**Title**

**Radiographic appearance and measurements of thoracic structures using four radiographic projections in goats**

**Abstract**

No one can deny the role of radiography in the diagnosis of different affections of the different regions of the animal’s body especially the thoracic cavity and its structures. Therefore, the present study was carried out to compare different radiographic projections on the positional variation, the visibility, and the measurements of different thoracic structures in goats. Moreover, the different angles formed between some of these structures were determined, measured, and their uses were declared. Twelve healthy native-breed goats were assigned for this study. Their ages and weights ranged between 2̵ 4 years and 13̵ 21 kg, respectively. The goats were subjected to a thorax examination using 4 different radiographic projections: right lateral view (RLV), left lateral view (LLV), dorsoventral view (DVV), and ventrodorsal view (VDV). The findings exhibited on both RLV and LLV were compared, and the DVV and VDV were also differentiated. The radiographic examinations included the inspection of the sternum, ribs, thoracic vertebrae, diaphragm, and its crura, and some of the intra-thoracic structures. Cardiac short axis (CSA), cardiac long axis (CLA), vertebral heart score (VHS), and different angles between the different thoracic structures were measured. The results conclusively revealed that there was no significant difference between the RLV and LLV regarding the values of different thoracic structures except for the cranial lobar pulmonary (CLP) arteries and veins, CSA, the ventral wall of caudal vena cava (CVC), and the mean length of CVC. The visibility of the CLP vessels had a more clear presentation on LLV. The RLV clearly identified the CVC, while the LLV enabled a better visualization of the aorta. The measured values obtained from the sternal (DVV) and dorsal (VDV) views were nearly similar, except; the shape of the heart, the heart shifted into left on the VDV and the CVC and aorta were better seen on VDV and DVV, respectively.

**Keywords:** Goats, radiographic projections, measurements, reference values, thoracic structures.

1. **Introduction**

Sheep and goats are important source of meat and milk for a great sector of population in many areas of the world. However, both animals received little attention regarding diagnosis and treatment of different surgical affections. Small ruminants may suffer from a multitude of health problems that may affect different systems. The thoracic structures, particularly the lungs and heart, are affected with congenital and acquired defects. Although the occurrence of surgical affections of the thoracic structures in goats is lower than that of the large ruminants, knowledge of the different affections is so important for diagnosis, management and predilection of prognosis. In the literatures, multiple anomalies were reported in caprine kids such as ectopia cordis, ventricular septal defect, Ebstein’s anomaly (tricuspid valve dysplasia) and atrial septal defect (**Narasimha Rao et al. 1980; Parry et al. 1982; Ramadan and Abdin-Bey 1993; Upadhye and Dhoot 2001; Laus et al., 2011; Matthew, 2016**). Anomalies of the great vessels were discussed in few studies which included persistence of the left cranial vena cava (**Waibl 1973**), dextroposition of the aorta (**Parry et al. 1982)** and aortic stenosis (**Scarratt et al., 1984**). A case of pericarditis and pleuropneumonia has been reported in a goat infected with Mycoplasma mycoides (**Williamson et al., 2007**), and another case suffered traumatic reticulopericarditis was recorded (**Çevik et al. 2010**).

Diagnosis of the different thoracic affections in goats depends on the history, clinical signs, stethoscope, and other diagnostic tools such as conventional x-ray units and advanced tools such as computed radiography (CR), digital radiography (DR). These tools may become available in all clinics. The other diagnostic tool which is so important in detection of thoracic affections that could not be visualized by the traditional x-rays is the computed tomography (CT). Unfortunately, this tool is expensive and unavailable in most veterinary clinics (**Ohlerth et al., 2012**). There are different studies dealt with the radiographic anatomy of the caprine thorax or heart (**Ukaha et al., 2013; Makungu and Paulo 2014 and Ukaha 2015**). There have been several studies in small animals (dogs and cats) evaluating the thoracic structures radiographically either in normal or diseased conditions (**Groves and Ticer, 1983; Avner and Kirberger 2005 and Guglielmini et al., 2014**).

The current study was designed to investigate the effect of different radiographic projections on visibility, positional variation and measurement values of different thoracic structures, and to determine the reference values of these structures and new different measured angles intended for prediction of the cardiac or pulmonary diseases.

1. **Materials and methods**
   1. **Animals**

This study was carried out on twelve native-breed goats of different sexes (4 males and 8 females) and weights (13-21 kg, mean= 17.63). Their ages ranged from 2 to 4 years (mean= 2.9). The clinical examination was performed for all animals including measurements of temperature, heart rate, respiratory rate and capillary refill time. The animals were examined for any nasal or ocular discharge. The mucous membrane and superficial lymph nodes were inspected. Once the animals were determined as clinically healthy and free from any disorder especially the respiratory and cardiovascular, they were subjected to the following radiographic examination.

* 1. **Radiographic examination**

The radiographic examination of the thorax and the cranial abdomen was performed using the fixed x-ray apparatus (PHILIPS, Philips medical systems Netherlands, B.V. Veenpluis 4-6, 5684 PC Best, The Netherlands, Manfactured in September, 1996). The exposure factors ranged from 50- 60 kV and 25- 35 mA-S with focal film distance (FFD) 70- 75 cm. The processing of the films was manual in the dark room. The animals did not receive any tranquilizer or sedative. Four radiographic views (left lateral, right lateral, ventrodorsal and dorsoventral views) were obtained for each goat at the end of inspiration. The animals were in right recumbent position for the evaluation of the left hemi-thorax, and vice versa. The different structures within the thoracic cavity were evaluated and measured on the radiographs. A systemic evaluation of the thoracic radiograph was carried out including the thoracic wall (ribs, sternum, the thoracic spine and soft tissue), cardiac silhouette, large blood vessels (B.Vs), the pulmonary tissue and pulmonary B.Vs, trachea, and diaphragm. Different angles within the thorax were measured such as spine phrenic angle, caval phrenic angle, caval cardiac angle, cranial mediastinal cardiac angle, sterno-costal angle.

* + 1. **Sternum, thoracic vertebrae, ribs and diaphragm**

The length of the sternum and the number of sternebrae were evaluated on the radiographs. The conformation of the sternum was inspected to detect any abnormalities such as pectus carinatum or excavatum. The number of thoracic vertebrae was recorded in each animal. The thoracic spine was evaluated for any anomaly such as hemivertebra and transitional one. Special attention was given to the fourth thoracic vertebra to determine the VHS. The pairs of ribs were counted on the LLV and RLV in all animals. The shape of the diaphragm was examined on the different views. Cardiac diaphragmatic space was evaluated on the different radiographic views. The position of the diaphragmatic crura was evaluated on the left and right lateral projections.

* + 1. **Trachea and esophagus**

The height of the trachea was measured and compared to the height of the thoracic inlet on both lateral views. The tracheal height was measured at the level of the thoracic inlet. The measured line extended from the dorsal to the ventral tracheal wall. The distance from the dorsal tracheal wall to the mid-body of fourth thoracic vertebra [T4] at its ventral wall was valued and recorded on both lateral views (Figures 1 & 2). The esophagus was traced and looked for on the lateral views especially the caudo-dorsal thorax on the LLV in the area between the aorta and CVC (Figure 2).

* + 1. **Heart**

Cardiac length and width were measured on the four radiographic views (Figures 1 & 3). The heart size was calculated by the three different known ways, which are the vertebral heart score (VHS), cardiac length: thoracic length ratio and the cardiac width relative to the number of the intercostal spaces (ICS) or the thoracic width on the lateral or DVV & VDV respectively **(Buchanan and Bucheler, 1995; Coulson and Lewis, 2008; Almeida et al., 2015; Azevedo et al., 2016).** The ICS is measured in the mid-thorax (at the level of CSA) from the caudal border of certain rib (e.g. 4th rib) to the cranial border of the subsequent one (5th rib).

The thoracic length was measured along the same line of the long axis of the heart start from the ventral border of mid-body of T4 to dorsal border of the sternum.

The VHS was performed according to (**Bahr 2018**). The imaginary lines of the cardiac width and length were perpendicular to each other. The cardiac length starts from the ventral aspect of the carina to the apex of the heart. The obtained cardiac width was the longest width which starts in all animals from the caudal border of the heart at the ventral aspect of the caudal vena cava to the cranial border of the heart. Both the lines of cardiac length and width are bisecting each other. The obtained measured length (cardiac long axis; CLA) and width (cardiac short axis; CSA) are summed and scaled against the vertebral bodies starting from the cranial border of the body of fourth thoracic vertebra (T4). (Figure 1). The contact between the cardiac silhouette and sternum was evaluated on the lateral radiographs. The shift of cardiac apex was examined on the VDV and DVV.

* + 1. **Radiographic measurements of conspicuous blood vessels**

**Aorta**

The height of the aorta just dorsal to the trachea was measured and compared to the width of the fourth rib at the point of their dissection and the length of the cranial end of the fourth thoracic vertebra. (Figure 2)

**Caudal vena cava**

The height of the CVC was measured at two points (near to the heart and near to diaphragm) and the average was estimated. CVC height was compared to the width of the sixth rib at the point of dissection. Also, the CVC was compared to the T4 height. The CVC dorsal wall from the diaphragm to the caudal border of the heart was measured. Likewise, the ventral wall of CVC was measured. The means of the summation of CVC dorsal and ventral walls were calculated. (Figure 1).

**Visibility of CVC & aorta**

The visibility of the CVC and aorta on the RLV and LLV was determined and recorded according to Avner & Kirberger (2005) with some modification. The blood vessels were evaluated with scores as not seen (0), vaguely seen (1), seen (2) and well seen (3).

**Cranial vena cava**

The cranial vena cava (CrVC) was determined and measured within the cranial mediastinum. It represents the ventral portion of CM. The cranial mediastinum (CM) on the LLV and RLV was estimated, recorded and analyzed. It was measured from the ventral wall of the trachea to the dorsal border of the cranial lung lobe. (Figure 2).

**Pulmonary blood vessels**

The clarity of cranial pulmonary blood vessels were evaluated and measured on the lateral radiographs and compared to the width of the narrowest point (in the midpoint between the trachea and spine) of the 4th rib. (Figure 4). The clarity of the caudal pulmonary blood vessels was evaluated and measured with the width of seventh or eighth ribs at the point of their dissection on the DVV and VDV.

**2.2.5. Radiographic measurement of different angles within the thorax** (Figure 5)

**Cranial mediastinal-cardiac angle**

The cranial mediastinal-cardiac angle represents the angle between the ventral border of the cranial mediastinum and the cranial border of the heart at their junction.

**Sterno-costal angle**

The sterno-costal angle represents the angle between the distal end of the 1st rib and the cranial end of the sternum (manubrium).

**Spino-phrenic angle**

The spino-phrenic angle represents the acute angle between the ventral border of the caudal thoracic vertebrae and the diaphragmatic crus dorsally.

**Caval-cardiac angle**

The caval-cardiac angle represents the angle between the ventral border of the caudal vena cava and the caudal border of the heart.

**Caval-phrenic angle**

The caval-phrenic angle: represents the angle between the ventral border of the caudal vena cava and the diaphragm.

* 1. **Software for measurements**

All the measurements were carried out using Image J software program version 2.1.4.7 i1. All the values were measured using mm or cm units, while the angles were with degree (°) unit.

* 1. **Statistical analysis**

Data were presented as mean and standard deviation (mean± SD). The data were analyzed using statistical package for the Social Sciences for Windows (SPSS, version 21, Chicago, IL, USA). Paired t test was used for comparison of the values obtained on the LLV and RLV, as well as the measured values on both of VDV and DVV were also compared. Differences were considered significant when P < 0.05.

1. **Results**

The clinical examination of animals revealed that the temperature ranged from 38.9- 40.1°, the heart rate from 50- 60 bpm and the respiratory rate from 25- 30 rpm. The physical restraint of the animals helped in the radiographic examination of animals without the need for chemical restraint.

The length of the sternum varied from 16- 27.5 cm (mean= 22.4 cm), and the number of sternebrae was seven in 9 out of 12 goats, while the other 3 animals had sternum composed of 6 sternebrae. The sternum was extended to the level of 7th rib in 11 goats, but the sternum of the remained animal extended to the 6th rib. The number of thoracic vertebrae was 12 and 13 in 3 and 9 animals respectively.

There were 13 pairs of ribs in 9 out of 12 animals; the other remaining 3 goats had 12 pairs of ribs. The direction of ribs differed between the VDV and DVV. In the VDV, the ribs form an acute angle with the spine. However, they are somewhat perpendicular to the spine on the DV view. Moreover, the shape of the ribs is more rounded laterally on the DVV than on the VDV.

The caudal lung lobes (right and left) are more clear and wider on the VDV than DVV.

The distance from the thoracic inlet to the diaphragm at the level of the ventral wall of CVC was measured and recorded in Table (1). There was no significant difference in this distance on the lateral views.

There was no clear space between the heart and diaphragm on both the VDV and DVV, but the difference was in the area of contact. The area of contact between the heart and diaphragm is larger in the DVV than the VDV.

The tracheal height was measured in all animals on the lateral views of the radiographs, then recorded and analysed as in Table (1). The trachea was clear on the lateral radiographs than on the VDV and DVV. The tracheal walls were clear as fine radiopaque lines enclosed a radiolucent lumen. There was no significant variation in the measurements of tracheal height between the LLV and RLV. The thoracic inlet height was determined and measured as in Table (1). The ratio between the tracheal height and the height of the thoracic inlet was calculated and recorded (Table 1). The ratio was mostly similar between the LLV and RLV. It ranged from 0.12 to 0.21 on the RL view and 0.13 to 0.22 on LLV. Furthermore, the statistical analysis did not reveal any significant correlation between the tracheal height and thoracic inlet on the same view (RLV: r= 0.434 & P= 0.159; LLV: r= 0.541 & P= 0.069). The distance from the tracheal dorsal wall to the ventral mid-way point of the thoracic vertebra number 4 was measured on the RLV and LLV. It ranged between 3.5 to 6.5 cm (mean= 4.59± 1.1) and from 2.9 to 6.8 cm (mean= 4.8± 1.3) on the RLV and LLV respectively. There was no significant difference on both lateral views in this distance. (Table 1). The esophagus was detected in one goat at the caudo-dorsal aspect of the thorax on the left lateral view (Figure 2).

The heart was spaced from the sternum in 4 and 5 animals on the left lateral and right lateral views respectively. It was contact with the sternum in most animals on both lateral views (8 and 7 animals on LLV and RLV respectively). The shape of the cardiac silhouette was round and oval on both the DVV and VDV in all goats respectively. The heart was in the middle of the thoracic cavity on the DVV projection, while it shifted to left on the VDV. The heart on both lateral views included 2.5 to 3 intercostal spaces (ICS). The distance of the ICS was 1.92 and 1.75 cm on the LLV and RLV respectively. The apex of the heart located between the fifth to sixth sternebra in 7 animals, from the sixth to seventh sternebra in 4 animals, and the cardiac apex of the last animal located between the fourth to fifth sternebra. The cardiac length and width on all projections were measured and recorded (Tables 1 & 2). The vertebral heart score was measured on the LLV and RLV views and tabulated (Table 1). There were no significant changes between the cardiac length and VHS on the lateral views, but a significant difference between the cardiac short axis or the cardiac width on the lateral views (P= 0.007) was evident. The VDV and DVV did not lead to significant changes in the cardiac length or width. The cardiac length to thoracic length ratio on the lateral views did not change significantly. Similarly, the cardiac width to the thoracic width ratio did not change clearly on the DVV and VDV.

The main blood vessels (the aorta and caudal vena cava (CVC) were identified and measured on the lateral radiographs then recorded and analysed as in Table (1). According to the VDV and DVV, the identification of the aorta and CVC was less distinct than in the lateral views. The CVC was best recognized in 5 out of 12 goats on the VDV view, while the aorta (left wall) was clear in 4 animals (3 DVV and 1 VDV). The CVC was recognized on the VDV as a radiopaque structure to the right of midline (after 6 o’clock) and medial to the caudal pulmonary blood vessels. The aorta especially its left wall is identified more clearly on the DV view superimposed on the sternum with radiodensity higher than the cardiac silhouette.

The total score of visibility of the aorta was 26 (72.2 %) and 20 (55.55 %) on the LLV and RLV respectively. However, the CVC was 25 (69.4 %) and 31 (86.1 %) on LLV and RLV respectively.

Cranial lobar pulmonary blood vessels were detected and measured in all animals on the LLV. However, its visibility on the RLV was clear in 9/12 and 10/12 for the cranial pulmonary artery and vein respectively. The height of cranial lobar pulmonary B.Vs and its ratio relative to the 4th rib width were recorded in Table (1). There was a significant difference between the cranial pulmonary arteries on the different lateral views (P= 0.029). The cranial pulmonary veins on the different lateral views were significantly different (P= 0.013). Moreover, a significant change was detected between the cranial pulmonary artery and vein on the LLV (P= 0.047). The ratio between the cranial pulmonary blood vessels and the width of the 4th rib was significantly changed on the LLV and RLV (P= 0.042 and 0.02 respectively).

Caudal lobar pulmonary blood vessels were not obvious in all animals. The caudal pulmonary artery was detected and measured in 10/12 of animals on both DVV and VDV. The caudal pulmonary vein was detected and measured in 9/12 of goats on both DVV and VDV. The widths of caudal lobar pulmonary B.Vs and its ratios relative to the width of 7th or 8th ribs at the point of dissection were recorded in Table (2). The left and right caudal arteries were lateral to the veins and could be detected at the level of 5 and 7 o’clock respectively on the DVV. The left and right caudal veins were medial to arteries and could be demarcated at the level of 5.5 and 6.5 o’clock respectively on the DVV. There were no significant changes between the caudal arteries on the dorsal or sternal views. Likewise, the caudal veins did not change significantly. In addition, there was no significant difference between the caudal artery and vein on the same view.

1. **Discussion**

The present study was conducted to assess the effect of different radiographic positions on the visibility of the different thoracic structures. The radiographic normal reference values of some thoracic structures were measured and determined. As well as, it aimed to conclude the most favourable radiographic projection that clearly displays a specific thoracic structure in caprine clinical cases. The study determined and measured for the first time the different angles within thorax on the lateral views that may aid in diagnosis of some of the thoracic affections.

The radiography is considered an important available diagnostic tool for evaluation of the different structures of the thorax (**Ukaha et al., 2013; Makungu and Paulo, 2014 and Ukaha, 2015**). The knowledge of the normal shape, density, position, and size of different tissues help the inspectors or the radiologist to detect the lesion and abnormality of tissue.

Generally, the position of the animals for the radiographic examination of the thoracic cavity is unlike the other systems. The animal’s part which is subjected to radiographic evaluation should be contacted to the cassette. In the thoracic cavity, for evaluation of the right hemi-thorax, the animal should be in the left recumbent lateral view and vice versa. The results of this study revealed some variations in the external skeleton of the thoracic cavity between goats either in the number of the thoracic vertebrae or the number of sternebrae. The thoracic vertebrae were 12 in 3 animals (25 %), and 9 animals (75 %) had 13 thoracic vertebrae. These results are consistent with the results of the previous study (**Makungu and Paulo, 2014**) and what has been reported in textbooks of the caprine anatomy (**Liebich and Konig, 2004**; **Akers and Denbow, 2013**). These results should be considered at the examination of the thoracic radiograph in goats to avoid misinterpretation that the number of thoracic vertebrae is lower than normal and the missed vertebra is added to the lumbar spine as a transitional vertebra.

The length of the sternum ranged from 16 to 27.5 cm (mean= 22.42 cm). It consisted of 7 (9/ 12) or 6 (3/ 12) sternebrae. It is worth mentioning that 2 out of 3 goats with 12 thoracic vertebrae had 6 sternebrae. It is common that goats have thirteen thoracic vertebrae and seven sternebrae (**Akers and Denbow, 2013; Makungu and Paulo, 2014**). It was evident that a wide range in the sternal length between the animals was recorded. This may be attributed to the decrease in the number of sternebrae in 3 out of 12 animals. As well as, there was a highly significant positive correlation between the body weight of animals and their sternal length (r= 0.79; P= 0.002).

The sternum of 12 goats is straight and forms an angle with the first rib ranged from 102° to 133° and 103° to 135° on the RLV and LLV respectively (Table 1). This angle is important to determine the degree of sternal deviation or sternal curvature as was reported in dogs suffered pectus exacavatum and pectus carinatum (**Schwartz and Beale, 2011; Hassan et al., 2018**). There was full compatibility between the number of thoracic vertebrae and the pairs of ribs. There were 9 goats with 13 thoracic vertebrae and 13 pairs of ribs, while the remaining 3 animals had 12 thoracic vertebrae and 12 pairs of ribs. Hence, it could be concluded that the number of thoracic vertebrae ranges from 12 to 13, and the pairs of ribs are the same. This is very important for the clinician and the radiographer to be kept in their consideration during the radiological examination and interpretation.

The shape of the ribs, in particular at their lateral boundaries, is more rounded on the sternal (DVV) than the dorsal (VDV) view. This may be attributed to the ribs at its junction with the sternum (costochondral junction) become curved than at its junction with the thoracic vertebrae. Thereby, the sternal position which is considered the dependent side closer to the cassette displays the ribs more rounded on the DVV than VDV (**Liebich and Konig, 2004**).

The diaphragm appears as one piece on both VDV and DVV, but its shape is different. It appears more uniform and smoothly rounded on the VDV than the other view. This conformation differs than what has been reported in dogs. The diaphragm on the VDV appears as 3 independent pieces, while on the DVV view it appears as one integrated piece due to pushing of diaphragm cranially as a result of the compressive effect of abdominal contents (**Thrall and Robertson 2016**; **Randall, 2018**). In goats, the diaphragm appeared similar on both sternal and dorsal views may be due to the stomach is of multi-compartments, unlike the simple stomach in dogs. So the diaphragm is pushed cranially either on the dorsal and sternal recumbent position.

The position of the crura on the two lateral views was nearly similar, but there were some differences. Undoubtedly, the labelling of radiographs either during or after processing represents a crucial point in the differentiation of the recumbent views during reading and interpretation of radiographs. Yet, there were some radiographic signs that may help in recognition of the recumbent view during the exposure to x-rays. The entrance of the caudal vena cava (CVC) into the right crus of the diaphragm was easily detected and may determine the recumbent view of the animal**.** Additionally, visualization of the caudal thoracic portion of the oesophagus verifies the LLV **(Granger, 2016)**. The caudal thoracic portion of the oesophagus was detected in one goat on the LLV as a radiopaque structure in the space between the aorta and CVC. This description was discussed in a previous study (**Avner and Kirberger, 2005**). So, the examination of the oesophagus by plain radiography is invaluable, and other diagnostic techniques and tools such as esophagography, CT and endoscopy are required (**Gaschen, 2018**). The compartmentalization of the rumen and visualization of the internal pillars of reticulum may overweigh the LLV than the RLV (Figure 4). This was noticed in just one animal. Moreover, the two crura on the LLV were parallel to each other from the spine to meet at the level of CVC in all animals of this study as was recorded in dogs (**Avner and Kirberger, 2005; Thrall and Robertson, 2016**). However, on the RLV, there were some notable changes. The crura meet proximally at spine and distally at the level of CVC, and diverge at the midway (3 goats). The two crura were being overlapped proximally toward spine and space out distally toward the CVC (2 goats), while in 7 goats they were parallel to each other and did not meet. The parallelism of the right and left crura on the RLV in 7 out 12 goats was compatible with the position of crura in dogs (**Thrall and Robertson, 2016**). The changes of the crura in the other five animals on RLV may be attributed to the pressure of compound stomach on the diaphragm, or inadequate recumbent right lateral position of goats during radiographic exposure to x-rays, especially because the animals did not receive any sedative or anaesthetic drugs.

The values of tracheal height at the thoracic inlet on both lateral views were nearly consistent. These values are close to the tracheal values which were recorded using CT examination in goats (**Ohlerth et al., 2012**). In the present study, the tracheal height ranged from 1- 2 cm (mean= 1.36± 0.26 or 1.35± 0.27) on RLV and LLV respectively. The tracheal height on CT ranged from 1.1 to 2.3 (mean= 1.6± 0.4). In the present work, The tracheal height to thoracic inlet height ratio ranged from 0.12-0.21 (mean= 0.16± 0.026) and from 0.13 to 0.22 (mean= 0.16± 0.025) on RLV and LLV respectively. **Ohlerth et al., (2012)** calculated the ratio on CT, where it ranged from 0.08 to 0.19 (mean= 0.13± 0.03). Undoubtedly, the calculation on CT is more accurate than radiographic measurements. This is because the CT is a multiplanar system which allows three-dimensional demonstration of the structure.

The distance from the dorsal tracheal wall to the ventral body of T4 was nearly the same on the different lateral views. These results were on contrary to the findings which were recorded before (**Avner and Kirberger, 2005)**. According to the results of that study, the distance from the trachea to the ventral body of the corresponding the thoracic vertebra was larger on LLV but in small breed dogs. The authors attributed the reasons behind their findings to the higher obesity grading and the globoid cardiac silhouette of the dogs. These factors may lead to displacement of the cardiac apex from the sternum to the left side which may displace the carina and trachea ventrally and in turn increase the distance from the trachea to spine.

Although the results of the present study revealed a significant difference in the cardiac short axis (CSA) between the RLV and LLV, the vertebral heart score (VHS) did not show any change. The latter ranged from 8 to 9.5 (mean= 8.88± 0.58 (RLV); 8.95± 0.496 (LLV)). The previous studies in dogs were categorized into two distinct groups in regard to comparability of the VHS on lateral views. The first support our results and verified there was no difference in the VHS between the lateral views **(Buchanan 2000; Marin et al., 2007; Gugjoo et al., 2013).** The other group found a significant difference in the VHS between the RL and LL views (**Baveghems et al., 2005; Greco et al., 2008; Ghadiri et al., 2010 and Bodh et al., 2016)**. The results of this study regarding heart shape, heart sternal contact and heart shift were consistent with what has been reported in the previous literature (**Ruehl and Thrall, 1981; Avner and Kirberger, 2005; Thrall and Robertson, 2016**).

The visibility score of aorta and CVC was high on the LLV and RLV respectively. This may be ascribed to the fact that aorta is situated close to the cassette on LLV, the CVC is close to the cassette on RLV, and in turn, there is a little magnification distortion. These results were in agreement with those reported before (**Avner and Kirberger, 2005**). The results of the present study revealed that the height of aorta ranged from 1.4 to 2.8 cm (mean= 2.1), and from 1.5 to 2.7 cm (mean= 2.1) on the RLV and LLV respectively. These results were harmonious to the findings recorded on CT examination in goats (**Ohlerth et al., 2012**). In the present work, the height of the aorta on both lateral views was compared to the width of the 4th rib at the point of bisection and also compared to the height of the cranial end of the fourth thoracic vertebra. These measurements aimed to facilitate the easy detection of the changes in the aorta. There were no significant changes in the ratios on both lateral views. The height of aorta: 4th rib width ranged from 1.4 to 2.8 (mean= 2.1± 0.43), and from 1.5 to 2.7 (mean= 2.1± 0.37) on the RLV and LLV respectively. However, the height of aorta: cranial end height of thoracic vertebra no. 4 ranged from 1.1 to 2 (1.64± 0.27) and from 1.1 to 2.1 (1.55± 0.27) on RLV and LLV respectively. It is optional to the examiner to use any one of the lateral projections. It could be summarized that the height of aorta ranged nearly from1.5 to 3 times the width of the 4th rib, and from 1 to 2 times the height of the cranial end of thoracic vertebra no. 4 (T4).

The results of the present study revealed that the CVC is better seen on VDV. It was detected in 5 out of 12 animals. This is in accordance with the previous studies (**Ruehl and Thrall, 1981; Avner and Kirberger, 2005)**. On the other side, the aorta was detected in 3 goats on the DVV and one goat on the VDV. The left wall of the aorta was more distinct as the right wall is superimposed on the spine and sternum. The visibility of the aorta on the DVV may be attributed to the more aerated pulmonary tissue surrounding the blood vessels which impart or improve the contrast. The same results were recorded in dogs (**Avner and Kirberger, 2005**).

There were no significant changes in the measurements of CVC height between the LLV and RLV. The height of the CVC was not affected by different positioning of the animals. The values of CVC height are close to the values measured in goats on CT (**Ohlerth et al., 2012**). The length of CVC dorsal wall which extended from the caudal border of the heart to the diaphragm did not show any significant difference on both lateral views, but the length of CVC ventral wall and mean of CVC whole length (dorsal wall + ventral wall / 2) showed significant changes. It was noticed that the length of CVC is longer on the RLV relative to LLV as was summarized in Table (1). Elucidation of these results may be attributed to the RL positioning is more comfortable to the animals than LL positioning, which makes the ventilation easy, providing more aeration of pulmonary tissue and thus increases the distance between the heart and diaphragm. The anatomical filling of the left side of the abdominal cavity by the rumen and reticulum induce more pressure on the diaphragm in case of LL positioning. The cranial pushing of the diaphragm by the abdominal contents decreases its distance with the heart and eventually the CVC appears shorter than on RLV.

The authors of the present study compared the height of the CVC to the width of the 6th rib at the point of dissection. According to the clinical point of view, this is considered an easy method for determining the changes in the height of CVC on the lateral radiograph. This method of measurement is similar to the method used for evaluation of the height of caudal pulmonary blood vessels when compared to the width of rib no. 9 at their point of dissection in dogs (**Thrall and Robertson, 2016**). The results of the present study showed no significant difference in the ratio between CVC height and width of rib no. 6 on both lateral radiographs. This resulted from a non-significant difference between the height of CVC on LLV and RLV.

The height of cranial vena cava (CrVC) was measured in all goats especially at its entrance into the heart. This means that CrVC could be demarcated from other structures of the cranial mediastinum (CM). Presence of fat between the CrVC and other structures increases contrast and differentiation of this main blood vessel (**Thrall and Robertson, 2016**). The height of CrVC on the RLV and LLV ranged from 0.91 to 2.3 cm (mean= 1.5± 0.4), and from 0.85 to 2.5 cm (mean= 1.5± 0.5) respectively. These values are close to the values recorded before using CT in goats (**Ohlerth et al., 2012**). The height of the cranial mediastinum ranged from 2.3 to 4.85 cm (mean= 3.4± 0.9) and 2.4 to 4.9 cm (mean= 3.3± 0.86) on the RLV and LLV. It was noticed from the findings of this study there was no significant difference between CrVC heights on the lateral views. Likewise, no significant change between the heights of CM on the lateral views was observed. The ratio between the CrVC and CM on both lateral views ranged from 0.3 to 0.66 (mean= 0.44± 0.08) on the RL view and from 0.3 to 0.7 (mean= 0.47± 0.1) on the LLV. Consequently, there was no significant difference between these ratios on RLV and LLV. These results demonstrated that the CrVC represents about a third to two-thirds of the CM height. The results of the present work displayed a non-significant difference between the CVC and CrVC either on the RLV or LLV (**Ohlerth et al., 2012**).

The cranial pulmonary blood vessels which could be detected either on the LLV or RLV were two vessels in goats. This is unlike than the four cranial pulmonary vessels that were distinguished on the LLV in dogs (**Thrall and Robertson, 2016**). According to previous literature, the pulmonary artery is dorsal to the pulmonary vein (**Losonsky et al., 1983; Thrall and Robertson, 2016)**. Although the previous researchers reported the equality in size between artery and vein, the results of the current study revealed a significant difference in size between them either on LLV or RLV. The pulmonary veins are significantly larger than arteries. The visibility of the cranial pulmonary vessels was better identified on the LLV than RLV. This finding was consistent with the results that were reported in dogs (**Avner and Kirberger, 2005 and Thrall and Robertson, 2016)**. This may be attributed to the more aeration of the right hemithorax (which is considered larger than left) during the left lateral recumbency of the animals.

Detection of the four caudal lobar pulmonary vessels, especially on the sternal (DV) view, was in accordance with previous results found in dogs (**Avner and Kirberger, 2005 and Thrall and Robertson, 2016**). There were no significant changes in the size between the pulmonary arteries and veins either on the DVV and VDV. Also, the different radiographic positioning of the animals (sternal or dorsal) did not affect the values related to the size of the arteries and veins. These results were in agreement with those recorded in the previous study (**Avner and Kirberger, 2005**). In the present study, the recumbent radiographic positioning of animals did not influence the visibility of caudal pulmonary vessels. The caudal lobar pulmonary artery was detected in 10 out of 12 animals on VDV and DVV. The caudal vein was identified in 9 animals on both views. Previous studies revealed more visibility of caudal vessels on DVV than VDV (**Ruehl and Thrall, 1981 and Avner and Kirberger, 2005)**. They ascribed these effects to the more aeration of the lung, and the vessels were perpendicular to the x-ray beam on DVV. In our study, the more visibility of caudal artery relative to vein may arise of the laterality of the artery to the vein which may aid in its easy identification.

The novelty in this study was measurements of the different angles between the thoracic structures. Calculation of these angles aimed to determine the normal reference values, as well as, to introduce an easy method for detection of the abnormal position of the structures forming these angles. The previous studies measured different angles in other animals such as angle of divergence of the principal bronchi in dogs, calves and rabbits (**Avner and Kirberger, 2005; LE Roux et al., 2012; Ohlerth et al., 2014; Müllhaupt et al., 2017**), the angle between trachea and spine in dogs and rabbits (**Ohlerth et al., 2012; Müllhaupt et al., 2017**), the angle between the medial walls of both principal bronchi in dogs (**Ohlerth et al., 2012)**, the cardiac angle between the heart base and the apex in rabbits (**Müllhaupt et al., 2017**). Those studies measured these angles either on CT or DV projection of radiograph. In the present work, several angles such as cranial mediastinal-cardiac angle, sterno-costal angle, spino-phrenic angle, caval-phrenic angle and caval-cardiac angle on both of LLV and RLV were measured and tabulated (Table 1). As aforementioned, these angles are of great importance to determine the position of the structures forming these angles. For example, the spino-phrenic angle ranged from 27-55° (mean= 29.25°± 7.5) on RLV and from 24 to 49° (mean= 37.59°± 6.5) on LLV. An increase of this angle may be expected in cases of pneumothorax, tension pneumothorax, and pleural effusion due to the backward movement of the diaphragm, and vice versa in case of peritoneal effusion or ascites. The study revealed no significant changes in the different angles between the LLV and RLV except the caval-phrenic angle. This angle was significantly higher on the RLV than LLV (P= 0.03). This may be attributed to the significant changes in measurements of the CVC length on the lateral views in the current study. Furthermore, the diaphragm may not be pushed cranially on the RLV relative to LLV owing that the right hemi-abdomen is relatively not filled with large viscera as left hemi-abdomen (rumen and reticulum).

It could be concluded from this study that there was no significant effect of the lateral views (RLV and LLV) on the values of different thoracic structures except the cranial lobar pulmonary (CLP) arteries and veins, ratios of CLP arteries and veins to the 4th rib at its narrowest point, cardiac short axis (CSA), ventral wall of CVC, and mean length of CVC. The visibility of the CLP vessels was better on the LLV. The RLV clearly identified the CVC, while the LLV enabled the better visualization and tracing of the aorta. The reference values and findings of the thorax that were obtained from the sternal (DV) and dorsal (VD) views are nearly similar except for three key findings; (i) The shape of the heart which was elongated and ovoid on the VD view and round on DV view; (ii) The heart shifted to the left on the VD view; and (iii) the VD view is preferred for better visualization of the CVC, while the DV view is superior to the VD view for detection of the aorta, especially its left wall.

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**Figures**

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| Figure. 1. The measurements on the lateral radiograph including tracheal height (A; red line) relative to height of thoracic inlet (B; black line). The cardiac long and short axes (long and short green double arrows) were scaled to the vertebral bodies starting from thoracic vertebra no. 4 (T4). The dorsal and ventral walls of the caudal vena cava (CVC) were outlined with long and short red lines. |

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| Figure. 2. The right lateral radiograph of the thorax with clear different structures. A. aorta, T. trachea, CM. cranial mediastinum, H. heart, CVC. caudal vena cava, and E. esophagus. |

|  |
| --- |
| B  A |
| Figure. 3. A. Ventro-dorsal (VD) view of the thorax showing the cardiac long and short axes (red and black double arrows). B. Close up of the figure 3.A. short arrow refer to caudal vena cava (CVC) |

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| --- |
|  |
| Figure. 4. Left lateral radiograph of the thorax showing the different thoracic structures. Arrows refer to cranial lobar pulmonary vessels (black arrow refer to artery, and gray arrow refer to vein). Notice the compartementalization of the cranial abdomen (reticulum and rumen). |
|  |
| Figure. 5. Right lateral radiograph of the thorax showing the different measured angles. Spino-phrenic angle (A), caval-phrenic angle (B), caval- cardiac angle (C), cranial mediastinal- cardiac angle (D), and sterno-costal angle (E). |

**Tables**

**Table 1.** The different values measured for thoracic structures in goats on the right lateral view (RLV) and left lateral view (LLV).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Structure** | **View** | **Minimum** | **Maximum** | **Mean** ± **SD** |
| Tracheal height at the thoracic inlet | RLV | 1 | 2 | 1.36± 0.26 |
| LLV | 1 | 2 | 1.35± 0.27 |
| Thoracic inlet (TI) height | RLV | 7 | 10.5 | 8.58± 1.07 |
| LLV | 6.5 | 10.5 | 8.675± 1.1 |
| Trachea: TI | RLV | 0.12 | 0.21 | 0.1588± 0.0262 |
| LLV | 0.13 | 0.22 | 0.1558± 0.0255 |
| Trachea to spine (T4) distance | RLV | 3.5 | 6.5 | 4.59± 1.1 |
| LLV | 2.9 | 6.8 | 4.8±1.3 |
| Distance from thoracic inlet to diaphragm at level of CVC ventral wall | RLV | 14.4 | 21 | 17.12± 2.08 |
| LLV | 12.48 | 22 | 17.4± 2.7 |
| Cranial pulmonary artery height | RLV | 0.3 | 0.6 | **0.33± 0.21\*** |
| LLV | 0.3 | 0.7 | **0.48± 0.127\*** |
| Cranial pulmonary vein height | RLV | 0.4 | 0.6 | **0.39± 0.19\*** |
| LLV | 0.25 | 0.7 | **0.54± 0.13\*** |
| 4th rib width at narrowest point | RLV | 0.5 | 1 | 0.71± 0.16 |
| LLV | 0.5 | 0.9 | 0.71± 0.12 |
| Pulmonary artery height: 4thrib width | RLV | 0.38 | 0.8 | **0.45± 0.3\*** |
| LLV | 0.44 | 0.86 | **0.68± 0.14\*** |
| Pulmonary vein height: 4th rib width | RLV | 0.4 | 0.86 | **0.55± 0.28\*** |
| LLV | 0.44 | 1 | **0.76± 0.17\*** |
| Cardiac long axis (CLA) | RLV | 10 | 15 | 13.17± 1.44 |
| LLV | 11 | 15 | 12.86± 1.17 |
| Cardiac short axis (CSA) | RLV | 6 | 10 | **7.7± 1.26\*** |
| LLV | 6.5 | 10.5 | **8.15± 1.24\*** |
| Thoracic length (TL) | RLV | 14.6 | 22 | 18.675± 2.23 |
| LLV | 14 | 22.20 | 18.41± 2.4 |
| CLA: TL | RLV | .66 | 0.76 | 0.7± 0.03 |
| LLV | .65 | 0.84 | 0.7± 0.05 |
| Vertebral heart score (VHS) | RLV | 8 | 9.50 | 8.88± 0.58 |
| LLV | 8 | 9.50 | 8.95± 0.496 |
| Heart Width (CSA) by intercostal spaces | RLV | 2 | 3 | 2.48± 0.31 |
| LLV | 2 | 3 | 2.58± 0.29 |
| Aorta height | RLV | 1.4 | 2.8 | 2.1± 0.43 |
| LLV | 1.5 | 2.7 | 2.1± 0.37 |
| Aorta height: 4th rib width | RLV | 1.8 | 2.9 | 2.21± 0.38 |
| LLV | 1.6 | 2.9 | 2.18± 0.37 |
| T4 cranial end height | RLV | 1 | 1.7 | 1.3± 0.19 |
| LLV | 1.1 | 1.7 | 1.4± 0.18 |
| Aorta: T4 ratio | RLV | 1.1 | 2 | 1.64± 0.27 |
| LLV | 1.1 | 2.1 | 1.55± 0.27 |
| Caudal vena cava height (CVC) | RLV | 1 | 2.39 | 1.76± 0.38 |
| LLV | 0.9 | 2.6 | 1.74± 0.5 |
| CVC dorsal wall length | RLV | 4.3 | 8.6 | 6.3± 1.5 |
| LLV | 3.4 | 7.4 | 5.4± 1.25 |
| CVC ventral wall length | RLV | 2.1 | 5.7 | **3.7± 0.96\*** |
| LLV | 1.7 | 4.3 | **2.9± 0.9\*** |
| CVC mean length | RLV | 5.35 | 10.8 | **8.13± 1.9\*** |
| LLV | 4.48 | 9.3 | **6.6± 1.6\*** |
| CVC height: 6th rib ratio | RLV | 1.8 | 2.9 | 2.2± 0.38 |
| LLV | 1.6 | 2.9 | 2.2± 0.38 |
| CVC: T4 height | RLV | 0.72 | 1.71 | 1.35± 0.27 |
| LLV | 0.7 | 1.61 | 1.27± 0.296 |
| Cranial vena cava height | RLV | 0.91 | 2.3 | 1.5± 0.4 |
| LLV | 0.85 | 2.5 | 1.5± 0.5 |
| Cranial mediastinum height | RLV | 2.3 | 4.85 | 3.4± 0.9 |
| LLV | 2.4 | 4.9 | 3.3± 0.86 |
| Spino-phrenic angle | RLV | 27 | 55 | 39.25±7.496 |
| LLV | 24 | 49 | 37.59± 6.5 |
| Sterno-costal angle | RLV | 102 | 133 | 116.8± 9.8 |
| LLV | 103 | 135 | 117.25± 10.33 |
| Lung cranial border cardiac angle | RLV | 87 | 119 | 104.92± 10.93 |
| LLV | 90 | 136 | 103.67± 12.27 |
| Caval-cardiac angle | RLV | 88 | 116 | 99.92± 8.49 |
| LLV | 83 | 104 | 96.08± 7.17 |
| Caval-phrenic angle | RLV | 23 | 39 | **31.8± 5.08\*** |
| LLV | 27 | 43 | **36.41± 5.52\*** |

Bold values superscripted by asterisks (\*) indicates significant changes (P< 0.05).

SD: standard deviation.

**Table 2.** The different values measured for thoracic structures in goats on the ventrodorsal view (VDV) and dorsoventral view (DVV).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Structure** | **View** | **Minimum** | **Maximum** | **Mean± SD** |
| Pulmonary artery width | VD | 0.3 | 0.6 | 0.4± 0.22 |
| DV | 0.2 | 0.7 | 0.41± 0.24 |
| Pulmonary vein width | VD | 0.3 | 0.7 | 0.39± 0.27 |
| DV | 0.4 | 0.7 | 0.42± 0.27 |
| Width of 7thrib | VD | 0.4 | 0.9 | 0.53± 0.13 |
| DV | 0.3 | 0.9 | 0.55± 0.16 |
| CLA | VD | 7 | 13 | 10.54± 1.97 |
| DV | 7.8 | 12 | 9.5± 1.3 |
| CSA | VD | 6 | 11 | 8.1± 1.36 |
| DV | 6.9 | 10 | 8.19± 1.12 |
| Thoracic width | VD | 13.3 | 23.5 | 17.57± 3.13 |
| DV | 13.4 | 20 | 16.7± 2.34 |
| CSA: Thoracic width | VD | 0.38 | 0.59 | 0.46± 0.06 |
| DV | 0.43 | 0.57 | 0.49± 0.04 |
| Caudal pulmonary artery: 7th rib width | VD | 0.5 | 1.2 | 0.76± 0.43 |
| DV | 0.4 | 1.67 | 0.77± 0.49 |
| Caudal pulmonary vein: 7th rib width | VD | 0.5 | 1.4 | 0.75± 0.53 |
| DV | 0.67 | 1.67 | 0.78± 0.56 |