Thoracic radiographic anatomy in sheep

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SUMMARY

The objective of this study was to describe the normal radiographic anatomy of the thorax in sheep and to provide reference ranges for clinical use. Radiography of the thorax was performed in six East African blackheaded sheep. Right lateral (RL), left lateral (LL), dorsoventral (DV) and ventrodorsal (VD) radiographic views of the thorax were obtained under general anaesthesia at the end of inspiration. The number of thoracic vertebrae ranged from 12(1/6) to 13(5/6). The sternum was concave upward with the manubrium sterni almost vertically positioned. It consisted of manubrium sterni, xiphoid process and four (4/6) or five (2/6) sternebrae. There was no significant difference (P = 0.77) observed in the mean vertebral heart score (VHS) obtained on the LL (10.28 ± 0.37) and RL (10.23 ± 0.43) views. The mean ratio of the caudal vena cava (CVC) diameter to the height of the fourth thoracic vertebral body and aorta diameter was 1.19 ± 0.08 and 0.85 ± 0.08, respectively. The mean VHS on the VD view (8.62 ± 0.40) was significantly (P = 0.02) larger compared to that of the DV view (8.03 ± 0.25). The mean ratio of the trachea diameter to thoracic inlet distance was 0.14 ± 0.03. The right pulmonary cupula pleura was more radiolucent, wide and extended further cranially than the left pulmonary cupula pleura. Knowledge of the normal thoracic radiographic anatomy of individual species is important for accurate interpretation of thoracic radiographs.
Keywords: sheep, thorax, radiography, anatomy

INTRODUCTION

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). The normal thoracic radiographic anatomy of various species has been reported by several authors, which serves as a reference for interpretation of thoracic radiographs (Farrow, 1981; Nelson *et al.*, 2011; Thrall and Robertson, 2011; Makungu and Paulo, 2014).

Like other domestic animals, thoracic conditions such as pneumonia (Aiello and Mays, 1998), neoplasia (Rosadio *et al.*, 1988), diaphragmatic hernia (Williams *et al.*, 2016) and megaoesophagus (Nascimento *et al.*, 2016) have been reported in sheep, which affect their survival. The aim of this study was to describe the normal radiographic anatomy of the thorax in sheep and to provide reference ranges for clinical use.

MATERIALS AND METHODS

Animals

Six adult healthy East African blackheaded female sheep from the Sokoine University of Agriculture, College of Veterinary and Medical Sciences, Animal Research Unit (ARU) were used in this study. The mean age of the animals was 34 ± 9.03 months with a range of 24 to 48 months. The minimum and maximum weights of the animals were 17.5 kg and 25.5 kg, respectively (mean: 20.58 ± 2.96).

Radiography

Radiography of the thorax was performed under general anaesthesia. Xylazine hydrochloride (KEPRO, Holland) at the dosage of 0.03 mg/kg and Ketamine hydrochloride (ROTEXMEDICA, Germany) at the dosage of 2 mg/kg were used as a sedative and general anaesthetic, respectively. All drugs were administered intravenously through the jugular vein. Animals were fasted for 12-24 hours but water was given *ad libitum* until shortly before administration of general anaesthesia.

Radiography was performed using Roller 30 (SMAM X-RAY EQUIPMENTS, Italy) x-ray machine. Right lateral (RL), left lateral (LL), dorsoventral (DV) and ventrodorsal (VD) radiographic views of the thorax were taken at the end of inspiration. A source to image distance (SID) of 100 cm was used with a stationary focused grid. A kVp range of 80 to 86 was used for lateral views, whereas for the DV and VD views a kVp range of 90 to 98 was used. In all radiographs a charge of 2 mAs was used. Medium speed screen type medical x-ray green films (CARESTREAM HEALTH, France) were used in combination with Green 400 (KIRAN MEDICAL SYSTEMS LTD, India) intensifying screens. Exposed films were processed manually using Kodak GBX (CARESTREAM HEALTH, France) developer and fixer. Radiographic images were digitalised using a digital camera CANON PC1192 (CANON INC., Tokyo, Japan)

Radiographic evaluation

The visibility, shape, size, number, opacity and location of thoracic organs and structures on lateral, DV and VD views were recorded. The number of ribs, sternebrae and that of thoracic vertebrae were recorded. The ratio of thoracic width (Tw) to thoracic depth (TDp) was calculated (Buchanan and Bücheler, 1995). The Tw was measured as a maximum distance between the left and right pleural surfaces of the sixth ribs on the DV view (Figure 1) (Makungu and Paulo, 2014). The TDp 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 (Figure 2) on the RL view (Buchanan and Bücheler, 1995).

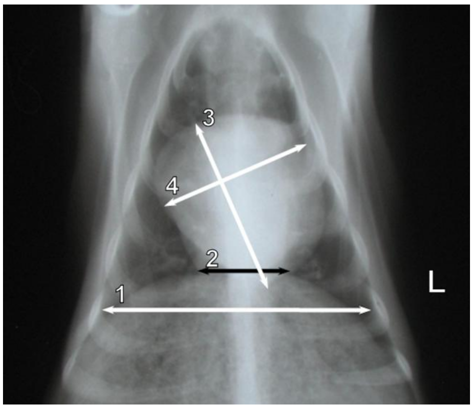

Figure 1. Dorsoventral thoracic radiograph of a 25.5 kg female East African blackheaded sheep illustrating selected radiographic measurements. 1 = thoracic width, 2 = cardiodiaphragmatic contact, 3 = cardiac silhouette long axis measurement, 4 = cardiac silhouette short axis measurement. L = left.

The cardiosternal contact was measured on lateral views (Figure 2) from the cardiac apex to the point where the cranioventral margin of the cardiac silhouette diverges from the sternum (Nelson *et al.*, 2011). The cardiodiaphragmatic contact was measured on the DV, VD and lateral views. On lateral views (Figure 2), it was measured from the cardiac apex to the dorsal point of intersection of the cardiac silhouette and diaphragm (Nelson *et al.*, 2011). On the DV and VD views, it was measured as the distance between the right and left points of intersection of the cardiac silhouette and diaphragm (Figure 1). The vertebral heart score (VHS) was measured as previously described in dogs on the DV, VD and lateral views (Buchanan and Bücheler, 1995). The cardiac silhouette long axis and short axis measurements on lateral (Figure 2), VD and DV (Figure 1) views were used to calculate VHS on lateral, VD and DV views, respectively. The size of the cardiac silhouette with respect to intercostal spaces was recorded on lateral views. Additionally, the positions of the cranial and caudal borders of the cardiac silhouette were recorded on lateral views.

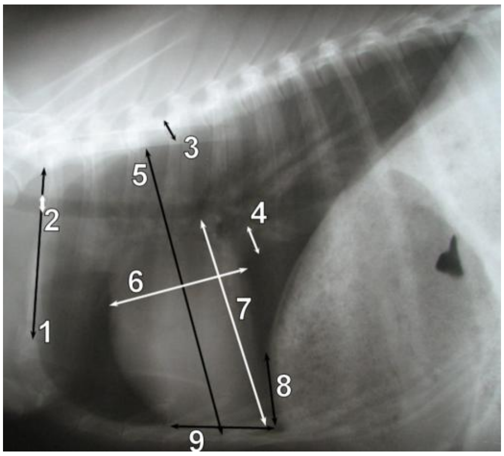

Figure 2. Right lateral thoracic radiograph of a 25.5 kg adult female East African blackheaded sheep illustrating selected radiographic measurements. 1 = thoracic inlet diameter, 2 = trachea diameter, 3 = height of the fourth thoracic vertebral body, 4 = caudal vena cava diameter, 5 = thoracic depth, 6 = cardiac silhouette short axis measurement, 7 = cardiac silhouette long axis measurement, 8 = cardiodiaphragmatic contact, 9 = cardiosternal contact.

The maximum diameter of the caudal vena cava (CVC) (Figure 2) was measured caudal to the cardiac silhouette and cranial to the diaphragm perpendicular to the long axis of the CVC (Makungu *et al.*, 2014). The diameter of the CVC was also compared to that of the aorta and the height of the fourth thoracic vertebral body (T4). The height of T4 (Figure 2) 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). The maximum diameter of the aorta was measured on the RL view at the level of the T4 perpendicular to the long axis of the aorta.

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). The ratio of the tracheal diameter (TD) to thoracic inlet diameter (TID) was calculated on the RL view as previously described (Hayward *et al.,* 2008). The TID 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 sterni (Figure 2). The TD (Figure 2) was measured between the internal surfaces of the tracheal wall perpendicular to the tracheal long axis at the point where the TID crosses the midpoint of the tracheal lumen (Hayward *et al.,* 2008). The position of the carina with respect to thoracic vertebra was recorded on the RL view (Makungu *et al.,* 2014). 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 *et al.,* 2014).

Data analysis

Data were analysed using Microsoft Office excel 2007. Mean, range and standard deviation (SD) were calculated. Student's *t*-test was used to compare the mean of cardiosternal contact, cardiodiaphragmatic contact, VHS and crossing point of the diaphragmatic crura/crus to the thoracic spine in relationship to the cranial thoracic vertebrae on the RL view versus (vs.) LL view and DV view vs. VD view. Statistical significance was accepted at $P \leq 0.05$. Data are expressed as mean ± SD.

RESULTS

Musculoskeletal system

Of the six animals examined, five (83.3%) had 13 thoracic vertebrae, whereas one (16.7%) animal had 12

thoracic vertebrae. The mean number of thoracic vertebrae was 12.8 ± 0.4. The thoracic spine sloped from caudal to cranial (Figure 3) and the anticlinal vertebra was thoracic vertebra 11 (T11) in five of six animals. In one animal it was T10. An animal with T10 as an anticlinal vertebra had 12 number of thoracic vertebrae. The mean anticlinal vertebra was 10.8 ± 0.4. Of the six animals, five had 13 pairs of ribs, whereas one animal had 12 pairs of ribs. An animal with 12 pairs of ribs had 12 thoracic vertebrae. The mean pair of ribs was 12.8 ± 0.4. The sternum was concave upward with the manubrium sterni almost vertically positioned (Figure 3). It consisted of the manubrium sterni, four (4/6) or five (2/6) sternebrae and a xiphoid process (Figure 3). The height of the sternum decreased from cranial to caudal (Figure 3). The mean number of sternebrae was 4.3 ± 0.52. Radiographic findings and measurements are summarised in Table 1.

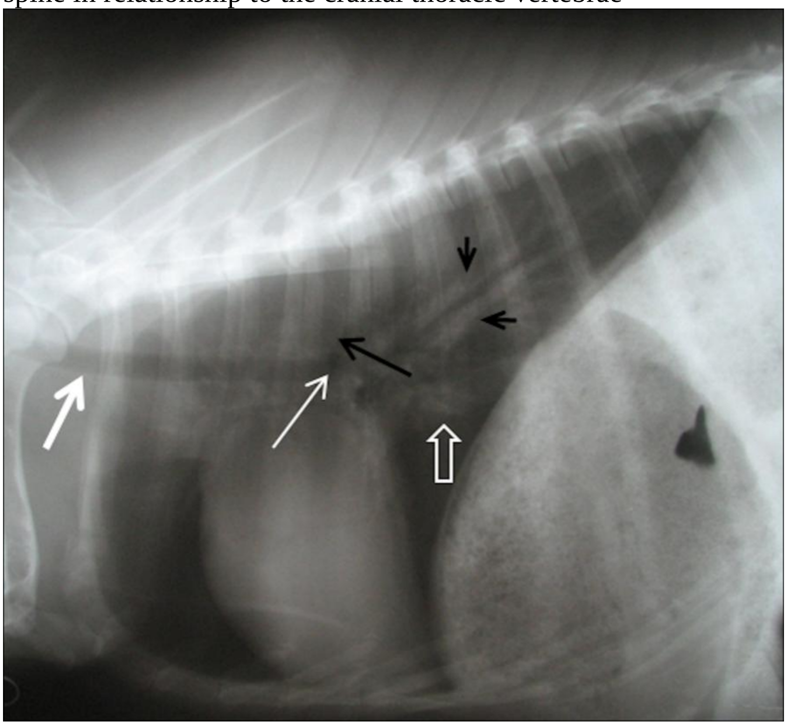

Figure 3. Right lateral thoracic radiograph of a 25.5 kg adult female East African blackheaded sheep. The sternum is concave upward consisting of manubrium sterni, xiphoid process and four sternebrae. The manubrium sterni is almost vertically positioned. The thoracic spine slopes from caudal to cranial. The ovoid cardiac silhouette is in contact with the diaphragm. The trachea (thick white arrow) is relatively narrow and

the carina (thin white arrow) is not clearly visible. The pulmonary cupula pleura is at the level of the first rib. The caudal vena cava and aorta are indicated by an open white arrow and a black arrow, respectively. Note the clear visualisation of the caudal lobar pulmonary artery and vein (small black arrows).

Table 1. Radiographic measurements and findings of the thorax not compensated for magnification in East African blackheaded sheep

Variable	Number of animals	Mean ± SD	Range (min – max)
TDp (cm)	6	17.48 ± 0.60	17.00 – 18.60
TW (cm)	6	12.87 ± 1.27	11.20 – 15.00
TDp:TW	6	1.37 ± 0.13	1.15 – 1.53
TD (cm)	6	1.28 ± 0.21	1.00 – 1.60
TID (cm)	6	9.17 ± 0.60	8.30 – 10.00
TD:TID	6	0.14 ± 0.03	0.10 – 0.18
Tracheal angle (º)	6	22.50 ± 3.02	19.00 – 27.00
Cranial crus/crura (RL)	6	10.43 ± 0.29	10.10 – 10.80
Cranial crus/crura (LL)	6	10.40 ± 0.37	10.00 – 10.80
VHS (RL)	6	10.23 ± 0.43	9.70 – 10.70
VHS (LL)	6	10.28 ± 0.37	9.90 – 10.80
VHS (DV)	6	8.03 ± 0.25	7.70 – 8.30
VHS (VD)	6	8.62 ± 0.40	8.10 – 9.30
CDC (RL) cm	6	6.65 ± 1.67	4.30 – 8.80
CDC (LL) cm	6	6.85 ± 1.16	5.50 – 8.80
CDC (DV) cm	6	3.33 ± 1.39	1.50 – 4.80
CDC (VD) cm	2	0.58 ± 0.92	1.50 – 2.00
CSC (RL) cm	6	6.30 ± 0.75	5.50 - 7.50
CSC (LL) cm	6	6.37 ± 0.70	5.50 – 7.50
CVC diameter (cm)	6	1.63 ± 0.10	1.50 – 1.70
Height of T4 (cm)	6	1.37 ± 0.05	1.30 – 1.40
CVC diameter:Height of T4	6	1.19 ± 0.08	1.07 – 1.31
Aorta diameter (cm)	4	1.88 ± 0.10	1.80 – 2.00
CVC diameter:Aorta diameter	4	0.85 ± 0.08	0.75 – 0.94

CDC = cardiodiaphragmatic contact; CSC = cardiosternal contact

Cardiovascular system

On lateral views, the cardiac silhouette was ovoid and almost perpendicular to the thoracic spine (Figure 3). In all animals the cardiac silhouette was in contact with the diaphragm (Figure 3).

There was no significant difference in the mean cardiodiaphragmatic contact (P = 0.57) and cardiosternal contact (P = 0.72) obtained on the RL and LL views. The cranial border of the cardiac silhouette was frequently (5/6) positioned at the level of the third rib (Figure 3) and very rarely (1/6) at the level of the second rib. The caudal border of the cardiac silhouette was frequently (5/6) seen at the level of the sixth rib (Figure 3) and very rarely (1/6) at the level of the fifth rib. The cardiac silhouette was wider than two intercostal spaces, but did not exceed three intercostal spaces (Figure 3). There was no significant difference (P = 0.77) in the mean VHS obtained on the LL (10.28 ± 0.37) and RL (10.23 ± 0.43) views. The CVC was seen in all animals (Figure 3). The mean ratio of the CVC diameter to the height of the T4 was 1.19 ±0.08. The aorta was clearly seen in 4/6 animals (Figure 3). The ratio of the CVC diameter to aorta diameter was 0.85 ± 0.08.

On the VD view, the cardiac silhouette was mostly (5/6) seen angular (Figure 4A) and very rarely (1/6) ovoid. The cardiodiaphragmatic contact was seen in 2/6 animals. On the DV view, the cardiac silhouette was mostly (5/6) seen ovoid (Figure 4B) and rarely (1/6) angular. The cardiodiaphragmatic contact was seen in all animals (Figure 4B) and increased in heavy animals (Figure 5). The mean cardiodiaphragmatic contact on the DV view (3.33 ± 1.39 cm) was significantly (P = 0.01) larger compared to that of the VD view (0.58 ± 0.92 cm). The cardiac apex was frequently (5/6) positioned slightly to the left of the spine (Figure 4) and very rarely (1/6) at the midline. The mean VHS on the

VD view (8.62 ± 0.40) was significantly (P = 0.02) larger compared to that of the DV view (8.03 ±0.25).

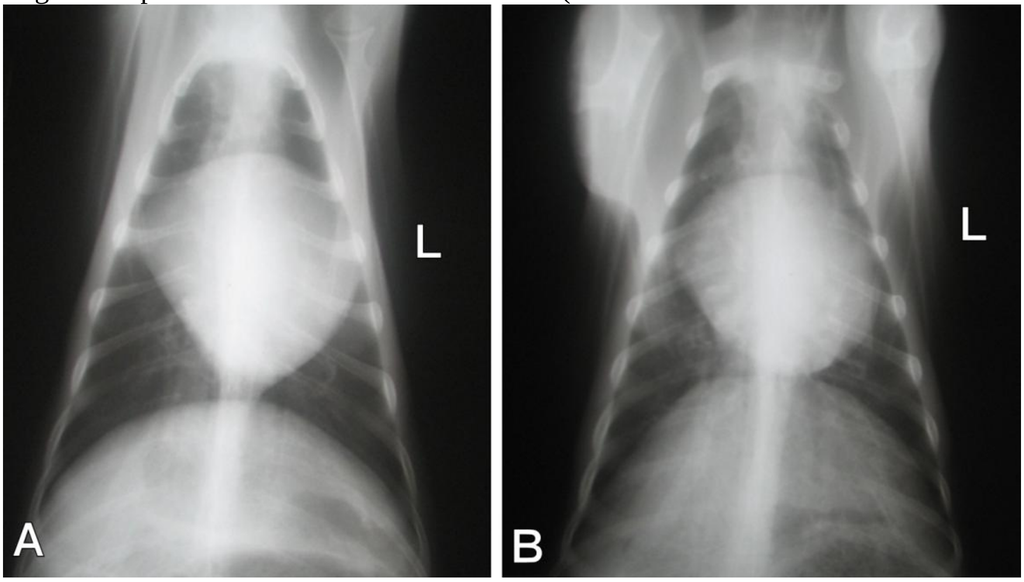

Figure 4. Ventrodorsal (A) and dorsoventral (B) thoracic radiographs of a 19.5 kg adult female East African blackheaded sheep. The right pulmonary cupula pleura is more radiolucent, wide and extend further cranially than the left pulmonary cupula pleura. The diaphragm is seen as a single dome and the width of the cranial mediastinum exceeds the width of the spine. The cardiac apex is positioned slightly to the left of the spine. **A:** The cardiac silhouette is angular shaped **B:** The ovoid cardiac silhouette is in contact with the diaphragm. L, left.

Respiratory system

On lateral views, the diaphragmatic crura were frequently seen to be parallel (4/6) and were less frequently superimposed (1/6) or diverged dorsally (1/6) (Figure 3). There was no significant difference (P = 0.81) in the mean crossing point of the diaphragmatic crura/crus in relationship to the cranial thoracic vertebra on the RL (10.43 ± 0.29) and LL (10.40 ± 0.37) views. The mean ratio of the TD to TID was 0.14 ± 0.03. The carina was either not clearly visible (3/6) (Figure 3) or not visible at all (3/6). In three animals it was positioned at the level of the fourth thoracic vertebra (Figure 3). Cranially, the pulmonary cupula pleura ended at the level of the first rib in all animals (Figure 3). The mean tracheal angle to spine was 22.5 ± 3.02°.

On the DV and VD views, the diaphragm was seen as a single dome in all animals (Figure 4). The right pulmonary cupula pleura was more radiolucent, wide and extended further cranially than the left pulmonary cupula pleura (Figure 4). The width of the cranial mediastinum exceeded the width of the spine in all animals (Figure 4).

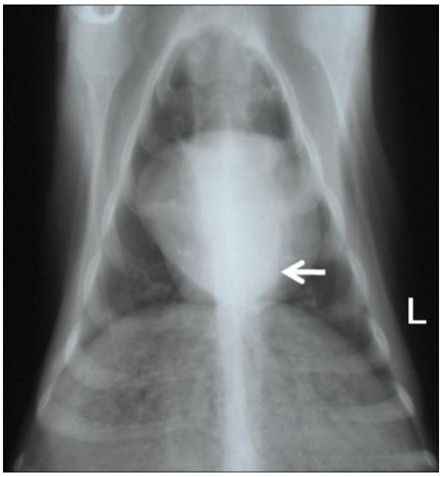

Figure 5. Dorsoventral thoracic radiograph of a 25.5 kg adult female East African blackheaded sheep. Note the extensive cardiodiaphragmatic contact compared to figure 4B. The left margin of the aorta is indicated by a white arrow. L, left.

DISCUSSION

The mean ratio of the depth of the thorax to thoracic width obtained in this study (1.37) indicates that East African blackheaded sheep have a deep thorax (Buchanan and Bücheler, 1995) similar to small East African goats (1.34) (Makungu and Paulo, 2014). The presence of 13 thoracic vertebrae in the majority of animals in this study is similar to small East African goats (Makungu and Paulo, 2014). Similar to this study, variation in the number of thoracic vertebrae has also been observed in small East African goats (Makungu and Paulo, 2014). The appearance of the manubrium sterni on lateral views i.e. almost vertically positioned is different from small East African goats (Makungu and Paulo, 2014). The mean number of sternebrae obtained in this study (4.3) is lower than the reported mean in small East African goats (4.8) (Makungu and Paulo, 2014). In small East African goats, variation in the number of sternebrae was seen in female animals, which had four to five sternebrae (Makungu and Paulo, 2014). Male animals had five sternebrae (Makungu and Paulo, 2014). The gender of the animals in this study might have contributed to the lower mean number of sternebrae.

The angular and rounded shaped cardiac silhouette, observed on the VD and DV views, respectively, in the majority of animals in this study is similar to small East African goats (Makungu and Paulo, 2014). The mean values of VHS measured on lateral views in this study (RL: 10.23; LL: 10.28) were higher than those reported in small East African goats (RL: 10.02; LL: 10.10), whereas, those measured on the DV and VD views (DV: 8.03; VD: 8.62) were lower than in small East African goats (DV: 8.21; VD: 9.42) (Makungu and Paulo, 2014). It is most likely that the cardiac silhouette in East African blackheaded sheep is more vertical in position in the thorax compared to small East African goats, which results in smaller appearance of the cardiac silhouette on the DV and VD views. In deep chested dogs the cardiac silhouette has also been reported to be almost perpendicular to the spine on lateral views and the apex is close to median plane on the DV (Johnson *et al.*, 2008). The mean ratio of the CVC diameter to the height of the T4 in East African blackheaded sheep (1.19) is almost similar to small East African goats (1.08) (Makungu and Paulo, 2014).

The mean ratio of the TD to TID obtained in this study (0.14) is higher than the reported mean (0.11) in small East African goats (Makungu and Paulo, 2014). Additionally, the mean tracheal angle to spine measured in East African blackheaded sheep in this study (22.5°) is higher than the reported mean in small East African goats (17.8°) (Makungu and Paulo, 2014). In ruminants, the right cranial lung lobe is larger than the left cranial lung lobe (Getty, 1975), which explains the more cranial extension of the right pulmonary cupula pleura than the left pulmonary cupula pleura in this study.

This study provides reference ranges of thoracic organs and structures in East African blackheaded sheep for clinical use. Additionally, indicates that species-specific differences exist in the normal radiographic anatomy of the thorax. Therefore, the knowledge of normal radiographic anatomy of the thorax of individual species is important for accurate interpretation of thoracic radiographs

ACKNOWLEDGEMENTS

The author would like to thank the Department of Veterinary Surgery and Theriogenology of Sokoine University of Agriculture for supporting this study. Mrs Sinao Kingongo and Mr. Antony Mhando of Sokoine University of Agriculture Animal Hospital for their assistance during radiographic examination.

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