ≥ 2 to < 3 m/s were classified as normal–mild and moderately elevated systolic PAP, respectively. A TR velocity of ≥ 3 m/s (systolic PAP > 36 mmHg) was considered to represent severe PH (Serres et al. 2007).

CDMD diagnosis was based on echocardiographic findings of left heart function indices: club-like mitral leaflets with or without protrusion into the atrium in the right parasternal long-axis view, a left atrial/aortic root ratio (LA/Ao) > 1.6 , and increased end-systolic dimension of the left ventricle with normal left ventricular wall thickness (Olsen et al. 2010). Echocardiography examinations were performed in conscious dogs undergoing continuous ECG monitoring. The dogs were gently re-

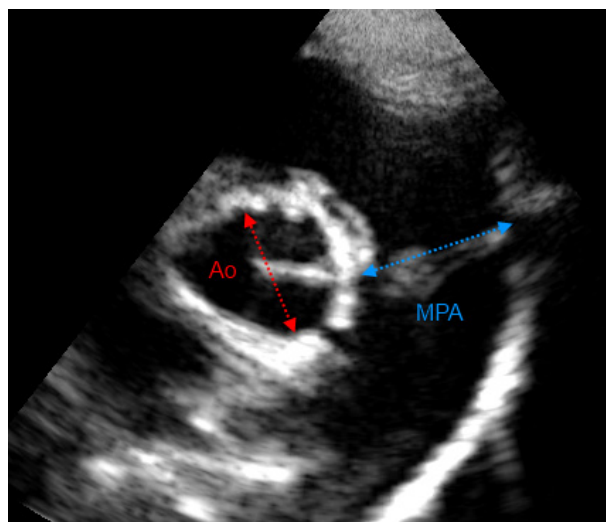


Figure 1. The main pulmonary artery/aorta root ratio obtained from a dog affected by heartworm disease

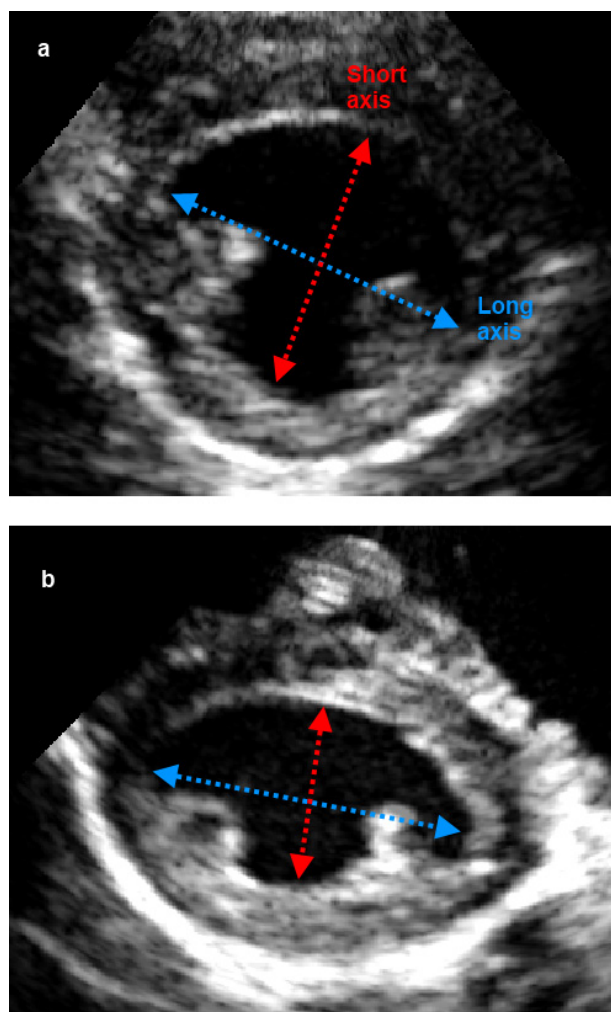


Figure 2. The end-diastolic left ventricular eccentricity index from a healthy dog (a) and a dog affected by heartworm disease (b)

strained in lateral recumbent positions using the two dimensional (2D)-guided M mode and Doppler mode with ultrasound units equipped with 2–5 and 5–7.5 MHz phased-array transducers (MyLabTM 50 Family, Esaote, Genova, Italy).

In 2D echocardiographic right heart function assessment the main pulmonary artery/aorta root ratio (MPA/Ao) was obtained using the right parasternal transaortic short-axis view. The end-diastolic MPA diameter and the aortic diameter were measured immediately after the pulmonic valve closed, and the MPA/Ao ratio was calculated (Figure 1) (Serres et al. 2007; Jurcut et al. 2010; Rudski et al. 2010). The end-diastolic and systolic left ventricular eccentricity indices (LV-EI) were measured as the ratio of long-axis to short-axis diameters of the left ventricle in the right parasternal short-axis view at the mid-ventricular

level (Figure 2). In the apical four-chamber view, tricuspid annular plane systolic excursion (TAPSE) was acquired by passing an M-mode cursor through the tricuspid annulus and measuring the distance of annular movement between the end-diastole and end-systole (Figure 3) (Pariaut et al. 2012). The relationship between TAPSE and aortic root diameter was estimated with the ratio of TAPSE/Ao. The end-diastolic right to left ventricular basal diameter ratio (RVD/LVD) was defined as the ratio of the right to left ventricular basal short-axis dimension in the apical four-chamber view that focused on the right ventricle (Figure 4). The RVD/Ao was also calculated. The diastolic mitral/tricuspid flow velocities, mitral valve regurgitation, and aortic flow were measured using the standard left apical view. Pulmonary flow velocity profiles were recorded at the basal level of the standard right parasternal short-axis view. The pulmonary outflow AT was measured from the onset of pulsed Doppler to peak flow. The pulmonary outflow ET was measured from the onset to the end of the pulsed Doppler flow; thereafter, the right ventricular systolic time interval (AT/ET) was calculated. TR and PR were also quantified with the Doppler-derived echocardiography from the standard left apical and right parasternal views.

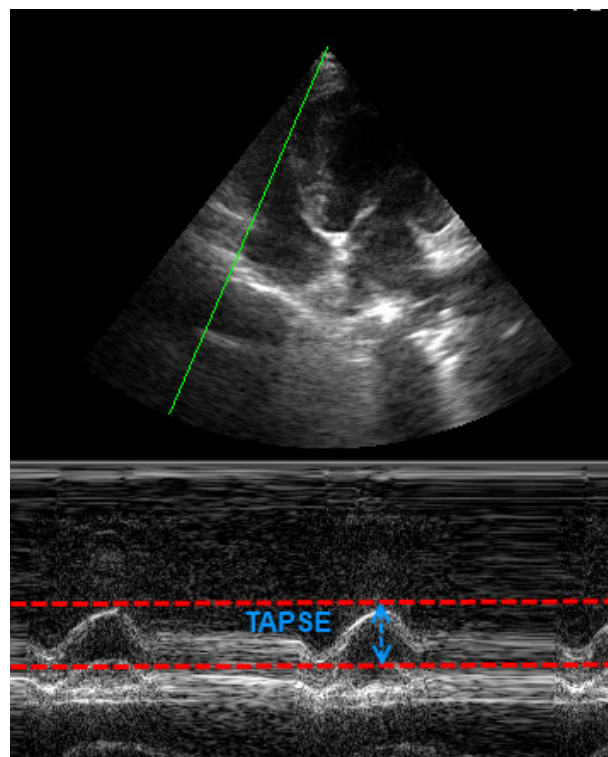


Figure 3. An example of the tricuspid annular plane systolic excursion obtained from a healthy dog

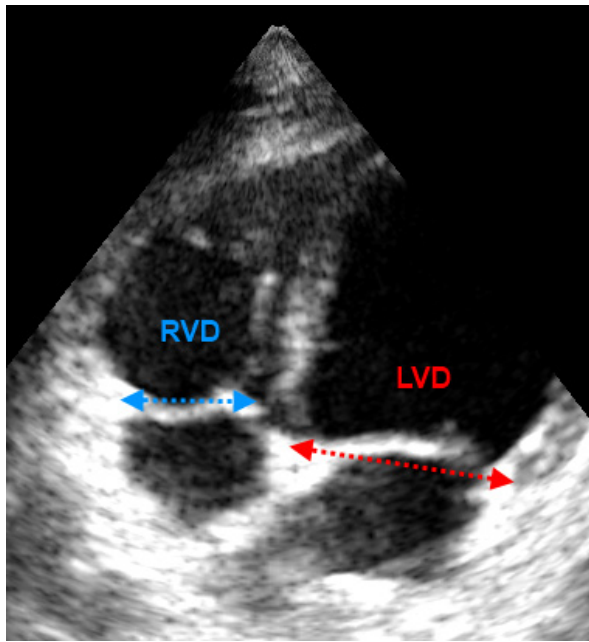


Figure 4. An example of the end-diastolic right-to-left ventricular basal diameter ratio obtained from a dog affected by mild to moderate chronic degenerative mitral valvular disease

Measurement variability. Within-day variability was tested in six conscious dogs. Repeated image acquisition for right heart indices was performed three times non-consecutively in each dog on a given day. The resulting mean values and standard

deviations (SD) were used to determine the coefficient of variation (CV).

Statistical analysis. Data were expressed as means \pm SD. The Kolmogorov-Smirnov test was used for testing the normal distribution of all data with a commercial statistical software package (SPSS Version 12.0.1, Lead Technologies Inc., Charlotte, North Carolina, USA). Differences in continuous variables between groups were evaluated with one-way analysis of variance, followed by Student's *t*-test with Bonferroni correction if necessary. Data which were not normally distributed were analysed using the Kruskal-Wallis test, followed by a post hoc Mann-Whitney *U*-test. Receiver operating characteristic analysis was used to evaluate the relationship between sensitivity and specificity. The Pearson product-moment correlation and Spearman rank order correlation coefficient (*r*) were used to assess the relationships between variables. All tests were two-tailed, and *P*-values smaller than 0.05 were considered statistically significant.

RESULTS

Animals

Forty client-owned clinically healthy dogs admitted to NTUVH for a general annual check-up

Table 1. Signalment and criteria of categorisation used in the study. Clinically healthy dogs (Group 1), non-cardiac-associated chronic respiratory disorders (Group 2), heartworm infestation without moderate to severely enlarged left atrium (Group 3), mild to moderate chronic degenerative mitral disease (CDMD) with enlarged left atrium and concomitant tricuspid regurgitation (Group 4), and cases of severe CDMD with markedly enlarged left atrium and concomitant tricuspid regurgitation (Group 5)

Indices	Group 1 (<i>n</i> = 40)	Group 2 (<i>n</i> = 33)	Group 3 (<i>n</i> = 35)	Group 4 (<i>n</i> = 61)	Group 5 (<i>n</i> = 40)
Age (year)	3.6 \pm 2.4	9.3 \pm 4.2*	8.5 \pm 4.3*	11.3 \pm 3.4*	12.0 \pm 3.0*
Sex (female/male, %)	54	45	44	45	53
BW (kg)	7.1 \pm 5.7	12.9 \pm 9.3*	20.2 \pm 10.9*	7.2 \pm 1.9	5.7 \pm 1.8
LA/Ao	1.36 \pm 0.08	1.46 \pm 0.11	1.43 \pm 0.09	1.60 \pm 0.25*	2.46 \pm 0.18*
TR (m/s)	–	2.27 \pm 0.43	2.44 \pm 0.35	2.01 \pm 0.29	2.13 \pm 0.45
Mild TR ^a (%)	–	44	24	50	64
Moderate TR ^a (%)	–	36	52	32	18
Severe TR ^a (%)	–	20	24	16	18
PR (m/s)	–	1.20 \pm 0.44	1.33 \pm 0.94	0.84 \pm 0.31	0.92 \pm 0.39
PR ^a (%)	–	55	57	25	38

LA/Ao = left atrial/aortic root ratio; PR = pulmonic regurgitation; TR = tricuspid regurgitation

^afrequency, **P* < 0.05 relative to Group 1

during this study were also included as the control group (Group 1). All these 40 dogs were free of any cardiac or respiratory disorders. Medical records with complete physical examinations, SBP measurements, routine blood examinations,

chest radiographies, ECG and echocardiography (2D, M-mode and Doppler) were taken for all dogs included in this group.

A total of 169 diseased dogs fulfilled the inclusion criteria and were included. These were further

Table 2. Mean electrical axis (MEA) derived from electrocardiography, radiographic vertebral heart scale (VHS) and echocardiographic indices in clinically healthy dogs (Group 1), non-cardiac-associated chronic respiratory disorders (Group 2), heartworm infestation without moderate to severely enlarged left atrium (Group 3), mild-to-moderate chronic degenerative mitral disease (CDMD) with enlarged left atrium and concomitant tricuspid regurgitation (Group 4), and cases of severe CDMD with markedly enlarged left atrium and concomitant tricuspid regurgitation (Group 5). Indices values are presented as mean \pm SD

Indices	Group 1	Group 2	Group 3	Group 4	Group 5
MEA	52.2 \pm 22.4	69.2 \pm 24.2	57.4 \pm 22.7	45.5 \pm 12.6	43.1 \pm 32.9
VHS	9.69 \pm 0.69	10.32 \pm 0.78	10.44 \pm 0.84	10.52 \pm 1.01*	12.7 \pm 1.69*
Left heart indices					
LVEDD (mm)	22.8 \pm 6.1	28.8 \pm 8.6	34.5 \pm 10.8*	26.2 \pm 7.8	30.5 \pm 7.5*
LVFWd (mm)	6.2 \pm 1.7	7.9 \pm 2.4*	8.0 \pm 1.6*	6.1 \pm 1.5	5.3 \pm 1.7
IVSd (mm)	6.1 \pm 1.6	8.2 \pm 2.2*	8.7 \pm 2.1*	6.8 \pm 1.3	5.5 \pm 1.9
EF (%)	75.2 \pm 14.7	72.4 \pm 10.1	71.8 \pm 9.0	77.0 \pm 9.6	80.8 \pm 9.3
FS (%)	44.3 \pm 6.8	41.0 \pm 8.7	41.3 \pm 8.4	45.1 \pm 8.9	50.0 \pm 8.5
Right heart indices					
MPA/Ao	1.00 \pm 0.06	1.05 \pm 0.13	1.17 \pm 0.17*	1.02 \pm 0.05	1.05 \pm 0.06
End diastolic LV-EI	1.02 \pm 0.04	1.08 \pm 0.12	1.41 \pm 0.25*	1.04 \pm 0.05	1.00 \pm 0.07
End systolic LV-EI	1.04 \pm 0.05	1.07 \pm 0.11	1.12 \pm 0.18	1.02 \pm 0.08	1.06 \pm 0.05
TAPSE/Ao	0.90 \pm 0.21	0.72 \pm 0.16	0.84 \pm 0.42	0.92 \pm 0.24	1.07 \pm 0.45
RVD/LVD	0.62 \pm 0.10	0.78 \pm 0.19*	0.84 \pm 0.23*	0.60 \pm 0.09	0.56 \pm 0.11
RVD/Ao	1.08 \pm 0.27	1.28 \pm 0.35	1.40 \pm 0.25*	1.10 \pm 0.24	1.15 \pm 0.48
Doppler-derived indices					
MR (m/s)	1.00 \pm 0.39	1.91 \pm 0.58	3.79 \pm 0.90*	3.84 \pm 1.75*	4.67 \pm 1.02*
Mitral E/A	1.33 \pm 0.16	1.11 \pm 0.11	1.17 \pm 0.14	1.10 \pm 0.11	1.76 \pm 0.50
Tricuspid E/A	1.29 \pm 0.16	1.11 \pm 0.14	1.22 \pm 0.18	1.13 \pm 0.19	1.15 \pm 0.28
Aortic flow (m/s)	0.85 \pm 0.09	0.96 \pm 0.14	0.99 \pm 0.13	0.81 \pm 0.10	0.77 \pm 0.09
Pulmonary artery flow (m/s)	0.77 \pm 0.08	0.89 \pm 0.13	0.85 \pm 0.07	0.75 \pm 0.13	0.72 \pm 0.09
Pulmonary artery AT/ET	0.46 \pm 0.06	0.44 \pm 0.09	0.34 \pm 0.09*	0.45 \pm 0.08	0.46 \pm 0.07
Pulmonary artery AT/ET < 0.31 (%)	–	6	42	4	–
Pulmonary artery AT/ET < 0.44 (%)	35	47	81	46	39

AT/ET = acceleration time/ejection time of pulmonary artery flow; EF = ejection fraction; EPSS = E-point to septal separation; FS = fractional shortening; IVSd = thickness of interventricular septum at end-diastole; LVEDD = left ventricular dimension at end-systole; LV-EI = left ventricular eccentricity index; LVFWd = thickness of left ventricular free wall at end-diastole; Mitral E/A = mitral early diastolic velocity/late diastolic velocity ratio; MPA/Ao = main pulmonary artery/aorta root ratio; MR = mitral regurgitation; RVD/Ao = right ventricular basal diameter to aortic root diameter ratio; RVD/LVD = right to left ventricular basal diameter ratio; TAPSE = tricuspid annular plane systolic excursion; Tricuspid E/A = tricuspid early diastolic velocity/late diastolic velocity ratio

* $P < 0.05$ relative to Group 1

categorised into four additional groups based on the aetiology of their disorders (Table 1).

Group 2 comprised cases of non-cardiac-associated CRD ($n = 33$). All dogs in this group presented clinical signs: chronic exercise intolerance, shortness of breath, resting or exercise-induced cyanosis, dry cough, bilateral respiratory crackles and marked diffuse interstitial pulmonary infiltrates on thoracic radiographs. Echocardiographic examinations of these dogs indicated TR without left-sided congestive heart failure; five dogs with a collapsed trachea, five dogs with brachycephalic syndrome, and 23 dogs with lower airway diseases were present in this group.

Group 3 comprised cases of HWD without moderate to severely enlarged left atria ($n = 35$). All dogs in this group were positive for circulating *D. immitis* antigens, which were detected using commercial ELISA kits (IDEXX SNAP®4Dx® Test Kit, IDEXX Laboratories, Inc., USA).

Group 4 comprised cases of mild-to-moderate CDMD and enlarged left atria ($1.5 \leq \text{LA}/\text{Ao} \leq 2$) with concomitant TR ($n = 61$). Dogs in this group had no evidence of concurrent respiratory tract disease based on thoracic radiographic examinations.

Group 5 comprised cases of severe CDMD and markedly enlarged left atria ($\text{LA}/\text{Ao} > 2$) with concomitant TR ($n = 40$). Dogs in this group had no evidence of concurrent respiratory tract disease based on thoracic radiographic examinations.

Electrocardiography and thoracic radiographic measurements: Electrocardiographic parameters were not significantly different among the five groups. Overall, the sensitivity of the right-axis-deviated mean electrical axis (MEA) of the ECG when detecting moderate-to-severe systolic PAP (TR > 2.8 m/s) was only 17.2% with a specificity of 92.8%.

The VHS of Group 5 was significantly higher than that of Groups 1, 2, 3, and 4 ($P < 0.001$ Table 2).

Echocardiographic measurements

Two-dimensional Echocardiography (left heart function assessment). The left ventricular diameter and wall thickness, E-point to septal separation, ejection fraction and fractional shortening of Groups 1, 2, 3, and 4 were within reference ranges (Table 2). The left ventricular diameters of Group 5 were significantly larger than those of Groups 1, 2, 3, and 4 ($P < 0.001$).

Two-dimensional Echocardiography (right heart function assessment). The MAP/Ao and diastolic LV-EI of Group 3 were significantly higher than in other groups ($P < 0.008$ and $P < 0.001$, respectively). The RVD/LVD was significantly higher in Groups 2 and 3 than in Groups 1, 4, and 5 ($P < 0.02$ and $P < 0.001$). The RVD/Ao was significantly higher in Group 3 than in Groups 1 and 4 ($P < 0.019$). There was no statistical significance for systolic LV-EI and TAPSE/Ao among the five groups (Table 2).

Doppler haemodynamic assessment. Based on the causes of PAP development in this study, 59.8% (101/169), 20.7% (35/169), and 19.5% (33/169) were associated with CDMD, HWD, and CRD, respectively.

The ratios of mitral early and late diastolic peak velocity (Mitral E/A) in Group 5 were significantly higher compared to Groups 2, 3, and 4 ($P < 0.01$), and the AT/ET of pulmonary artery flow in Group 3 was significantly lower than that in other groups ($P < 0.001$).

The sensitivity for predicting elevated PAP was 14% and 54% when the AT/ET of the pulmonary artery flow was set at ≤ 0.31 and ≤ 0.44 , respectively (Table 2).

Within-day intra- and inter-observer variabilities of right heart indices. CV for values of each right heart index (aortic root diameter, AT/ET, LVD, LV-EI, MPA, RVD and TAPSE), both within-

Table 3. Results of correlation analysis of systolic pulmonary artery pressure (SPAP) and right heart echocardiographic indices in 209 dogs in which SPAP was assessed using Doppler echocardiography

Independent variable	<i>r</i>	<i>P</i> -value
MEA	0.134	0.154
MPA/Ao	0.388	0.002
End diastolic LV-EI	0.116	0.344
End systolic LV-EI	0.167	0.233
TAPSE/Ao	0.090	0.629
RVD/LVD	0.283	0.016
RVD /Ao	0.261	0.036
AT/ET	-0.339	0.003

AT/ET = acceleration time/ejection time of pulmonary artery flow; LV-EI = left ventricular eccentricity index; MEA = mean electrical axis; MPA/Ao = main pulmonary artery/aorta root ratio; RVD/Ao = right ventricular basal diameter to aortic root diameter ratio; RVD/LVD = right to left ventricular basal diameter ratio; TAPSE = tricuspid annular plane systolic excursion

day intra- and inter-observer variabilities, were all lower than 16%.

A significant positive correlation ($P < 0.05$) was found between systolic PAP and MAP/Ao, systolic PAP and RVD/Ao, and systolic PAP and RVD/LVD. A significant negative correlation ($P < 0.05$) was found between systolic PAP and AT/ET (Table 3).

DISCUSSION

PH has been reported in dogs to be associated with respiratory disorders, HWD and CDMD, with incidences ranging from 8% to 50%, 1% to 6%, and 30% to 74%, respectively (Johnson et al. 1999; Pyle et al. 2004; Kellum and Stepien 2007; Serres et al. 2007; Guglielmini et al. 2010). CDMD was the most common cause among the three causes of PH in this study.

The MEA in dogs with CRD and HWD slightly deviated to the right axis compared to other groups. However, they were within the reference range. The right axis-deviated MEA of the electrocardiogram was not sensitive enough to predict moderate to severe elevated systolic PAP ($TR > 2.8$ m/s) in this study. The R wave amplitudes in leads I and II of dogs with CDMD were significantly elevated compared to dogs with CRD and HWD. The MEA might be affected by left ventricular enlargement.

Pathological changes in the pulmonary artery and right heart remodelling in left heart diseases are generally mild, compared to conditions with pre-capillary PH (Serres et al. 2007; Haddad et al. 2008). In this study, the PAP in conditions with pre-capillary PH (CRD and HWD) was generally higher than PAP in cases with post-capillary PH (mild-to-moderate and severe CDMD), but the difference was not significant. The indices of right ventricular remodelling (e.g. dilated MAP and RVD) in cases of pre-capillary PH were significantly different, compared to those in cases of post-capillary PH. The MPA/Ao and RVD/Ao were positively correlated with systolic PAP, and dogs with HWD had significantly elevated MPA/Ao and RVD/Ao ratios. AT/ET and the end-diastolic LV-EI of the HWD group were significantly different. This suggests that different haemodynamic processes may have developed among dogs in these three categories of PH. Furthermore, the RVD/LVD in dogs with HWD and CRD was significantly elevated in this study. These findings indicate that in dogs with pre-capillary PH there is a significant impact on right ventricular remodelling, compared to dogs with PH secondary

to post-capillary origins. However, the severity of right ventricular pressure and volume overload may be underestimated in dogs with CDMD because of increased left ventricular volume overload.

In this study, TAPSE/Ao was lower for dogs with CRD and HWD, but the difference was not significant. This might indicate that PH associated with chronic respiratory disorders and HWD may cause early right ventricular systolic dysfunction, compared to PH associated with CDMD.

This study had certain limitations. First, systolic PAP was estimated non-invasively on the basis of the peak TR velocity. The simplified Bernoulli equation may underestimate PH severity in dogs with severe PH because of higher right atrial pressure and right ventricular systolic dysfunction (Rudski et al. 2010). Second, no corresponding histopathological assessment was made in this study because the canine population was client-owned. Third, TR can be concomitant with certain degenerative changes of tricuspid valvular disease in aged dogs. Thus, indirect haemodynamic estimation based on the severity of PH may be affected.

CONCLUSIONS

Echocardiographic indices of the right heart were affected by CRD, HWD and moderate-to-severe CDMD in dogs. The severity of right ventricular remodelling was generally positively correlated with systolic PAP, and the right ventricular remodelling process was affected differently by the various aetiologies of PH. Pre-capillary PH, HWD and CRD, had significant effects on right ventricular remodelling. However, echocardiographic indices of the right heart derived from left heart measurements may be underestimated in dogs with CDMD.

Acknowledgements

The authors thank the Consulting Center for Statistics and Bioinformatics, College of Bio-Resources and Agriculture, National Taiwan University for assistance with the statistical analyses.

REFERENCES

- Berger M, Haimowitz A, Van Tosh A, Berdoff RL, Goldberg E (1985): Quantitative assessment of pulmonary

- hypertension in patients with tricuspid regurgitation using continuous wave Doppler ultrasound. *Journal of the American College of Cardiology* 6, 359–365.
- Buchanan J, Bucheler J (1995): Vertebral scale system to measure canine heart size in radiographs. *Journal of the American Veterinary Medical Association* 206, 194–199.
- Galiè N, Hoepfer MM, Humbert M, Torbicki A, Vachiery JL, Barbera JA, Beghetti M, Corris P, Gaine S, Gibbs JS (2009): Guidelines for the diagnosis and treatment of pulmonary hypertension. *European Heart Journal* 30, 2493–2537.
- Glaus TM, Tomsa K, Hassig M, Reusch C (2004): Echocardiographic changes induced by moderate to marked hypobaric hypoxia in dogs. *Veterinary Radiology and Ultrasound* 45, 233–237.
- Guglielmini C, Civitella C, Diana A, Di Tommaso M, Cipone M, Luciani A (2010): Serum cardiac troponin I concentration in dogs with precapillary and postcapillary pulmonary hypertension. *Journal of Veterinary Internal Medicine* 24, 145–152.
- Haddad F, Doyle R, Murphy DJ, Hunt SA (2008): Right ventricular function in cardiovascular disease, part II. *Circulation* 117, 1717–1731.
- Johnson L, Boon J, Orton EC (1999): Clinical characteristics of 53 dogs with Doppler-derived evidence of pulmonary hypertension: 1992–1996. *Journal of Veterinary Internal Medicine* 13, 440–447.
- Jurcut R, Giusca S, La Gerche A, Vasile S, Gingham C, Voigt JU (2010): The echocardiographic assessment of the right ventricle: what to do in 2010? *European Journal of Echocardiography* 11, 81–96.
- Kellihan HB, Stepien RL (2012): Pulmonary hypertension in canine degenerative mitral valve disease. *Journal of Veterinary Cardiology* 14, 149–164.
- Kellum HB, Stepien RL (2007): Sildenafil citrate therapy in 22 dogs with pulmonary hypertension. *Journal of Veterinary Internal Medicine* 21, 1258–1264.
- Olsen LH, Haggstrom J, Petersen HD (2010): Acquired valvular heart disease. In: Ettinger SJ, Feldman EC (eds.): *Textbook of Veterinary Internal Medicine: Diseases of the Dog and the Cat*. Saunders, St. Louis. 1299–1319.
- Pariaut R, Saelinger C, Strickland K, Beaufriere H, Reynolds C, Vila J (2012): Tricuspid annular plane systolic excursion (TAPSE) in dogs: reference values and impact of pulmonary hypertension. *Journal of Veterinary Internal Medicine* 26, 1148–1154.
- Pyle RL, Abbott J, MacLean H (2004): Pulmonary hypertension and cardiovascular sequelae in 54 dogs. *International Journal of Applied Research in Veterinary Medicine* 2, 99–109.
- Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, Solomon SD, Louie EK, Schiller NB (2010): Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *Journal of the American Society of Echocardiography* 23, 685–713.
- Sasaki Y, Kitagawa H, Hirano Y (1992): Relationship between pulmonary arterial pressure and lesions in the pulmonary arteries and parenchyma, and cardiac valves in canine dirofilariasis. *Journal of Veterinary Medical Science/the Japanese Society of Veterinary Science* 54, 739–744.
- Schober KE, Baade H (2006): Doppler echocardiographic prediction of pulmonary hypertension in West Highland White Terriers with chronic pulmonary disease. *Journal of Veterinary Internal Medicine* 20, 912–920.
- Serres FJ, Chetboul V, Tissier R, Sampedrano CC, Gouni V, Nicolle AP, Pouchelon JL (2006): Doppler echocardiography – derived evidence of pulmonary arterial hypertension in dogs with degenerative mitral valve disease: 86 cases (2001–2005). *Journal of the American Veterinary Medical Association* 229, 1772–1778.
- Serres F, Chetboul V, Gouni V, Tissier R, Sampedrano CC, Pouchelon J-L (2007): Diagnostic value of echodoppler and tissue doppler imaging in dogs with pulmonary arterial hypertension. *Journal of Veterinary Internal Medicine* 21, 1280–1289.

Received: 2013–08–04

Accepted after revision: 2013–12–02

Corresponding Author:

Hui-Pi Huang, Institute of Veterinary Clinical Science, National Taiwan University, No. 1, Section 4, Roosevelt Road, Taipei City, 106 Taiwan
E-mail: hphuang@ntu.edu.tw