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Radiographic appearance and measurement of thoracic structures in Nellore brown sheep

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Abstract
The present study was carried out on healthy ten adult sheep aged above one year and body weight ranging from 25-30 kgs presented to Department of Veterinary Surgery and Radiology, NTR College of Veterinary Science, Gannavaram for the study of normal thoracic radiographic anatomy. The mean values of tracheal angle to the spine, thoracic inlet diameter, tracheal diameter, thoracic width, thoracic depth, cardiac width, cardiosternal contact and height of T_4 were 21.66 ± 0.39^0, 9.63 ± 0.05, 1.52 ± 0.03, 18.36 ± 0.23, 19.21 ± 0.21, 9.08 ± 0.13, 5.45 ± 0.5 and 1.4 ± 0.01 in cm respectively. The mean values of Cranial mediastinal-cardiac angle, Sterno-costal angle, Spino-phrenic angle, Caval-cardiac angle, Caval-phrenic angle and tracheal angle were 87.54 ± 0.58^0, 130.3 ± 0.58^0, 41.2 ± 0.37^0, 41.2 ± 0.37^0, 40.09 ± 0.46^0 and 21.66 ± 0.39^0. The mean values of VHS measured on left lateral and right lateral views was 9.52 ± 0.06 and 9.41 ± 0.07 respectively.

Keywords: Radiographic anatomy, thorax, sheep, Nellore brown

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 thoracic affections. Small ruminants may suffer from a multitude of health problems that may affect different systems mostly the thoracic structures, particularly the lungs (Abdelhakiem *et al.*, 2020) [1]. Radiography is commonly used as the first diagnostic imaging technique for thoracic diseases in various animal species. It is cheap and readily available. For accurate interpretation of thoracic radiographs, knowledge of the normal radiographic anatomy of the thorax of individual species is important (Berry and Thrall, 2007) [2]. The present article describes about the normal thoracic anatomy of thorax in Nellore Brown Sheep.

2. Materials and Methods

The present study was conducted on apparently healthy ten adult sheep aged above one year and body weight ranging from 25-30 kgs and presented to the Department of Veterinary Surgery and Radiology and Department of Veterinary Clinical Complex, NTR College of Veterinary Science, Gannavaram from December, 2022 to December, 2023 for the study of normal thoracic radiographic anatomy and different measurements of thorax. Radiography was performed using Siemens's x-ray machine. The animals did not receive any tranquilizer or sedative. Four radiographic views (left lateral, right lateral, ventro dorsal and dorsoventral views) were obtained for each sheep at the end of inspiration. The animals were in right recumbent position for the evaluation of the left hemi-thorax and vice versa. The radiographic appearance of different structures within the thoracic cavity and various measurements of thorax were recorded. The range of exposure factors used for small to medium sized sheep were kVp range of 55 to 65 and mAs 8-15 was used for lateral views, whereas for the DV and VD views a kVp range of 65 to 70 was used. The obtained data were subjected to statistical analysis using SPSS software.

2.1 Various measurements of thorax
In the present study, various biometric values for various parameters of thorax of sheep in right lateral view (Fig. 1, 2 and 3).

2.1.1 Thoracic inlet diameter
It was measured from the ventral aspect of the vertebral column at the midpoint of the most cranial rib to the cranial border of the manubrium.

2.1.2 Tracheal diameter
It was measured between the internal surfaces of the tracheal wall perpendicular to the tracheal long axis at the point where the thoracic inlet diameter crosses the midpoint of the tracheal lumen (Hayward *et al.*, 2008) [3]. The ratio of the tracheal diameter (TD) to thoracic inlet diameter (TID) was calculated on the RL view as previously described by (Hayward *et al.*, 2008) [3].

2.1.3 Thoracic width
It was measured as a maximum distance between the left and right pleural surfaces of the eight ribs on the DV view.

2.1.4 Thoracic depth
It was measured from the craniodorsal edge of the xiphoid process to the ventral border of the vertebral column along a line perpendicular to the vertebral column on the RL view (Buchanan and Bücheler, 1995) [4]. The ratio of thoracic width (Tw) to thoracic depth (TDp) was calculated as per method described by Buchanan and Bücheler, 1995 [4].

2.1.5 Cardiosternal contact
It was measured on lateral views from the cardiac apex to the point where the cranioventral margin of the cardiac silhouette diverges from the sternum (Nelson *et al.*, 2011) [5].

2.2 Radiographic measurement of different angles within the thorax of sheep
2.2.1 Tracheal angle
The angle of divergence of the trachea from thoracic vertebrae was measured as the angle between the ventral margins of the third through the fifth thoracic vertebrae and the dorsal margin of the trachea at the thoracic inlet on the RL view (Nelson *et al.*, 2011) [5].

2.2.2 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.

2.2.3 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).

2.2.4 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.

2.2.5 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.

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

2.3 Radiographic measurements of conspicuous blood vessels
2.3.1 Diameter of Caudal vena cava (CVC)
The maximum diameter of the caudal vena cava (CVC) was measured caudal to the cardiac silhouette and cranial to the diaphragm perpendicular to the long axis of the CVC (Makungu and Paulo 2014) [6]. The diameter of the CVC was also compared to that of the aorta and the height of the fourth thoracic vertebral body (T_4). The height of T_4 was measured on the RL view along a line that extended between the craniodorsal and cranioventral borders of the vertebral body (Nelson *et al.*, 2011) [5].

2.3.2 Diameter of aorta
The maximum diameter of the aorta was measured on the RL view at the level of the T_4 perpendicular to the long axis of the aorta. The crossing point of the diaphragmatic crura/crus to the thoracic vertebra in relationship to the cranial thoracic vertebrae was recorded on lateral views (Makungu and Paulo 2014) [6].

2.3.3 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) [7] with some modification.

2.3.4 Pulmonary blood vessels
The clarity of cranial pulmonary blood vessels were evaluated on the lateral radiographs and also clarity of the caudal pulmonary blood vessels were evaluated on the DVV and VDV.

2.4 Vertebral heart score (VHS)
It used to determine cardiac enlargement by comparing the long and short axis of the cardiac silhouette with the number of thoracic vertebrae. The Buchanan and Bucheler's (1995) [4] method was used to measure VHS. The longest axis (LA) of the cardiac silhouette was measured from the ventral border of the carina to the most distant ventral contour of the cardiac apex. The short axis (SA) was measured at the widest part of the cardiac silhouette, perpendicular to the long axis (at the level of ventral margin of the caudal vena cava). Both these measurements were done using electronic calipers of CR system. The lines conforming to these measurements (LA and SA) were transposed over the vertebral column starting at the cranial edge of the vertebral body of fourth thoracic vertebra (T_4) Finally, the sum of both values (long and short axes) was equivalent to the vertebral heart size (Fig 4 and 5).

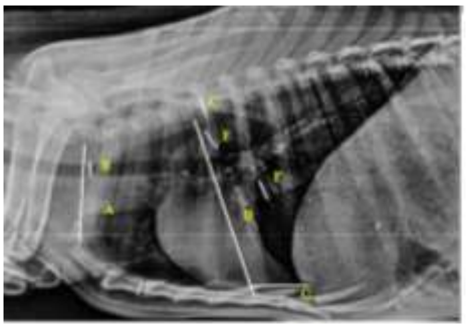

Fig 1: Skiagram showing various biometric values for various parameters of thorax of sheep in right lateral view- Thoracic inlet diameter (A), Tracheal diameter (B), Height of T_4 (C), Thoracic Depth (D), Diameter of Aorta (E), Diameter of Caudal vena cava (F) and Cardiostrenal contact (G).

Fig 2: Skiagram showing cardiac width (A) and thoracic width (B) of thorax of sheep in DV view.

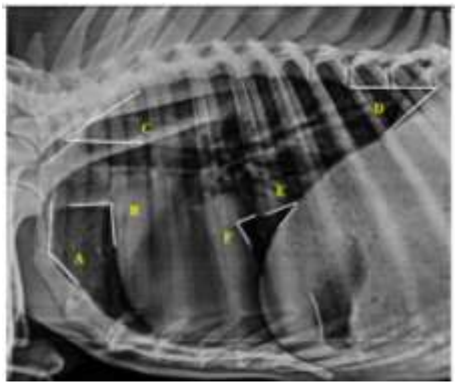

Fig 3: Skiagram showing different angles of thorax of sheep in right lateral view- Costo-sternal angle (A), Cranio mediastinal cardiac angle (B), Tracheal angle (C), Spino-phrenic angle (D), Caval phrenic angle (E) and Caval cardiac angle (F).

Fig 4: Skiagram showing assessment of VHS on right lateral view of thorax in sheep.

Fig 5: Skiagram showing assessment of VHS on left lateral view of thorax in sheep.

3. Result and Discussion

In the present study, the trachea was more clearly visible on lateral radiographs compared to ventro-dorsal and dorso-ventral views. The tracheal walls appeared as fine radiopaque lines surrounding a radiolucent lumen, indicating air-filled spaces. Similarly, Abdelhakiem *et al.* (2020) [1] observed the tracheal walls as distinct radiopaque lines enclosing a radiolucent lumen. Oesophagus was not visible in all the animals especially the caudal thoracic part of esophagus. The lungs were bounded with thoracic wall cavity laterally while mediastinum and heart medially, the apex of lung opposite the boundaries of the first and second rib cranially and the base of lungs extended up to the 10th -12th ribs caudally while restricted between the sternum ventrally and thoracic vertebra dorsally. On both the lateral views, the cardiac silhouette was ovoid in shape. In all animals the cardiac silhouette was in contact with the diaphragm and sternum. The cranial border of the cardiac silhouette was located at the level of the third rib whereas the caudal border of the cardiac silhouette was located at the level of the sixth rib. On both the lateral views, the heart included 2.5 to 3 intercostal spaces (ICS). The shape of the cardiac silhouette was round in dorsal-ventral view (DVV) and round to oval on ventral-dorsal view (VDV) in all the animals. On the DVV projection, the heart was in the middle of the thoracic cavity. On the VDV projection, apex was slightly shifted to the left. Similar to the findings of present study, Olatunji-akioye *et al*. (2020) [8] observed shape of the heart was consistently oval on lateral radiographs but was oval on the dorsoventral view tilting slightly left but was ovoid on ventrodorsal view in goats.

3.1 Various measurements of thorax

3.1.1 Thoracic inlet diameter

The mean ± SE value of thoracic inlet diameter was 9.63±0.05 and measured in all the 10 animals and recorded in Table 1. However, Makungu (2017) [9] recorded the mean ratio of the thoracic inlet diameter was 9.17±0.60 in East African black headed female sheep.

3.1.2 Tracheal diameter

The mean ± SE value of tracheal diameter was 1.52±0.03 measured in all the 10 animals on the lateral views of the radiographs, then recorded in Table 1. However, Makungu (2017) [9] recorded the mean of tracheal diameter was 1.28±0.21 in East African black headed female sheep.

3.1.3 Thoracic width

The mean ± SE value of thoracic depth was 18.36±0.23 measured in all 10 animals on DV view of radiograph, then recorded in Table 1. Makungu (2017) [9] recorded the mean values of thoracic width as 12.87±1.27 cm, with a calculated ratio of TDp to TW of 1.37±0.13. Further he observed that the mean ratio of thoracic depth to thoracic width (1.37) suggests that East African black-headed sheep tend to had a relatively deep thorax.

3.1.4 Thoracic depth

The mean ± SE value of thoracic depth was 19.21±0.21 measured in all 10 animals on right lateral view of radiograph, then recorded in Table 1. However, Makungu (2017) [9] recorded the mean value of thoracic depth (TDp) as 17.48±0.60 cm in adult healthy East African black headed female sheep.

3.1.5 Cardiac width

The mean ± SE value of cardiac width was 9.08±0.13 measured in all 10 animals on DV view of radiograph, then recorded in Table 1. However, Babicsak *et al.* (2017) [10] recorded the mean value of cardiac width 8.99±0.37 cm in young female Bergamasca sheep.

3.1.6 Cardiosternal contact
The mean ± SE value of cardiosternal contact was 5.45±0.5 measured in all 10 animals and recorded in Table 1. Makungu (2017) [9] observed mean value of cardiosternal contact was 6.30±0.75 and 6.37±0.70 on right and left lateral view in East African black-headed sheep.

3.1.7 Height of T_4
The mean ± SE value of height of T_4 was 1.4±0.01 measured in all 10 animals and recorded in Table 1. Makungu (2017) [9] recorded the mean values of height of the T_4 vertebra was 1.37±0.05 cm in East African black headed female sheep.

3.2 Radiographic measurement of different angles within the thorax of sheep
3.2.1 Cranial mediastinal-cardiac angle
The mean ± SE value of Cranial mediastinal-cardiac angle was 87.54±0.58^0 measured on the right lateral views of the radiographs, then recorded in Table 1.

3.2.2 Sterno-costal angle
The mean ± SE value of sterno-costal angle was 130.3±0.58^0 measured on the right lateral views of the radiographs, then recorded in Table 1. Abdelhakiem *et al.* (2020) [1] observed mean value of sterno-costal angle was 116.8±9.8 and 117.25±10.33 in right lateral and left lateral view in goats.

3.2.3 Spino-phrenic angle
The mean ± SE value of spino-phrenic angle was 41.2±0.37^0 measured in all the 10 animals on the right lateral views of the radiographs, then recorded in Table 1. Abdelhakiem *et al.* (2020) [1] observed mean value of Spino-phrenic angle was 39.25±7.496 and 37.59±6.5 right lateral and left lateral view in goats.

3.2.4 Caval-cardiac angle
The mean ± SE value of caval-cardiac angle was 103.42±0.24^0 measured in all the 10 animals on the right lateral views of the radiographs, then recorded in Table 1. Abdelhakiem *et al.* (2020) [1] observed mean value of caval-cardiac angle was 99.92±8.49 and 96.08±7.17 in goats.

3.2.5 Caval-phrenic angle
The mean ± SE value of caval-phrenic angle was 40.09±0.46^0 measured in all the 10 animals on the right lateral views of the radiographs, then recorded in Table 1. Abdelhakiem *et al.* (2020) [1] observed mean value of caval-phrenic angle was 96.08±7.17 and 36.41±5.52 in RLV and LLV of goats.

3.2.6 Tracheal angle
The mean ± SE value of tracheal angle was 40.09±0.46^0 measured on the right lateral views of the radiographs, then recorded in Table 1. However, Babicsak *et al.* (2017) [10] found average tracheal angle in young sheep was 14.72±3.08 degrees.

3.3 Radiographic measurements of conspicuous blood vessels
3.3.1 Diameter of Caudal vena cava (CVC)
The mean ± SE values of diameter of caudal vena cava was 1.86±0.02 cms and values were ranged from 1.6 to 1.9 cms and recorded in Table 1. Abdelhakiem *et al.* (2020) [1] reported the mean height of the caudal vena cava was 1.76±0.38 on the right lateral view and 1.74±0.5 on the left lateral view in goats.

3.3.2 Diameter of aorta
The mean ± SE values of height of aorta was 2.19±0.03 cms and values were ranged from 1.9 to 2.3 cms and recorded in Table 1. Makungu (2017) [9] recorded the mean value of aorta diameter (cm) was 1.88±0.10 in East African black headed female sheep. In the present study, the mean ratio of CVC diameter to aorta diameter was 0.85±0.02.

3.3.3 Visibility of CVC & aorta
The CVC was recognized on the VDV as a radiopaque structure to the right of midline 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. Aorta and CVC was bitterly seen in RLV than LLV.

3.3.4 Pulmonary blood vessels
Pulmonary blood vessels was clearly appreciable on lateral views. Cranial lobar pulmonary blood vessels were well detected in animals on the left lateral views. The cranial pulmonary artery was clearly visible on the 7/10 and cranial pulmonary vein was clearly visible 6/10 in right lateral view. The cranial pulmonary artery was clearly visible on the 8/10 and cranial pulmonary vein was clearly visible 7/10 in left lateral view. The caudal pulmonary artery and vein was clearly visible on the 6/10 in right lateral view.

3.3.5 Thoracic vertebrae, ribs, sternum and diaphragm
Skiagram of musculoskeletal system of thorax revealed that all the animals had 13 thoracic vertebrae and 13 pair of ribs. Makungu (2017) [9] observed that among the six adult healthy East African black-headed female sheep, five of the sheep had 13 thoracic vertebrae, while one animal had 12 thoracic vertebrae with the mean number of thoracic vertebrae was 12.8±0.4. The sternum was positioned in concave upward direction with the manubrium sterni almost vertically positioned. Out of 10 animals 9 had 7 sternebrae and remaining one had 6 sternebrae. The height of the sternum decreased from cranial to caudal. Similarly, Makungu (2017) [9] found that the sternum was concave upward with the manubrium sterni almost vertically positioned with the mean value of number of sternebrae was 4.3±0.52 in sheep. On left lateral view crura was seen frequently diverged dorsally (7/10) and in right lateral views, the diaphragmatic crura were frequently seen to be parallel (8/10) and some animals crura was super imposed. On the DV and VD views, the diaphragm was seen as a single dome in all animals. In one animal, right pulmonary cupula pleura was more radiolucent, wide and extended further cranially than the left pulmonary cupula pleura. The width of the cranial mediastinum exceeded the width of the spine in all animals.

3.4 Vertebral heart score (VHS)
In the present study, the mean ± SE values of VHS measured on left lateral and right lateral views was 9.52±0.06 and 9.41±0.07 respectively. Souza *et al.* (2012) [11] reported a higher mean VHS of 10.36±0.35 vertebrae in 5-month-old Santa Ines sheep, indicating a larger relative heart size compared to the present study. Similarly, Ukaha *et al.* (2013) [12] observed a mean VHS of 10.1±0.01 vertebrae in West African Dwarf goats, suggesting a slightly larger heart size in this goat breed compared to sheep.

Table 1: Various measurements of thorax in Nellore Brown sheep

S. No.	Parameter	Mean ± SE
1	Thoracic Depth (TDp)	19.21±0.21
2	Thoracic Width	18.36±0.23
3	TDp:TW	1.05±0.02
4	Cardiac Width	9.08±0.13
5	Tracheal Diameter (TD)	1.52±0.03
6	Thoracic inlet Diameter	9.63±0.05
7	TD: TID	0.16±0.01
8	Aorta	2.19±0.03
9	Caudal Vena Cava	1.86±0.02
10	Height of T_4	1.4±0.01
11	CVC diameter: Height of T_4	1.33±0.01
12	CVC diameter: Aorta diameter	0.85±0.02
13	VHS - LLV	9.52±0.06
14	VHS - RLV	9.41±0.07
15	Cardio sternal contact	5.45±0.5
16	Spino-phrenic angle	41.2±0.37^0
17	Caval phrenic angle	40.09±0.46^0
18	Caval cardiac angle	103.42±0.24^0
19	Cranio-mediastinal-cardiac angle	87.54±0.58^0
20	Sterno-costal angle	130.3±0.58^0
21	Tracheal spinal angle	21.66±0.39^0

4. Conclusion

In conclusion, the radiographic examination of the thoracic cavity in sheep provided valuable insights into the anatomical structures and dimensions. Lateral views proved superior in visualizing the trachea and cardiac silhouette, while dorso-ventral and ventro-dorsal views offered complementary perspectives. Consistent with previous research, the tracheal walls appeared as distinct radiopaque lines, and the cardiac silhouette exhibited consistent shapes across views. Various measurements, including thoracic inlet diameter, tracheal diameter, and cardiac width, highlighted anatomical variations among different sheep breeds. Additionally, angles within the thoracic cavity and dimensions of conspicuous blood vessels were measured, offering further anatomical detail. The findings contribute to the understanding of thoracic anatomy in sheep and provide baseline data for clinical and research purposes. Comparisons with previous studies underscore variations in anatomical parameters across different breeds, emphasizing the importance of breed-specific considerations in diagnostic and research settings. Overall, this study enhances our knowledge of sheep thoracic anatomy and lays the groundwork for future investigations in veterinary medicine and animal science.

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