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A Retrospective Study Correlating Modified Radiological Chest Volume and Vertebral Heart Score with Pulmonary Patterns in Dogs

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ABSTRACT

Veterinary practices rely on the Vertebral Heart Score (VHS) to determine cardiac silhouette size. In addition to cardiac silhouette, pulmonary patterns are examined to determine if clinical signs such as coughing are of cardiac or respiratory origin. Concept of interpreting pulmonary patterns are based on the anatomical structure involved within the lung parenchyma to make assumptions of manifestation of diseases. Modified Radiographic Chest Volume (mRCV) and Vertebral Heart Score (VHS) were retrospectively evaluated for correlation with pulmonary patterns in dogs. Patient data and thoracic radiographs were obtained from the digital repository of selected veterinary clinics in Malaysia. Findings revealed that there are wide variations in VHS and are significantly associated with pulmonary patterns ($p < 0.05$). Mean VHS values of 10.5 ± 1.2, and variations in mean mRCV across breed (26.74 ± 16.71) were observed. The mRCV weakly correlated with VHS denoting that changes in cardiac sizes does not necessarily synergise with lung volume. Therefore, it is recommended to evaluate pulmonary patterns alongside VHS while interpreting thoracic radiographs for cardiorespiratory diseases.

Keywords: Pulmonary patterns; Modified Radiographic Chest Volume (mRCV); Vertebral Heart Score (VHS)

INTRODUCTION

Respiratory conditions, including pneumonia, pulmonary oedema, chronic obstructive pulmonary disease, and pneumothorax, are common in dogs. Aetiologies of respiratory diseases include infectious, parasitic, allergic, congenital, toxic and trauma. Clinical presentation may include cough, tachypnoea, dyspnea (inspiratory or expiratory), exercise intolerance, syncope, and cyanosis (Koster and Kirberger, 2016). However, these clinical signs are also obtained in cardiovascular diseases such as cardiomyopathies, valvular disease, septal defects, congestive heart failure and myocarditis.

Diagnostic approaches to cardiorespiratory diseases include history taking, physical examination, thoracic x-rays, ultrasonography, bronchoscopy and other advanced imaging modalities. Chest x-rays are typical for dogs with lower respiratory signs, including cough, rapid and shallowed or laboured breathing (Koster and Kirberger, 2016). For thoracic radiographic evaluation, a minimum of two standard views (lateral and either ventrodorsal or dorsoventral) is required (Mattoon, 2010). Therefore, correct and consistent radiographic techniques with precise positioning are essential to reduce radiographic errors which may lead to misdiagnosis (Alexander, 2010).

The widely used VHS for cardiac size estimation was first described by Buchanan and Bücheler (1995). Vertebral Heart Score quantitatively compares the heart size to vertebrae length. This method helps in reducing false-positive findings (higher specificity and low sensitivity) of heart diseases due to breed and size variations among dogs (Marin *et al*., 2007). High VHS values could be an indication of cardiac conditions such as congestive heart failure (CHF), dilated cardiomyopathy (DCM) and mitral valve disease (MVD) requiring further tests (Lamb *et al*., 2002). Changes in cardiac silhouette size affect the structural conformation of the lungs (McKiernan and Johnson, 1992). Observable radiographical changes range from the development of pulmonary patterns (alveolar, bronchial, bronchointerstitial, bronchoalveolar, interstitial, or mixed), tracheal elevation and changes in cardiac silhouette (Philip, 2005; Olive *et al*., 2015).

Radiographic Chest Volume (RCV) is commonly used in human medical practice to estimate lung capacity. Various techniques have been established for measuring chest volume for humans, such as using Computed Tomography (CT) scans, chest radiography, body plethysmography (Loyd *et al*., 1966), nitrogen washout and helium dilution methods. A simple modified chest radiography method to measure RCV was later developed (Gamsu *et al*., 1975). It is calculated by multiplying the longitudinal distance from the apex of the right lung to the left costophrenic angle (L) and the transverse width from the right to the left costophrenic angle (W). Values calculated in centimetres are large and unfeasible for clinical use, hence the need to modify and adapt it for small animal practices. None of these methods has been adopted for use in veterinary practices (McKiernan and Johnson, 1992).

Pulmonary pathologies occur with a variety of structural and functional changes to the respiratory rate and lungs parenchyma (Nugent *et al*., 2019). Reduction in lung functional capacity is resultant from pulmonary changes seen on radiographs as pulmonary patterns, lung collapse or consolidations.

Pulmonary patterns such as the alveolar lung pattern appear when the alveolar sacs are occupied by either fluid or cells. This pattern appears as a localised area of increased soft tissue opacity without distinct borders. Presence of lobar signs, air bronchograms and increase the opacity of specific area without regular borders are the radiographic features of alveolar patterns. Common differential diagnoses for pulmonary alveolar pattern including pneumonia, haemorrhage, neoplasia, and lung lobe torsion (Torad and Hassan, 2014).

Bronchial pattern indicates there is increased bronchial visibility, often because of changes in bronchial wall thickness, size of the lumen or reduced visibility of surrounding vessels. The appearance of tramlines and doughnut markings are typical. In normal lungs, bronchial walls are usually seen only in the perihilar area, where the blood vessels are seen (Torad and Hassan, 2014).

Interstitial lung patterns can be subdivided into a structured and unstructured. The infiltration of cells and fluid causes interstitial lung pattern into the interstitial tissue. Linear or reticular structural changes characterise interstitial. If it is localised, there would be multiple nodules which indicate structured interstitial patterns. Structured interstitial patterns such as nodular interstitial pattern is possibly associated with neoplasia, small abscesses, granuloma, fluid-filled bullae, cysts, and hematoma. The unstructured interstitial pattern is characterised by generalised increased of lung opacity with a hazy appearance (Seiler, 2010).

The unstructured interstitial pattern occurs due to fluid accumulation, cells or fibrin within the connective tissue of lungs, which blurs the outlines of pulmonary vessels, bronchi and bronchioles (Seiler, 2010). Possible aetiologies are lymphosarcoma, interstitial fibrosis or pneumonia, oedema, and haemorrhages.

As increased heart size can cause displacement and compression of respiratory organs, there is a need to understand the effect of heart size on lung volume and radiographic patterns. Modified radiographic chest volume (mRCV) and vertebral heart score (VHS) were retrospectively evaluated in dogs to assess their relationship with pulmonary patterns as these have received little scholarly attention. Currently, VHS, which is widely used in small animal practices, could be complemented with the usage of mRCV and pulmonary patterns. Most of the time, VHS solely does not provide a definite diagnosis.

MATERIALS AND METHODS

A retrospective study using primary data from digital repository from selected Veterinary clinics in Malaysia was conducted. A total of 48sets of radiographic samples were collected using a random sampling method. Two-dimensional thoracic radiographs were retrieved in Digital Imaging and Communications in Medicine (DICOM) format. The radiographs were then analysed using Horos™ (Horos Project, United States). Patient medical data such as age, weight, breed and reasons for visits were recorded.

Sample data age ranged from 1-month-old to 15 years old dog were used. The records comprised of 23 bitches and 25 males across three breeds without respiratory-related diseases. The samples included were27 Mongrels, 8 Poodles and 13 Shih Tzus.

Modified Radiographic Chest Volume Measurement (mRCV)

Modified Radiographic Chest Volume was measured using imaging software, Horos™. Ventrodorsal or dorsoventral radiographs were used for mRCV measurement following the method described by Gamsu *et al*. (1975). It involved a simple line measurement of the longitudinal distance from the apex of the right lung to the left costophrenic angle (L) and the transverse width from the right to the left costophrenic angles (W). Then, two dimensions (L X W) were multiplied. The data were then divided by a factor of 10 for a practical purpose during the calculation.

(Longitudinal distance (L) x Transverse width (W)) / 10 = modified RCV … **Equation 1**

Vertebral Heart Score (VHS)

Vertebral Heart Score measurements were taken according to Buchanan and Bücheler (1995) method. As shown in Figure 1A, it involved summing of lines drawn for heart length (long axis – LA) and width at its greatest length (short axis – SA) and aligning with the vertebral bodies beginning from the fourth thoracic vertebra (T4). Typical VHS values range between 8.7 and 10.7 (Buchanan and Bücheler, 1995).

Long axis (LA) + Short axis (SA) = VHS ……………………… **Equation 2**

Analysis of Pulmonary Patterns

Each lateral radiograph was observed and analysed closely to detect any abnormalities. The alveolar pattern was confirmed by the presence of localised soft tissue opacity presence in the lung field. Additional evidence including the presence of lobar signs, air bronchograms and increase opacity of specific area without regular borders (Figure 1B).

Identification of bronchial pattern was based on the increased visibility of the bronchial tree, followed by a “tramline” appearance and the presence of “doughnut markings. The interstitial pattern was determined based on the presence of linear or reticular pattern (Figure 1C). Presence of multiple nodules indicates structured interstitial patterns. The unstructured interstitial pattern was characterised by generalised increased of lung opacity with a hazy appearance (Figure 1D). The bronchoalveolar pattern was identified as a combination of both bronchial and alveolar pattern, whereas bronchointerstitial pattern was identified when there was the presence of both bronchial and interstitial pattern.

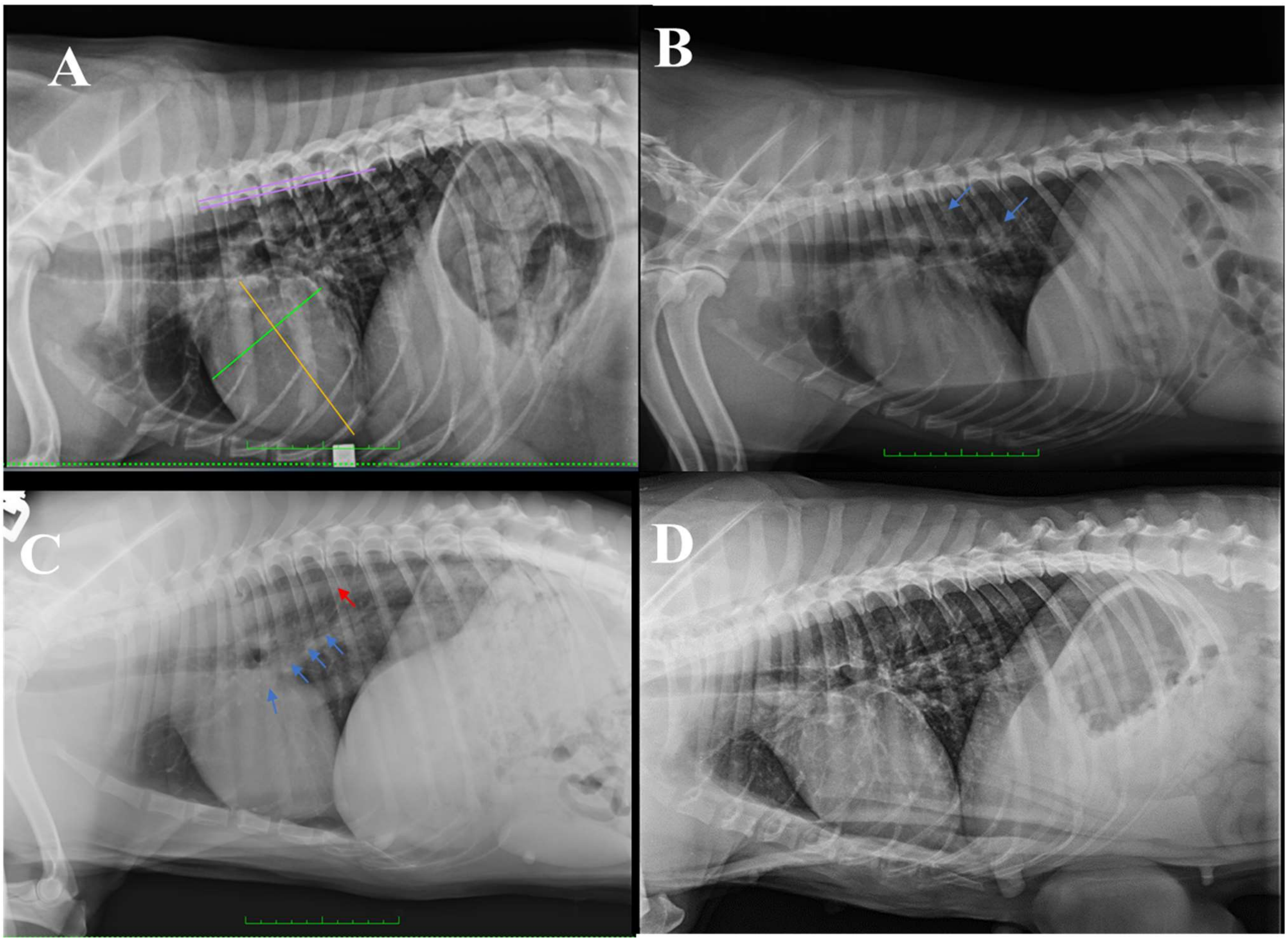

Figure 1: Demonstration of the method for measuring VHS from a left lateral radiograph of a dog; orange line denotes LA while green line denotes SA (**A**). Alveolar pattern; blue arrows pointing towards infiltrates, which produces a patchy appearance (**B**). Bronchial pattern. Blue arrows show the "doughnut" markings; Red arrow shows the "tramline" markings of thickened bronchi (**C**). Showing an interstitial pattern (**D**).

Data Analyses

The relationship between radiological chest volume and vertebral heart score with pulmonary patterns was analysed using Chi-Square. Correlation of risk factors including sex, age and weight with mRCV and VHS were done using paired T test. Forty-eight samples were categorised into four age groups (0 – 3 years, 4 – 7 years, 8 – 11 years, 12 – 15 years) and 3 different categories (0 – 9.9kg, 10 –19.9kg, 20 – 29.9kg) for weight.

RESULTS

Vertebral Heart Score (VHS) and Modified Radiographic Chest Volume(mRCV)

The Vertebral Heart Score of 48 dogs showed a wide variation with a mean value of 10.5±1.2, as shown in Table 1. The mRCV revealed a more extensive variation compared to the VHS, with a mean value of 26.45 ±16.71. Breed variation was also observed (Table 1). Shih Tzu showed the highest VHS value of 10.9 ± 1.2, followed by Poodles (10.7 ± 0.5) and least by Mongrel (10.2± 1.3).

Table 1: Breed variation in VHS and mRCV

Breed	VHS (Mean±SD)	mRCV (Mean±SD)
Mongrel	10.2±1.3	39.3±17.0
Poodle	10.7±0.5	18.4±7.94
Shih Tzu	10.9±1.2	18.3±3.77

Body weight played significant roles ($p < 0.05$) in the mRCV values obtained, in contrast to sex and age ($p > 0.05$). Sex and body weight did not significantly ($p > 0.05$) affect VHS, unlike age ($p < 0.05$) as presented in Table 2.

Pulmonary Patterns

There was 87.5% (42/48) occurrence of pulmonary patterns. The occurrence of the bronchial pattern was the highest (38.10%), while the alveolar pattern alone was the least common (7.14%) – Table 3. The distribution of pulmonary patterns across age (Table 4) revealed that oldest age group dogs had the highest occurrence of pulmonary patterns (35.71%) indicating that as dogs ages, the occurrence of pulmonary patterns increases.

Table 2: Variation in VHS and mRCV for dogs' sex, age and body weight

Parameters		VHS (Mean±SD)	mRCV (Mean±SD)
Sex	Male	10.6±1.2[b]	24.04±19.2[b]
	Female	10.3±1.1[b]	29.35±13.83[b]
Age groups (Months)	0-3	10.1±0.9[a]	21.47±11.16[b]
	4-7	10.4±1.0[a]	28.89±17.34[b]
	8-11	10.5±1.2[a]	25.18±11.99[b]
	12-15	10.7±1.4[a]	29.30±21.12[b]
Body Weight (Kg)	0 – 9.9	10.7±1.0[b]	17.33±6.63[a]
	10 – 20.9	10.1±1.2[b]	38.42±15.51[a]
	20 – 20.9	10.7±1.6[b]	48.76±10.81[a]

a. Significant difference ($p < 0.05$).
b. No significant difference ($p > 0.05$).

Table 3: Occurrence of different types of pulmonary patterns in dogs

Pulmonary patterns	Number of Dogs	Percentage Occurrence
Alveolar	3	7.14
Bronchial	16	38.10
Interstitial	8	19.04
Bronchointerstitial	6	14.29
Bronchoalveolar	9	21.43
Total	**42**	**100.0**

Table 4: Age distribution of dogs with pulmonary patterns

Age (Years)	Number of dogs	Percentage Occurrence
0-3	6	13.63
4-7	8	18.18
8-11	13	29.55
12-15	15	35.71
Total	**42**	**100.0**

There was a significant association between the VHS and the occurrence of pulmonary patterns. The mRCV had no such relationship ($p > 0.05$). Among 48 samples, 21 dogs showed VHS > 10.7. As VHS increased above 10.7 in 95.2% of cases, the occurrence of pulmonary patterns tended to rise, although 79.2% of dogs with a VHS less than 10.7 also showed changes in pulmonary patterns.

Bronchial and interstitial patterns had the highest occurrence (28.6%) among those dogs with VHS value greater than 10.7, followed by bronchoalveolar patterns (19.0%). Then bronchointerstitial and alveolar patterns, both at 9.5% occurrence. When combined, 53% of the bronchial patterns were observed in 57.1% of all dogs having VHS >10.7.

DISCUSSION

Correlation between vertebral heart score, modified radiographic chest volume and the occurrence of pulmonary patterns were retrospectively studied in 48 dogs. Sex, age, weight and breed were keyed in as factors in determining the roles they play in the changes in VHS and mRCV.

Measuring radiographic chest volume (RCV) is not a routine diagnostic workup for small animal practice; it is more applicable to human medical practice. Therefore, there are limited references regarding RCV use in dogs. Modifying and adapting human RCV measurement for dogs revealed a wide variation in chest volume among dogs (4.61 to 77.66). The mean value for mRCV value is 26.45 ± 16.71 among 48 dogs. It is typical among dogs due to breed differences and may not necessarily be associated with clinical diseases (Birks *et al*., 2017).

The mRCV for both male and female dogs were similar ($p > 0.05$), differing from the human medical findings. In humans, lung volumes and chest wall of women are smaller than males. The cross-sectional area of the rib cage, depth of rib cages and length of the diaphragm of women, is lower than the male (LoMauro and Aliverti, 2018). However, Choi (2014) also revealed that lung volume and density were not significantly affected by the sex of dogs. The dissimilarity of results between human and veterinary medicine could be due to different conformation and structural differences of animals.

Currently, there were few studies on the effect of age on lung volumes of dogs. This study revealed there were no significant differences between mRCV and age group ($p > 0.05$). However, Robinson and Gillepsie (1973) reported an increasing lung volume corresponding with ageing in dogs.

Samples studied by Robinson involving Beagles with unrelated with respiratory diseases and part of longevity study investing mammary carcinogenesis. Breed differences likely contributed to variations of results.

For instance, in healthy Beagles, the relationship between lung size and body weight were shown to be disproportionately associated (Liu *et al*., 2015). Liu's studies showed a significant difference between weight and mRCV ($p < 0.05$) was conducted in a single breed (24 male beagles) with similar body weight (10 – 14kg) and age (8.5 – 14months) corresponded with this study. However, the variable used in Liu's studies were functional residual capacity (FRC), whereas in this study mRCV was measured.

Mongrels showed higher mRCV than Poodles and Shih Tzu in this study. The mRCV variation across breeds was statistically insignificant. The closest report to this finding observed differences in inspiratory capacities normalised to body weights in dogs (Donati *et al*., 2018). Inspiratory capacity does not necessarily correspond with total chest volume may be the differential factor in comparison to this study. During inspiration, the contracted diaphragmatic muscles ensure an expanded lung field on radiography. This is a limiting factor in mRCV studies which can be standardised by maintaining radiographic measurements at full inspiration on expiration only.

Regarding vertebral heart score (VHS), the range found among sampled dogs was between 8.5 and 13.2 (10.5 ± 1.2). This study showed there was no significant between sex and VHS ($p > 0.05$) According to Lamb *et al*. (2001), sex was not a substantial factor in determining cardiac silhouette sizes, which correlated with this study. On the other hand, Gulanber *et al*. (2005) reported no significant difference concerning the sex of the dogs had been reported. This finding was also supported by Azevedo *et al*., (2018), who observed no significant differences between sex for VHS measured in the right and left decubitus views in healthy dogs. Similar findings were reported by Schillaci *et al*. (2009).

Jepsen-Grant *et al*. (2012) reported the insignificant correlation between age and VHS in eight dog breeds, where their results were similar to this study. Thus, denoting that age is not an essential factor in the size dynamics of the heart, but rather body conformation is a crucial factor. The heart size grows corresponding to the overall body growth (Sleeper and Buchanan, 2001).

While body growth corresponds with hearts size, it can also be inferred that there would be no significant impact of body weight on the heart size in dogs. This study observed no considerable correlation between body weight and VHS in line with earlier reports noting same (Bashir *et al*., 2013; Bodh *et al*., 2016). The VHS tended to increase as weight increased in positive correlation ($r = 0.96$), according to Azevedo *et al*. (2018). Thus, the continuous measurement of the VHS as puppies grow would show significant growth-related changes in contrast to a single shot correlation analysis.

Several studies have shown breed variations in VHS (Ghadiri *et al*., 2010). For example, the mean value of poodle has been reported to be 10.12±0.51 by Fonsecapinto and Iwasaki (2004), whereas for Dachshund is 9.7±0.5 (Jepsen-Grant *et al*., 2012), for Beagle is 10.5±0.4 (Kraetschmer *et al*., 2008). Therefore, it is recommended that breed variations be strongly considered when evaluating the clinical importance of VHS findings.

Pulmonary patterns were assessed in this study, as well. 42 out of 48 cases (87.5%) showed abnormal pulmonary patterns, with the highest occurrence of bronchial patterns (38.1%). Interstitial lung pattern usually accompanies bronchial lung pattern (Spasov *et al*., 2018). Out of 45 cases, only six dogs (14.29%) presented with bronchointerstitial pattern. Observation of bronchial pattern is not necessarily due to respiratory disease. In geriatric dogs, the bronchial pattern is usually seen despite lacking evidence of respiratory diseases (Spasov *et al*., 2018). As animal ages, mineralisation may extend along the bronchial tree and follow by fibrosis. Therefore, considering the age of animals is essential while evaluating thoracic radiographs.

For dogs with VHS above 10.7, 95.2% of them showed abnormal lung patterns. There were 16 cases (80.0%) with VHS within the normal range (< 10.7) showing abnormal lung pattern as well. In another study (Guglielmini *et al*., 2009), the dogs with clearly recognisable radiographic signs of a cough of cardiac origin had a higher VHS compared with those with a cough of non-cardiac origin which correlates with this study.

This study revealed that VHS and pulmonary patterns were significantly associated ($p < 0.05$) In contrast, there was no significant association between mRCV and pulmonary patterns. To date, there is no study done on the relation of VHS, mRCV and pulmonary patterns. Due to high breed variations among dogs, VHS itself could be insufficient for case diagnosis. Therefore, pulmonary patterns should be considered while evaluating VHS in thoracic radiograph interpretation for a better diagnosis.

Conclusion

Based on this study, body weight showed positive relations with mRCV, where there were no associations between sex and age. VHS significantly differed among age and was not affected by sex and weight. Bronchial patterns were the most observed in this study (84.4%%, included data from bronchial interstitial and bronchoalveolar patterns, excluded those with normal lung field). VHS and pulmonary patterns are significantly associated ($p < 0.05$), where mRCV and pulmonary patterns were not ($p > 0.05$). Therefore, the pulmonary pattern is a valuable diagnostic tool to be included along with VHS while interpreting thoracic radiographs for confirmation of cardiorespiratory diseases. Modified Radiographic Chest Volume (mRCV) did not show any diagnostic values in this case. The results above do not reflect all breeds of dogs.

Conflict of interest

The authors declare that they do not have any conflict of interest.

Authors Contribution

IAO and MTCC conceived, designed and curated data for this study. MTCC conducted the research, analyzed the data and drafted the manuscript. Research was conducted under supervision of IAO and ABH. All authors read and approved the final manuscript.

REFERENCES

Alexander, K. (2010). Reducing Error In Radiographic Interpretation. *Can Vet J*. 51(5), 533-536.

Azevedo, G., Pessoa, G., Moura, L., Sousa, F., Rodrigues, R., Sanches, M., Fontenele, R., Barbosa, M., Neves, W., Sousa, J. and Alves, F. (2018). Comparative Study of the Vertebral Heart Scale (VHS) and the Cardiothoracic Ratio (CTR) in Healthy Poodle Breed dogs. *Acta Sci Vet*., 44(1), 1-7.

Bashir, M., Hoque, M., Saxena, A. C., Zama, M., and Amarpal, A. (2013). Vertebral Scale System to Measure Heart Size in Dogs in Thoracic Radiographs. Adv Anim. Vet Sci. 1(1), 1-4.

Birks, R., Fine, D., Leach, S., Clay, S., Eason, B., Britt, L. and Lamb, K. (2017). Breed-Specific Vertebral Heart Scale for the Dachshund. *J. am. Anim. Hosp. assoc.*, 53(2), 73-79.

Bodh, D., Hoque, M., Saxena, A., Gugjoo, M., Bist, D. and Chaudhary, J. (2016). Vertebral scale system to measure heart size in thoracic radiographs of Indian Spitz, Labrador retriever and Mongrel dogs. *Vet. World.*, 9(4), 371-376.

Buchanan, J.W. and Bücheler, J. (1995). Vertebral scale system to measure canine heart size in radiographs. *J. Am. Vet. Med. Assoc.,* 206, 194–199.

Choi, S. (2014). Quantitative CT Evaluation for Lung Volume and Density in Dogs. *J. Vet. Clin.*, 31(5), 376-381.

Donati, P., Gogniat, E., Madorno, M., Guevara, J., Guillemi, E., Lavalle, M., Scorza, F., Mayer, G. and Rodriguez, P. (2018). Sizing the lung in dogs: the inspiratory capacity defines the tidal volume. *Rev Bras Ter Intensiva*, 30(2), 144-152.

Fonsecapinto, B.C., and Iwasaki, M. (2004). Radiographic evaluation of the cardiac silhouette in clinically normal Poodles through the vertebral heart size (VHS) method. *Braz. J. Vet. Res. Anim. Sci.*, *41*, 261-267

Gamsu, G., Shames, D., McMahon, J. and Greenspan, R., (1975). Radiographically Determined Lung Volumes at Full Inspiration and During Dynamic Forced Expiration in Normal Subjects. *Invest. Radiol.*, 10(2), 100-108.

Ghadiri, A., Avizeh, R., and Fazli, G.H (2010). Vertebral heart scale of common large breeds of dogs in Iran. *Iran. J. Vet. Med.,* 4(2), 107-111.

Guglielmini, C., Diana, A., Pietra, M., Di Tommaso, M. and Cipone, M. (2009). Use of the Vertebral Heart Score in Coughing Dogs with Chronic Degenerative Mitral Valve Disease. *Vet. Med. Sci.,* 71(1), 9-13.

Gulanber, E.G., Gonenci, G., Kaya, U., Aksoy, O., and Birsik, H.S. (2005). Vertebral scale system to measure heart size in thoracic radiographs of Turkish Shepherd (Kangal) Dogs. *Turk. J. Vet. Anim. Sci.,* 29, 723-726.

Jepsen-Grant, K., Pollard, R. and Johnson, L. (2012). Vertebral Heart Scores in Eight Dog Breeds. *Vet. Radiol. Ultrasound*., 54(1),.3-8.

Koster, L. and Kirberger, R. (2016). A syndrome of severe idiopathic pulmonary parenchymal disease with pulmonary hypertension in Pekingese. *Veterinary Medicine: Research and Reports*, p.19.

Kraetschmer, S., Ludwig, K., Meneses, F., Nolte, I. and Simon, D. (2008). Vertebral heart scale in the beagle dog. *J. Small. Anim. Pract.*, 49(5), 240-243.

Lamb, C.R., Wikeley, H., Boswood, A., and Pfeiffer, D.U. (2001). Use of breed-specific ranges for the vertebral heart scale as an aid to the radiographic diagnosis of cardiac disease in dogs. *Vet. Rec., 148*, 707-711.

Liu, Q., Gao, Y.H., Hua, D.M., Li, W., Cheng, Z., Zheng, H., *et al*. (2015). Functional residual capacity in beagle dogs with and without acute respiratory distress syndrome. *J. Thorac. Dis.,* 7(8), 1459–1466.

LoMauro, A. and Aliverti, A. (2018). Sex differences in respiratory function. *Breathe*, 14(2), 131-140.

Loyd, H.M., String, S.T., and DuBois, A.B. (1966). Radiographic and plethysmographic determination of total lung capacity. *Radiology, 86*,7-14

Marin, L., Brown, J., McBrien, C., Baumwart, R., Samii, V. And Couto, C. (2007). Vertebral Heart Size in Retired Racing Greyhounds. *Vet. Radiol. Ultrasou nd.,* 48(4), 332-334.

Mattoon, J. S. (2010). Imaging of the thorax (proceedings). *Veterinary Medicine, dvm360 com,* 166-177.

McKiernan, B. and Johnson, L. (1992). Clinical Pulmonary Function Testing in Dogs and Cats. *Vet. Clin. North Am. Small Anim. Pract.,* 22(5), 1087-1099.

Nugent, K., Dobbe, L., Rahman, R., Elmassry, M. and Paz, P. (2019). Lung morphology and surfactant function in cardiogenic pulmonary oedema: a narrative review. *J. Thorac. Dis.*, 11(9), 4031-4038.

Olive, J., Javard, R., Specchi, S., Bélanger, M., Bélanger, C., Beauchamp, G. and Alexander, K. (2015). Effect of cardiac and respiratory cycles on vertebral heart score measured on fluoroscopic images of healthy dogs. *J. Am. Vet. Med. Assoc.*, 246(10), 1091-1097.

Philip, R. (2005). The Normal Thoracic Radiograph: Why You Must Understand Normal to Recognise Abnormal. *Proceedings of the World Small Animal Veterinary Association - WSAVA2005.*

Robinson, N. and Gillespie, J. (1973). Lung volumes in ageing beagle dogs. *J. Appl. Physiol*., 35(3), 317-321.

Schillaci, M.A., Parish, S., and Jones-Engel, L. (2009). Radiographic measurement of the cardiothoracic ratio in pet macaques from Sulawesi, Indonesia. *Radiography.,* 15(4), 29-33.

Seiler, S. G. (2010). How to Make Sense of Pulmonary Patterns in Dogs and Cats. *Proceedings of the World Small Animal Veterinary Association - WSAVA2010*.

Sleeper, M.M., and Buchanan, J.W. (2001). Vertebral scale system to measure heart size in growing puppies. *J. Am. Vet. Med. Assoc*.*,* 219, 57-59.

Spasov, K., Kunovska, M., and Dimov, D. (2018). Lung patterns in the dog–normal and pathological. *TMVM.,* 3 1(4), 7–14

Torad, F. and Hassan, E. (2014). Two-dimensional cardiothoracic ratio for evaluation of cardiac size in German shepherd dogs. *J. Vet. Cardiol.,* 16(4), 237-244.