Ultrasonography of the Cardiopulmonary System in Camels (*Camelus dromedarius*)

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**Abstract**

This article reviews the normal cardiac chamber appearance and quantitative dimensions in healthy dromedary camels. Besides, it shows results of ultrasonography of the lungs and pleura and its dimensions in camels. First part of the review deals with technique of echocardiography of the normal camel heart and cardiac dimensions, echocardiographic protocol and the results of the right and left parasternal ultrasonograms. It also reviews the minimum, maximum, mean values, standard deviations and coefficient of variation for the internal echocardiographic measurements in healthy camels. Second part of this review article deals with pulmonary ultrasonography and its technique and ultrasonographic finding in healthy camels. It also reviews the measurements for the dorsal and the ventral lung borders and the resulting dorsoventral dimensions of the right and left lungs. Both first and second parts are then followed by practical application of cardiopulmonary ultrasonography in camel medicine. This section shows in order the ultrasonographic findings in camels with white muscle disease (Vitamin E/Selenium deficiency), chronic pneumonia and pleuropneumonia in diseased camels.

**Key words:**
Camels, Cardiovascular, Cardiopulmonary, Echocardiography, Ultrasonography.

**Echocardiography of the normal camel heart: technique and cardiac dimensions**

In the camel, heart diseases include pericarditis, vegetative valvular endocarditis, hypertrophic cardiomyopathy, necrotic myocarditis and congenital defects including septal defects, patent ductus arteriosus, transposition of the aorta and pulmonary artery, persistent aortic trunk, and persistent right aortic arch and sarcocystosis [1-7]. These heart diseases are mostly diagnosed at slaughterhouses or incidentally discovered at postmortem examination [8], showing that the diagnosis of camel heart disease is a challenging task especially when typical clinical signs of heart failure are absent. For these reasons, ancillary tests are required to confirm the diagnosis in the living animal. This is of particular importance to avoid further therapeutic investments in a low-value patient when the prognosis is perceived to be poor or to early initiate treatment in valuable animals [7].

Echocardiography is a good ancillary tool to assess the heart in other ruminant species. It has been used extensively in cattle and can be used as a prognostic tool in some diseases since the extension and importance of the disease are better assessed [9-12]. The procedure is a non-invasive, straightforward method for assessment of the bovine heart [13]. It has been used extensively in cattle and can be used as a prognostic tool in some diseases since the extension and importance of the disease are better assessed [10, 14]. The procedure is a widely used imaging tool in small animals, horses, and cattle for evaluation of morphologic changes, abnormal wall thickness, chamber size and valvular appearance and
function [15, 16]. This section of this article reviews normal cardiac chamber appearance and quantitative dimensions in adult camels.

**Echocardiographic protocol**

The forelimb of the camel should be firstly bent and tied with a rope on the carpal joint. The head is then held and the animal is pushed until it is positioned in sternal recumbency. The fore-and-hind limbs are then tied by a rope near the carpal and hock joints, respectively. All echocardiographic examinations are best performed in the recumbent animal. Camels, if nervous, maybe lightly sedated using xylazine (0.02mg/kg IV). Echocardiographic examinations are performed using an ultrasound machine with a 3.5 MHz sector transducer [17].

In preparation for the echocardiography, the intercostal spaces (3rd to 6th) on both sides of the thorax are clipped, shaved and swabbed with alcohol to remove excess oil, and coupling gel is applied. The third, fourth and fifth intercostal spaces in the cardiac region are then examined ultrasonographically on the right and then the left sides of the thorax. The thoracic limbs are moved cranially to facilitate better contact between the probe and the intercostal space. In the cardiac area, the heart, valves, and major blood vessels are imaged. Four two-dimensional (2-D) parasternal images are obtained from the right and three 2-D parasternal images from the left. Additionally, M-mode images are obtained from the right and left sides of the thorax. Two-dimensional images from both the right and left hemithorax are used to guide the placement of the probe and obtain accurate M-mode recordings (Figure 1).

Coupling gel is applied to the transducer, and this is applied to the skin approximately in the 3rd and 4th and 5th right and left intercostal spaces. On the right side, the images are obtained in the following order: a caudal long-axis view of the right and left ventricles, a caudal long-axis view of the left ventricular outflow tract (LVOT), a caudal short-axis view of the ventricles and a cranial long-axis view of the right ventricular outflow tract (RVOT). On the left side, a caudal long-axis view of the heart (four-chamber view), a caudal long-axis view of the LVOT and a cranial long axis-view of the RVOT are obtained. The intercostal space and probe orientation used to obtain each image are recorded at the end of each examination. Echocardiographic measurements are performed using the electronic ultrasound calipers [17].

Three non-consecutive cardiac cycles are measured and later measurements are averaged in order to eliminate some of the measurement errors. Eighteen measurements are recorded from the 2-D images. Right ventricular diameter in systole (RVs) and diastole (RVd), right atrial diameter in systole (RA) and diastole (RAd), right ventricular wall thickness in systole (RVWs) and diastole (RVWd), interventricular septal thickness in systole (IVSs) and diastole (IVSd) and tricuspid valve diameter in systole (TVDs) are measured from the right parasternal caudal long-axis four-chamber view with the probe placed in the 5th intercostal space (ICS) with a slight clockwise rotation or perpendicular in the 6th ICS. Left ventricular diameter in systole (LVs) diastole (LVd), left atrium diameter in systole (LAs) and diastole (LAd), left ventricular wall thickness in systole (LVWs) and diastole (LVWd) and mitral valve diameter in systole (MVDs) are measured from the left parasternal view with the transducer positioned in the 5th or 6th ICS and directed slightly caudodorsally. Aortic diameter in diastole (AoD) is measured from the left parasternal view with the transducer placed in the 4th ICS turned slightly more cranially and rotated slightly counterclockwise. Pulmonary artery diameter in diastole (PAd) is measured from the left parasternal view with the transducer placed obliquely in the 3rd ICS. Systolic measurements are measured during the closure of the atrioventricular valves and opening of the semilunar valves, whilst diastolic measurements were measured during the opening of the atrioutricular valves and closure of the semilunar valves. Ventricular measurements are measured at the level of the papillary muscles close to the chordae tendinae, whilst atrial measurements were measured at the widest part of the atria [17].

**Right parasternal ultrasonograms**

When the probe is placed longitudinally in the 5th intercostal space with a slight clockwise rotation or perpendicular in the 6th ICS, the caudal long-axis four-chamber view of the ventricles, atria, and the interventricular septum is imaged (Figure 2). In this position, the right and left ventricles, tricuspid valve and right and left atria are visible [17]. Placing the probe slightly more cranially in the 4th ICS with the transducer rotated cranially, the caudal long-axis view of the LVOT (the left ventricle, left atria, aortic
valve, and the aortic root) can be imaged (Figure 3). From this position, the right and left ventricles and interventricular septum (IVS), the right and atria and the tricuspid valve are visible [17]. A hybrid view between a “four-chamber” and “LVOT view” could be imaged from the same position (Figure 4). A slight clockwise rotation in the 4th ICS, the short-axis view of the cardiac ventricles is obtained (Figure 5). The right ventricle, interventricular septum, and left ventricle are visible [17]. Placement of the transducer in the 3rd ICS allowed the visualisation of the RVOT in which the right ventricle, the pulmonary valve, pulmonary artery, aorta, and aortic valve are imaged [17] (Figure 6).

**Left parasternal ultrasonograms**

When the probe is placed longitudinally in the 5th or 4th ICS and directed slightly caudodorsally, a view of the ventricles, atria, and the atrioventricular valves is obtained (Figure 7). In this position, the right and left ventricles, the mitral and tricuspid valves, and the interventricular septum are visible [17]. The LVOT is imaged in the 4th ICS and the probe is turned slightly more cranially and rotated slightly counter clockwise (Figure 8). In this position the right ventricle, tricuspid valve, and the right atrium are imaged. The ossa chordis is also visible in the same position as a sub-aortic hyperechoic thin shadowing area [17]. The RVOT is seen from the 3rd intercostal space (Figure 9). In this position, the right ventricle, tricuspid valve, right atrium, and pulmonary artery are visible. An oblique section of the aorta is also visible. The minimum, maximum, mean values, standard deviations and coefficient of variation for the measured variables are summarized in Table 1 [17].

**Ultrasonography of the lungs**

In camels, pulmonary diseases are common. The most important include atelectasis, bronchiectasis, pneumoconiosis, pneumonia, hydatidosis, pleuritis, emphysema, pneumothorax, hydrothorax, haemothorax, empyema and pulmonary tumors [4, 7, 8, 18]. In a study carried out on the lungs of 387 slaughtered camels, one or more gross lesions were encountered on 300 lungs (77.5%). The gross and histopathological examination of these lesions had revealed 60.2% emphysema, 21.2% hydatidosis, 18.6% pneumonia, 10.6% atelectasis, 4.9% aspiration of blood, 3.9% pneumoconiosis, 2.6% pulmonary oedema and congestion, 1.6% abscess, 1% pleurisy, and 0.8% granulomatous pneumonia [19]. Thus a clinical examination of the lungs and pleura is important in camels. Methods for examining the lungs and pleura are invasive and noninvasive. Noninvasive methods include auscultation of the lungs before and after interruption of breathing by manual occlusion of mouth and nostrils, the percussion of the thoracic wall, lung function tests, radiography, ultrasonography, and endoscopy. Pulmonary biopsy and thoracocentesis are examples of invasive methods [4, 7, 20].

In human medicine, ultrasonography of the lungs is one of the important tools in the management of critical patients and urgent cases, not only for the detection of pleural effusion but also for the identification of pneumothorax, alveolar consolidation, and interstitial syndromes [21]. In cattle, ultrasonography of the lungs and pleura is particularly useful for the detection and characterization of pleural effusion, especially small amounts, the detection of superficial pulmonary lesions or consolidation, pulmonary atelectasis, and pneumothorax [20, 22-27]. This section of this article reviews ultrasonography of the lungs and pleura and its dimensions in healthy camels. Informative ultrasonography of the lungs and pleura in the camel should provide reliable data about the condition of the pleura, the pulmonary surface and the dimensions of the lungs.

**Technique of pulmonary ultrasonography**

Firstly, the camel should be maintained as for echocardiography. Both sides of the thorax are clipped and the skin shaved. Ultrasonographic examination is carried out using a 3.5 MHz sector transducer. After the application of transmission gel to the transducer, the lungs are examined transcutaneously on the right and then the left sides beginning at the 11th through the 4th intercostal space (ICS). Each ICS is examined dorsal to ventral with the transducer held parallel to the ribs. Visualization of the pleura and lungs is assessed. The pleural space is then examined for possible fluid accumulation, and attempts are made to differentiate between the parietal (costal) and visceral (pulmonary) pleura. To estimate the position and dorsoventral dimension of the lungs, the dorsal and ventral lung borders are assessed. The position of the dorsal and ventral lung margins are measured in relation to the dorsal midline. Measurements are made in each ICS; they included determinations of the dorsal and ventral lung borders and the
The different layers of the thoracic wall appear as narrow bands of variable echogenicity. Medial to the thoracic wall was an echogenic line that represents the costal and pulmonary pleurae. Lung borders can be easily differentiated from the parietal pleura during inspiration/expiration in real time. Reverberation artefacts appear as lines of variable echogenicity that run parallel to the pulmonary surface medial to the pleura (Figure 10). They result from reflection of the ultrasound waves by air in the lungs. The reverberation artefacts become progressively weaker as distance from the body surface increased; they were no longer seen at depth of 7 to 8 cm. The pulmonary parenchyma cannot be visualized because of its air content [28]. On the right side, back musculature, thoracic wall with pleura and pulmonary surface and parts of the liver and the omasum are seen (Figure 11). The pulmonary surface and the pleurae are imaged with approximately the same frequencies on the right side. There is a difference in the 11th ICS where only the pulmonary surface and the pleurae are imaged in 15 of the 22 camels. This difference is caused by cranial displacement of the lung by the rumen. The measurements for the dorsal and the ventral lung borders and the resulting dorsoventral dimensions of the lungs are similar to those on the right side (Table 2) [28].

Practical application of cardiopulmonary ultrasonography in camel medicine

White muscle disease (Vitamin E/Selenium deficiency)

White muscle disease or nutritional muscular dystrophy (NMD) is most common in fast growing young animals and is associated with an inadequate intake or utilization of vitamin E or selenium (Se), or both. The disease occurs in all farm animal species, especially in rapidly growing neonates. The disease is characterized by subacute skeletal muscle degeneration and acute cardiac muscle degeneration. Deficiencies of Se and vitamin E induce lipoperoxidation in the tissues, which results in hyaline degeneration with calcification and severe necrosis in myocardial and skeletal muscle [29]. Many cases have been reported in camels in their natural habitat [30, 31]. Camel selenium supplementation is often necessary and different methods are used: injection, drenching and trace minerals salt mixture. But, selenium requirements in this species are extrapolated from those of other ruminants [32, 33]. The biological role of selenium in the dromedary is identical to that of the other ruminants, but the metabolism seems differ [34]. Due to lack of references, the present synthesis aimed to give more details on the serum selenium values based on four experiments focused on selenium intake [35], excretion [36] and tolerance [36, 37] achieved for a better understanding of the selenium metabolism in this species. Ultrasonographic examination of the heart reveals tachycardia and an elevated myocardium echogenicity (Figure 13).

Chronic pneumonia

Inflammation of the lung is common among camels of various ages. It may involve the bronchi and lung parenchyma, which is called bronchopneumonia. If the inflammation involves the interstitial tissues of the lung it is called interstitial pneumonia. Pneumonia is a frequent diagnosis at a gross necropsy because the normal lung tends to be...
slightly edematous and hyperemic. That pneumonia occurs there is no doubt, but a thorough examination and evaluation are necessary to exclude diseases of other organ systems. Pulmonary edema is a common terminal lesion seen in animals dying from numerous diseases. The causal bacterial agents of camelpid pneumonia are similar to those causing pneumonia in livestock and horses. Most infectious cases result from opportunistic bacteria. Septicemic animals usually develop pneumonia, and the most common agent isolated in the author’s practice has been *Escherichia coli*. Other causes of pneumonia include inhalation of toxic vapors. Signs are exaggerated in the neonate and include dyspnea, coughing, elevated body temperature, variable nasal exudation, depression, and anorexia. Sounds heard at auscultation vary with the degree of exudation and consolidation [18, 38]. Broad-spectrum antibiotic therapy is recommended until sensitivity results are available, because Gram-negative organisms are frequently involved. General nursing care and supportive treatment are indicated [4, 7]. In a calf, the left lung contained a capsulated 7.6×6.8 cm lesion that contained anechoic fluid. Acoustic enhancement was imaged below the lesion (Figure 14). Aspiration of the lesion revealed a purulent material confirming abscess formation [18].

The camel calves with lung consolidation are presented because of decreased appetite, weakness, dyspnea, and dry cough. Dry rales is heard over the right lung at the cranioventral lung lobes. An increased vesicular sound is heard over the left lung. Thoracic ultrasonography shows consolidation of the right apical lung lobes with sub-pleural anechoic fluids [18]. Ultrasonography of the left lung detected numerous comet-tail artifacts in the form of bright, closely situated echo bands starting at the lung surface and running perpendicular to the pleura in the lung tissue are observed upon ultrasonography, a picture of pulmonary emphysema (Figure 15). Thoracic ultrasonography may also shows consolidation of the right and left apical lung lobes (Figure 16). Thoracic ultrasonography in camel calves with drenching pneumonia shows a bilaterally consolidated apical lung lobes with sub-pleural hyperechoic fluid (Figure 17).

**Pleuropneumonia**

Inflammation of the pleura is known as pleuritis or pleurisy. It is usually associated with inflammation of the lung, the condition is called pleuropneumonia [4]. Pleural effusion is usually secondary to pleuritis, pericarditis, or right heart insufficiency. Inspiratory dyspnea is the most prominent sign. The absence of sounds in the lower thorax and a dull sound on percussion in the same area are diagnostic. A definitive diagnosis is based on radiography and thoracocentesis. The nature of the pleural fluid must be determined, because it may be a modified transudate or exudate. Therapy is determined by the etiology. Excess fluid may be removed via thoracocentesis, but the critical factor is to prevent recurrence. The prognosis for a neoplasm is grave. Infectious pleuritis should be treated with broad-spectrum antibiotics until results of culture and sensitivity tests are known [7]. The camel calves with pleuropneumonia were presented because of anorexia, difficult respiration and progressive weight loss. The vesicular lung sounds were hardly audible. Thoracic ultrasonography revealed anechoic fluid with fibrin net of the and right and left pleurae with consolidation of the antero-ventral lung lobes. Approximately 500 mL of slightly reddish fluid was aspirated (Figure 18).

![Figure 1. B-M mode images obtained from both the right (a) and left (b) hemithorax. Ds, dorsal; Vt, ventral; IVS, interventricular septum; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve.](image-url)
Figure 2. Right parasternal caudal long-axis view of the left and right ventricles (four-chamber view). The chordae tendinae of the tricuspid valve are also seen as echoic lines (arrow). Ds, dorsal; Vt, ventral; IVS, interventricular septum; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve; CT, chordae tendinae.

Figure 3. Right parasternal caudal long-axis view of the left ventricular outflow tract showing both ventricles and interventricular septum together with the aorta and the aortic valve. Ds, dorsal; Vt, ventral; Ao, aorta; Av, aortic valve; IVS, interventricular septum; LA, left atrium; LV, left ventricle; RV, right ventricle.

Figure 4. Right parasternal caudal long-axis view showing the four-chamber view together with the left ventricular outflow tract view. The chordae tendinae of the mitral valve are also seen as echoic lines Ds, dorsal; Vt, ventral; Ao, aorta; Av, aortic valve; IVS, interventricular septum; LA, left atrium; LV, left ventricle; RV, right ventricle; TV, tricuspid valve; CT, chordae tendinae; PM, papillary muscles.

Figure 5. Right short-axis view of the cardiac ventricles. Both ventricles are seen in a transverse section. Ds, dorsal; Vt, ventral; RVW, right ventricular wall; RV, right ventricle; IVS, interventricular septum; LV, left ventricle.

Figure 6. Right parasternal cranial long-axis view of the right ventricular outflow tract on the third intercostal space. Ds, dorsal; Vt, ventral; RV, right ventricle; PA, pulmonary artery; PV, pulmonary valve; Ao, aorta; AV, aortic valve.

Figure 7. Left parasternal caudal long-axis view of the heart. In this view, the four cardiac chambers are observed as well as the atrioventricular valves. Ds, dorsal; Vt, ventral; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve; IVS, interventricular septum.
Figure 8. Left parasternal caudal long-axis view of the left ventricular outflow tract. The left ventricle and aorta are observed. The transversa view of the aortic valve is recognized as a thin echoic line. Ds, dorsal; Vt, ventral; RV, right ventricle; LV, left ventricle; RA, right atrium; IVS, interventricular septum, Ao, aorta; AV, aortic valve; Oc, ossa chordis.

Figure 9. Left parasternal cranial long-axis view of the right ventricular outflow tract. The left ventricle and aorta are observed. The transversa view of the aortic valve is recognized as a thin echoic line. Ds, dorsal; Vt, ventral; RV, right ventricle; RA, right atrium; TV, tricuspid valve; Ao, aorta; PA, pulmonary artery; PV, pulmonary valve.

Figure 10. Ultrasonogram of the normal camel lung obtained from the 8th intercostal space on the right side. 1 = Thoracic wall; 2 = Pleura; 3 = Reverberation artifacts; DS = Dorsal; VT = Ventral.

Figure 11. Ultrasonogram of the normal camel lung, liver and omasum obtained perpendicular from the middle 6th intercostal space on the right side. 1 = Thoracic wall; 2 = Pleura; 3 = Reverberation artifacts; 4 = liver; 5 = omasum; DS = Dorsal; VT = Ventral.

Figure 12. Ultrasonogram of the normal camel lung and rumen obtained from the upper 10th intercostal space on the left side and slightly rotated caudally. 1 = Thoracic wall; 2 = Pleura; 3 = Pulmonary parenchyma; 4 = rumen; DS = Dorsal; VT = Ventral.

Figure 13. Echocardiography of a camel calf with vitamin E/selenium deficiency during systole (left) and diastole (right). RV, right ventricular diameter; LV, left ventricular diameter; RA right atrium diameter; LA, left atrium diameter; IVS, interventricular septum; TV, tricuspid valve; MV, mitral valve.
Figure 14. Ultrasonographic findings in a camel calf with chronic pneumonia. Left image shows consolidated right apical lobes with sub-pleural anechoic fluid (F). Right image shows a capsulated 7.6×6.8 cm abscess.

Figure 15. A camel calf with chronic pneumonia and compensatory emphysema. Ultrasonographic findings included consolidation of the right apical lung lobes with sub-pleural anechoic fluids (F) (left image). Right image shows numerous comet-tail artifacts in the form of bright, closely situated echo bands starting at the lung surface and running perpendicular to the pleura in the lung tissue were observed upon ultrasonography, a picture of pulmonary emphysema.

Figure 16. A camel calf with chronic pneumonia. Right image shows consolidation of the right lung apical lobes.

Figure 17. A camel calf with severe drenching pneumonia showing an orange vomitus. Right image shows thoracic ultrasonography in the same where a bilaterally consolidated apical lung lobes with sub-pleural hyperechoic fluid was imaged.

Figure 18. A female camel with pleuropneumonia. Thoracic imaging (right) shows anechoic fluid with fibrin net within the pleura.

Table 1. Internal echocardiographic measurements in healthy adult camels (n=22).

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<th>Variable</th>
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<th>Max</th>
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<th>SD</th>
<th>CV</th>
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N, number of the camels; Min, minimum value; Max, maximum value; SD, standard deviation; CV, coefficient of variation; RV, right ventricular diameter; LV, left ventricular diameter; RA, right atrium diameter; LA, left atrium diameter; RVW, right ventricular wall thickness; IVS, interventricular septal thickness; LVW, left ventricular wall thickness; AO, aortic diameter; PA, pulmonary artery diameter; TVD, tricuspid valve diameter; MVD, mitral valve diameter; d, diastole; s, systole.
Table 2. Dimensions (means ± SD) of the right and left lungs obtained at the 4th through the 11th intercostal spaces in healthy camels (n=22) as estimated by ultrasound.

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<th>9th</th>
<th>8th</th>
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<th>6th</th>
<th>5th</th>
<th>4th</th>
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<td>Dorsal margin*</td>
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<td>33±2</td>
<td>29±2</td>
<td>29±2</td>
<td>53±6</td>
<td>55±4</td>
<td>62±5</td>
<td>62±2</td>
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<td>64±3</td>
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<td>75±6</td>
<td>76±6</td>
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<td>13±3a</td>
<td>22±4b</td>
<td>31±2b</td>
<td>11±4a</td>
<td>14±4a</td>
<td>13±7a</td>
<td>14±7a</td>
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<td><strong>Left lung</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>Dorsal margin*</td>
<td>35±4</td>
<td>34±2</td>
<td>28±2</td>
<td>28±2</td>
<td>51±5</td>
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<tr>
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<td>20±6b</td>
<td>29±4b</td>
<td>12±3a</td>
<td>13±2a</td>
<td>12±5a</td>
<td>12±5a</td>
</tr>
</tbody>
</table>

*Centimetres ventral to the dorsal midline.

In conclusion, echocardiography and scanning of the lungs and pleura is a useful supplement to the existing methods of examination of the thorax of camels can be easily translated in the field. The study provides information about the normal cardiac chamber appearance and quantitative dimensions in adult camels. Besides, ultrasonography provides information about the condition of the pleura and lungs and could be used as a reference for further studies concerning camels with respiratory diseases.

**Funding**
No funding

**Conflict of interest**
No conflict of interest

**References**


