The Screening and Diagnostic Value of Posterior Lung Field Angles on Abnormal Pulmonary Function

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ABSTRACT

Radiography has been applied widely in clinical diagnosis of canine pulmonary diseases for the sensitive and direct perception to the abnormal changes. Due to few of relevant reports about different measurement methods and indexes, the simple radiographic findings are difficult to be used in accurate clinical evaluation. This test aimed to develop a radiographic method of comparing canine posterior lung field angles include vertebrophrenic angle (cranial), vertebrophrenic angle (caudal), sterno-diaphragmatic angle, costophrenic angle (left), costophrenic angle (right) to identify whether pulmonary disordered. Meanwhile this method also introduced the indexes of thorax, such as height, width and their ratio which were measured and/or calculated for further normalizing the differential indexes. Healthy pulmonary radiographies (n=76) were selected to scale the normal parameter threshold, and patients with respiratory diseases and obvious clinical syndromes (n=57) were selected as trials to evaluate and confirm the availability of these indexes for the diagnosis of canine pulmonary function. The most valuable indexes for the clinical diagnosis of abnormal pulmonary function were selected with correlation analysis and single factor analysis of variance. The posterior lung field angles and the thoracic indexes showed no correlation in both healthy group and unhealthy group (r<0.3). The posterior lung field angles and the thoracic indexes between healthy with unhealthy dogs showed low correlation (r<0.5). The thoracic indexes between both groups were no significantly different (p>0.05). Only vertebrophrenic angle (cranial) and vertebrophrenic angle (caudal) in all angles measured significantly differed in healthy group versus unhealthy group (p<0.01).

INTRODUCTION

The radiographic features of the canine pneumopathy are presented in size, profile, location and density (Armato *et al.*, 1999; Lamb *et al.*, 2011). These changes are also described as four lung patterns include alveolar pattern, vascular pattern, bronchial pattern and interstitial pattern. All these patterns are based on subjective assessment, and different veterinarians might make different diagnosis on same pneumopathy radiography. Lung lobe in chest is hard to make accurate measurement in canine radiography due to the impacted by body position, abdominal organs pressed

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on the diaphragm and exposure with different breath phase. The breed and age also obviously affect the imaging. In human, an automated lung segmentation method was used to identify the aerated lung regions (Amis *et al.*, 1986). This method is based on gray-level thresholding techniques and is aim to fully automatically analyse abnormal asymmetry of digital posteroanterior (PA) in chest radiographs (Amis *et al.*, 1986), but it's almost impossible on canine because of the significantly different body shape, lacking of instruments and relative software, and uncontrollable exposure in same breath phase in veterinary clinic.

The lung is located in and protected by thorax (Chan *et al.*, 2017). The thorax is composed of the thoracic vertebrae, the sternum and the ribs. The location and structure of these bones are relatively stable and their volume rarely changes after the body maturation (De *et al.*, 2005). Therefore, thorax height (TH), width (TW) and their ratio (TR) could be measured with these bone structures for our study (Akhtar *et al.*, 2008).

More accurate measurements can be done when the thorax indexes are introduced, which can largely reduce

the influence of breed, body position and age. Posterior lung field angles (PLFA), such as vertebrophrenic angle (cranial) (VAcr) and vertebrophrenic angle (caudal) (VAca), sterno-diaphragmatic angle (SA), costophrenic angle (left) (CAl) and costophrenic angle (right) (CAr), are normalized with thoracic indexes to quantify the size and aerated state of the lung, which could eliminate the above bad effect.

The purpose of this study was to develop an evaluation and diagnostic method on abnormal pulmonary function in canine which was based on the measurements and screening of PLFA. This pilot study has comparatively analyzed the PLFA combined with the thoracic indexes between healthy with unhealthy dogs so as to find out their differences. The thoracic indexes were conducted to further eliminate the impact of the canine species and age on the screening and measurement of the PLFA.

MATERIALS AND METHODS

Dogs and cases

76 healthy dogs without respiratory diseases and 58 dogs with respiratory diseases above 6 months' age were conducted in this test. Dogs with respiratory diseases meet the following conditions: (1) suffering from lung diseases, such as bacterial or fungal pneumonia, edema, emphysema, bronchiectasis, bronchopneumonia, lobular pneumonia, lung abscess, tuberculosis, etc. (2) Suffering from lung diseases during the treatment. (3) They all accept laboratory examination and radiographic evaluation. (4) Continuous therapy for at least 3 days and no transfer treatment. (5) No surgery. These canines were used for statistical comparisons with data of healthy dogs. All animals received humane care according to the National Institutes of Health (USA) guidelines, approved by the Ethical Committee on Animal Research at Huazhong Agricultural University (HZAUMO-2015-12). Laboratory animal husbandary is under great control to avoid the random errors (Shaukat *et al.*, 2019).

Image acquisition

The right lateral position and the ventral-dorsal position were selected as the projection position (Armato *et al.*, 1994). Since the respiratory movement affects the exposure of the chest image, the phase at the end of inspiration is uniformly selected.

The standard projection angle of the right lateral position is that the spine is at the same height as the sternum. The standard projection angle of the ventral-dorsal position is the superposition of sternum with thoracic vertebra. Proper anaesthesia should be taken if the dog was restless.

Measurement of PLFA

VAcr: On right lateral position, the angle is between the thoracic vertebrae and the diaphragm on the cranial side. The apex is the intersection of the thoracic vertebrae and the diaphragm. Since all thoracic connection is not a straight line, the top side of the vertebrophrenic angle extends in a cephalad direction along the thoracic vertebre from the apex, ends at two thoracic lengths. The below side of the vertebrophrenic angle extends in a tangent direction of the diaphragm stops at the nearest rib (Fig. 1A).
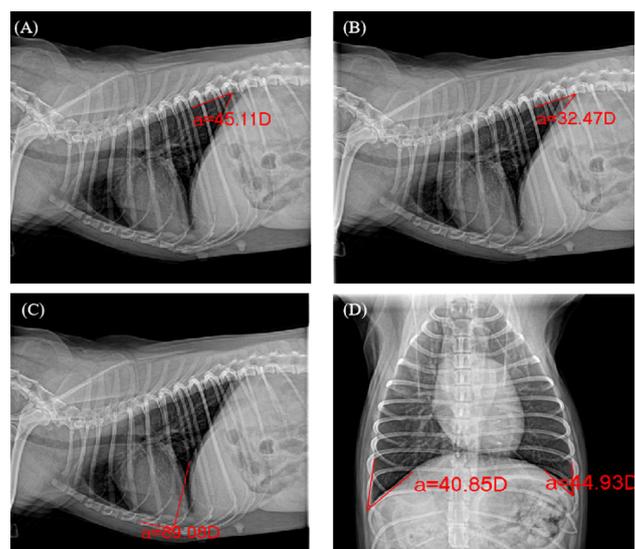
Fig. 1. Imaging of PLFA. A, VAcr on the right lateral view. B, VAca on the right lateral view. C, SA on the right lateral view. D, CAl and CAr on the ventral-dorsal view.

VAca: On right lateral position, the angle is between the thoracic vertebrae and the diaphragm on the caudal side. The apex is the intersection of the thoracic vertebrae and the diaphragm. This apex is located on the caudal side of the VAcr apex. The direction and length of the VAca is as same as the VAcr (Fig. 1B).

SA: On right lateral position, the angle is between the sternum and diaphragm. The apex is the midpoint of the seventh sternal caudal edge. The top side is the line segment whose starting point is the apex and ending point is the highest point of the diaphragm arc. The below side is the line segment whose starting point is the midpoint of the seventh sternal caudal edge and ending point is the midpoint of the cranial edge of sixth sternal (Fig. 1C).

CAl: On the ventral-dorsal view, the angle between the diaphragm and the left thoracic wall. The apex is the intersection of the diaphragm and the left thoracic wall. One side is the extension along the thoracic wall in the cranial direction from the apex which is ended at the second rib near the apex. Another side is the tangent of the

apex and diaphragm (Fig. 1D).

CAr: On the ventral-dorsal view, the angle between the diaphragm and the right thoracic wall. The apex is the intersection of the diaphragm and the right thoracic wall. The direction and length of the two sides of this angle are as same as the CAl (Fig. 1D).

Cardiophrenic angle: since the cardiophrenic angle is largely affected by the volume of the heart, the measurement won't be taken.

Measurement of thoracic indies

TH: The distance between the midpoint of the tenth thoracic cranial edge and the apex of the bottom and rear edge of the seventh sternum on the right lateral view (Fig. 2A).

TW: On the ventral-dorsal view, the width are got by making a perpendicular line from the midpoint of the tenth thoracic cranial edge to the chest wall (Fig. 2B).

TR: The ratio of the thoracic height to width.
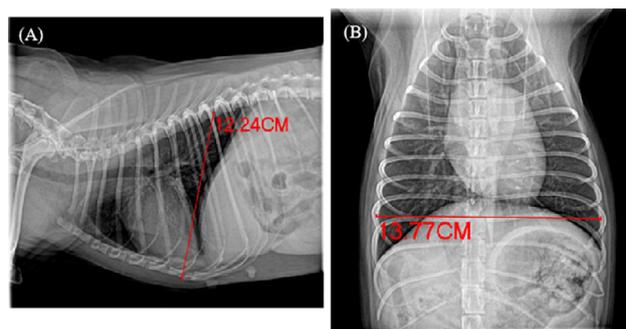
Fig. 2. Imaging of thoracic height and width. A, TH on the right lateral view. B, TW on the ventral dorsal view.

PLFA parameter

$$VAcr\ parameter = VAcr/(TH/TW)$$
$$VAca\ parameter = VAca/(TH/TW)$$
$$SA\ parameter = SA/(TH/TW)$$
$$CAl\ parameter = CAl/(TH/TW)$$
$$CAr\ parameter = CAr/(TH/TW)$$

Statistical analysis

The entire measurement procedure was performed on a dedicated software (Chun Ren Medical Management, Nanjing, China). The date of the angles and thorax indexes were calculated on SPSS 19.0 (IBM, Chicago, U.S.A.).

All the data were averages after measured and record three times. The date of posterior lung field angle and thoracic indexes were processed by correlation analysis and single factor analysis.

If the absolute value of the correlation coefficient is less than 0.3 ($r < 0.3$), which means no correlation; if the absolute value of the correlation coefficient is between 0.3 and 0.5 ($0.3 \leq r < 0.5$), which means low correlation; if the absolute value of the correlation coefficient is between 0.5 and 0.8 ($0.5 \leq r < 0.8$), which means significant correlation; if the absolute value of the correlation coefficient higher than 0.8 ($r \geq 0.8$), which means high correlation. To screen the significantly different posterior lung field angle or thoracic indexes, the single factor variance analysis was used between healthy group and unhealthy group. If $p > 0.05$, there were no significant difference between healthy group and unhealthy group; if $0.01 < p < 0.05$, there were significant difference between healthy group and unhealthy group; if $p < 0.01$, there were extremely difference between healthy group and unhealthy group.

RESULTS

The result of correlation analysis between PLFA and thoracic indexes in healthy group showed low or no correlation (Fig. 3A). The result of correlation analysis between PLFA and thoracic indexes in unhealthy group showed low or no correlation (Fig. 3B). The correlation between the PLFA of healthy and unhealthy group showed no correlation (Table I). The correlation between the thoracic indexes of healthy and unhealthy group showed no correlation (Table II). The correlation between the PLFA parameter of healthy and unhealthy group showed no correlation (Table III).
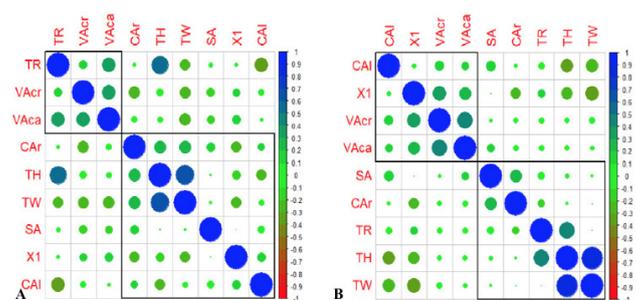
Fig. 3. **A**, Correlation analysis matrix of PLFA with thoracic indexes in healthy group. **B**, Correlation analysis matrix of PLFA with thoracic indexes in unhealthy group. Correlation is represented by circles of different colors and sizes, in which blue indicates positive correlation, red indicates negative correlation and green indicates low or no correlation. The darker the color is, the larger the circle is indicating higher correlation. The correlation between the PLFA and the thoracic indexes showed low or no correlation in healthy group as well as the unhealthy group.

The VAcr of healthy group and unhealthy group were significantly different ($p < 0.01$) as well as the VAca (Fig. 4); The VAca parameter and the VAcr parameter between

healthy group and unhealthy group were significantly different (p<0.01) (Fig. 6).
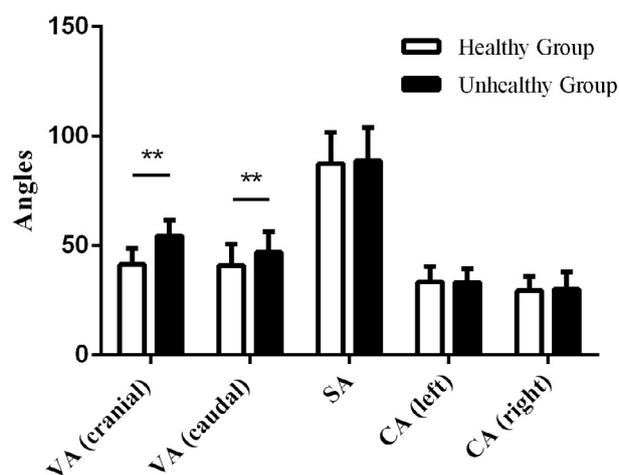
Fig. 4. Variance analysis of PLFA in healthy group and unhealthy group. The bar with (**) indicates a significant difference ($p<0.01$) between the healthy group and the unhealthy group.
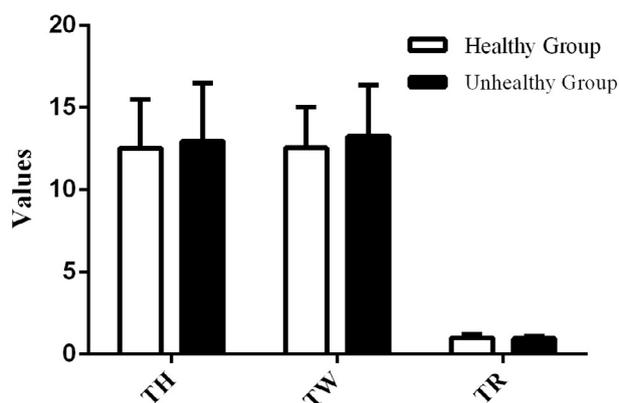
Fig. 5. Variance analysis of thoracic indexes in healthy group and unhealthy group. There were no significantly different between the healthy group and the unhealthy group.

All the results above showed that regardless the healthy situation of the canines, the size of the PLFA have low or no correlation with the thoracic indexes.

This result means that the thoracic indexes have little or no impacts on the screening and measuring of these angles and indirectly confirms the screening and measuring of the PLFA were not severely affected by factors like breed, age, body situation, etc. of the canines which illustrated the feasibility and operability of this test.
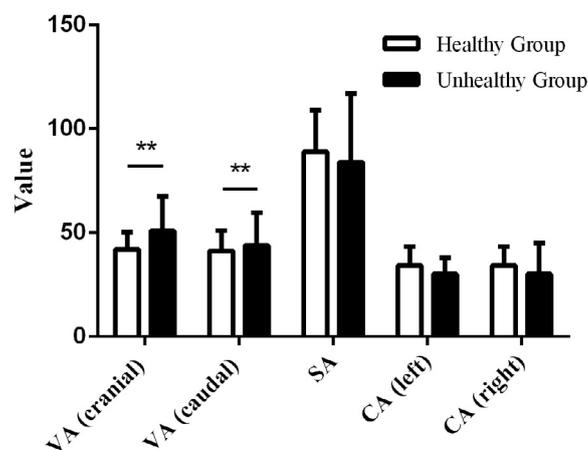
Fig. 6. Variance analysis of the PLFA parameter between healthy group and unhealthy group. The bar with (**) indicates a significant difference ($p<0.01$) between the healthy group and the unhealthy group.

Correlation analysis of the PLFA and the thoracic indices of healthy group

Among the healthy dogs, the correlation between the CAr and the height of thorax was the highest, and up to r=0.268, which means the CAr and the thoracic height showed no correlation (Fig. 3A); the correlation between the CAr and the width of thorax was the highest, and up to r=0.279, which means the CAr and the thoracic width showed no correlation (Fig. 3A); the correlation between the CAl with the thoracic ratio was the highest, and up to r=0.345, which means the CAl and the thoracic ratio showed low correlation (Fig. 3A).

Correlation analysis of the PLFA and the thoracic indices of unhealthy group

Among the unhealthy dogs, the correlation between the CAl with the thoracic height was the highest, and up to r=0.308, which means the CAl and the thoracic height showed low correlation; the correlation between the VAcr with the thoracic width was the highest, and up to r=0.289, which means the VAcr and the thoracic width showed no correlation; the correlation between the VAcr with the thoracic ratio was the highest, and up to r=0.246, which means the VAcr and the thoracic ratio showed no correlation.

Correlation analysis of the PLFA between healthy group and unhealthy group

The correlation analysis of the PLFA between healthy dogs group and unhealthy dogs group showed that the VAca of two groups had the highest correlation, and up to r=0.141, which means the PLFA between healthy group

and unhealthy group showed no correlation (Table I).

Table I. Correlation analysis of the posterior lung field angles between healthy dogs group and unhealthy dogs group.

Posterior lung field angles	Correlation indices
VAcr	-0.094
VAca	-0.141
SA	-0.028
CAl	-0.121
CAr	0.026

Table II. Correlation analysis of the thorax indexes between healthy dogs group and unhealthy dogs group.

Thoracic parameter	Correlation indices
Thoracic height	-0.116
Thoracic width	0.120
Thoracic ratio	0.014

Table III. Correlation analysis of the posterior lung field angles parameter between healthy dogs group and unhealthy dogs group.

Posterior lung field angles	Correlation indices
VAcr	0.108
VAca	-0.119
SA	-0.075
CAl	-0.120
CAr	0.014

Correlation analysis of the thoracic indices between healthy group and unhealthy group

The correlation analysis of the thoracic indexes between healthy dogs group and unhealthy dogs group showed that the thoracic width of two groups had the highest correlation, and up to r=0.120, which means the thoracic index between healthy group and unhealthy group showed no correlation (Table II).

Correlation analysis of the PLFA parameter between healthy group and unhealthy group

The correlation analysis of the PLFA parameter between healthy dogs group and unhealthy dogs group showed that the CAl of two groups had the highest correlation, and up to r=0.120, which means the PLFA parameter between healthy group and unhealthy group showed no correlation (Table III).

Variance analysis of the PLFA between healthy group and unhealthy group

The variance analysis of the PLFA of healthy group and unhealthy group. The ratio of VAcr between healthy group and unhealthy group was significantly different (p<0.01) as well as the VAca, the other angles showed no significant differences (p>0.05) (Fig. 4).

Variance analysis of the thoracic indices between healthy group and unhealthy group

The variance analysis of the thoracic indexes (thoracic height, thoracic width, thoracic ratio) of healthy group and unhealthy group showed that the ratio of thoracic indexes between healthy group and unhealthy group were no significantly different (p>0.05) (Fig. 5).

Variance analysis of the PLFA parameter between healthy group and unhealthy group

The variance analysis of the PLFA parameter of healthy group and unhealthy group showed that the ratio of VAcr parameter between healthy group and unhealthy group was significantly different (p<0.01) as well as the VAca parameter, the other angle's parameter showed no significant differences (p>0.05) (Fig. 6).

DISCUSSION

Due to a lack of published data for PLFA screening in dogs as well as the thoracic indexes, this test did not directly compare with other methods. The method of screening and measurement was based on canine radiograph in this test, which was consulted the costophrenic angles' measurement in human. Some scholars used an automated lung-segmentation for delineating the costophrenic angles in digital posteroanterior chest radiographs. The diaphragmatic aspect of the costophrenic angle was delineated based on column-wise contrast information, and the costal aspect was delineated based on row-wise gray-level maxima. The angle formed by the convergence of these two aspects provided the basis for assessing abnormality (Armato et al., 1998). This method was optimized in 2016, a research indicated that they used the chest wall contour as a landmark structure, in addition to the lung segmentation. Region descriptors are proposed based on intensity and morphology information in the region around the costophrenic recess. Random forest classifiers are trained to classify left and right hemithoraces. Using this method can take more accuracy measurement of costophrenic angles (Armato et al., 1999).

In canine radiograph, we do not keep such advanced instruments and software for measurement and calculation. In addition, due to the lack of chest radiograph reading and

recording system of canines, it's hard to get enough cases. Hence, All the data were measured manually three times and calculated the averages on the radiograph of limited canines.

In human, the blunting of costophrenic angles can't be ignored in radiographic diagnosis, which may indicating the presence of pleural effusion (Findik, 2012). The costophrenic angle size in digital posteroanterior chest radiographs are become larger associated with the larger lung volume and the pathologic change is more obvious than physiological change (Maduskar *et al*., 2016). The bigger costophrenic angle also indicates substantial pleural effusions, pleural thickening and pleural adhesion (Smith *et al*., 2013). In this test the VAcr and the VAca in physiological situation and pathologic situation are significantly different, which may be caused by the change of lung volume, the respiration intensity, the degree of thoracic expansion and the respiration rate. This sign showed similar diagnosis value with costophrenic angle in human.

Canines are different in many factors include breed, age and body size. These side effects were largely eliminated by the application of thoracic indexes. The thoracic bone structure are relatively stable and rarely change after the body maturation. Fig. 3 showed that the thoracic indexes have low or no correlation with PLFA in healthy group as well as unhealthy group which proved that the screening and measurement of the PLFA can rarely influenced by the canines' body factors.

CONCLUSIONS

In summary, the results of this pilot study indicated that PLFA in dogs combine with thoracic indexes can be a promising method for the diagnosis of canine respiratory system diseases. The interpretation and evaluation of the vertebrophrenic angles (cranial) and the vertebrophrenic angles (caudal) in dogs shows similar diagnosis value as the costophrenic angles in human. In canine clinical diagnosis, if the vertebrophrenic angles (cranial) size changed within (41.47 ±7.30)° as well as the vertebrophrenic angles (caudal) size changed within (41.09±9.74)°, it can be regard as physiological change. If the vertebrophrenic angles (cranial) size changed within (54.62 ±7.11)° as well as the vertebrophrenic angles (caudal) size changed within (47.07±9.35)°, it can be regard as pathological change.

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