Radiographic appearance of the thorax of clinically normal alpaca crias

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Objective—To quantitatively and qualitatively assess the radiographic appearance of the thorax of clinically normal alpaca crias.

Animals—21 clinically normal alpaca crias.

Procedures—Left-right lateral (LR), right-left lateral (RL), dorsoventral (DV), and ventrodorsal (VD) projections of the thorax were acquired. To account for differences in cria size, measurements of thoracic structures were compared with other anatomic landmarks.

Results—Mean ± SD vertebral heart scale was 9.36 ± 0.65 for LR projections, 9.36 ± 0.59 for RL projections, 8.21 ± 0.51 for DV projections, and 8.65 ± 0.57 for VD projections. Dimensions of the heart were compared with the length of the T3 through T5 vertebral bodies, third to fifth rib distance, and thoracic height and width, which provided additional methods of cardiac evaluation. For RL projections, mean ratio of the right cranial pulmonary artery diameter to the third rib width was 0.41 ± 0.10 and mean ratio of the right cranial pulmonary vein to the third rib width was 0.44 ± 0.10. Caudal lobar pulmonary vessels and the caudal vena cava were difficult to quantitatively assess on DV or VD projections. On lateral projections, the trachea was increased in diameter at the origin of the right cranial lobar bronchus. No qualitative differences were found between LR and RL radiographs. The lungs were generally better inflated on VD projections, with more separation of the heart and diaphragm.

Conclusions and Clinical Relevance—Establishment of radiographic values for alpaca crias should prove useful in assessment of thoracic disease in this species. (*Am J Vet Res* 2011;72:1439–1448)

Thoracic radiography is often one of the first diagnostic tests performed when pulmonary or cardiac disease is suspected in alpaca crias. Thoracic diseases are relatively common in camelid crias and include pneumonia, congenital heart malformations, and pathological changes related to trauma.[1,2] Correct interpretation of test results requires a thorough understanding of anatomy and variations in morphology or organ visibility unique to this species and age of patient. Although the thoracic radiographic appearance of many clinically normal animals, including adult llamas, has been described, little information is available for alpaca crias. The purpose of the study reported here was to quantitatively and qualitatively assess the radiographic appearance of the thorax of clinically normal alpaca crias.

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Abbreviations

CVC	Caudal vena cava
DV	Dorsoventral
LR	Left-right lateral
RL	Right-left lateral
VD	Ventrodorsal

Materials and Methods

Animals—Thoracic radiography was performed at The Ohio State University College of Veterinary Medicine on 21 alpaca crias (13 females and 8 males); crias were part of a herd maintained by the College of Veterinary Medicine. Crias were considered healthy on the basis of results of pulmonary and cardiac auscultation. The study was approved by The Ohio State University Institutional Animal Care and Use Committee.

Procedures—Radiographs (DV, VD, LR, and RL projections) were obtained in a small animal radiographic suite by use of a 400-speed rare earth screen-film combination,[a,b] a focal-film distance of 101.6 cm, and a movable 12:1 grid. Calipers were used to determine the maximum DV height and lateral width of the thorax of each cria. A standard technique chart for dogs (high peak kilovoltage and low milliampere-second) was used. Crias were not sedated, and minimal manual restraint was applied. Radiographs were obtained during maximal inspiration. There was not a consistent order for acqusition of radiographic projections for all crias.

Radiographs were evaluated separately by the investigators to obtain direct measurements of thoracic structures. Exact locations for thoracic measurements on LR, RL, DV, and VD projections were described (**Figures 1 and 2**). Radiographs were also evaluated collectively by the investigators to compare the general thoracic appearance of DV with VD projections and LR with RL projections and to determine whether there was a subjective difference in radiographic appearance for younger versus older crias.

The long and short axes of the heart were measured on lateral projections and the VD and DV projections. On lateral projections, the cardiac long axis was the distance between the apex of the heart and the ventral border of the origin of the mainstem bronchi. The cardiac short axis was the length of a line perpendicular to the cardiac long axis; that line originated at the junction of the caudal border of the heart and ventral margin of the CVC and extended to the cranial margin of the heart. On DV and VD radiographs, the long axis was the distance from the cranial edge of the heart to the cardiac apex on a plane parallel to the thoracic vertebrae. The short axis was measured along the widest portion of the heart on a line perpendicular to the cardiac long axis.

Additional cardiac measurements were recorded. On lateral projections, cardiophrenic contact was the distance from the apex of the heart to the dorsal intersection of the heart with the diaphragmatic margin. On DV and VD radiographs, cardiophrenic contact was the distance between the left and right points of intersection of the heart and diaphragm. To account for differences in size among crias, these distances were divided by the cardiac long axis on lateral projections and by the cardiac short axis on DV and VD projections. Cardiosternal contact was estimated as the number of sternebrae contacted by the heart, with values recorded to the nearest half-sternebra. Similarly, the number of intercostal spaces spanned by the heart was estimated on lateral projections, with values recorded to the nearest half-intercostal space.

On lateral projections, thoracic height was measured along a line that extended from the apex of the heart, passed through the ventral margin of the origin of the mainstem bronchus, and ended on a defined ventral margin of T3 through T5. Because the ventral margins of the thoracic vertebrae were concave, the distance varied by a few millimeters, depending on the point at which the line intersected the vertebrae. Therefore, a defined end point was necessary for this measurement. As defined elsewhere,[3] the ventral margin of T3 through T5 was determined by drawing a line that connected the ventral aspect of these vertebrae; measurement of thoracic height was determined via the intersection with this line. On DV and VD projections, thoracic width was determined by drawing a line perpendicular to the vertebrae that extended between the medial aspect of the right and left thoracic walls at the widest part of the heart.

On lateral projections, the length of T3 through T5 was measured from the midpoint of the cranial end plate of T3 to the caudal edge of the end plate of T5. The midpoint of the end plate of T3 was chosen because slight curvatures in the ventral margins of the vertebrae would have caused variation in measurements obtained at these sites. On LR and RL projections, the height of T4 was measured along a line that extended between the

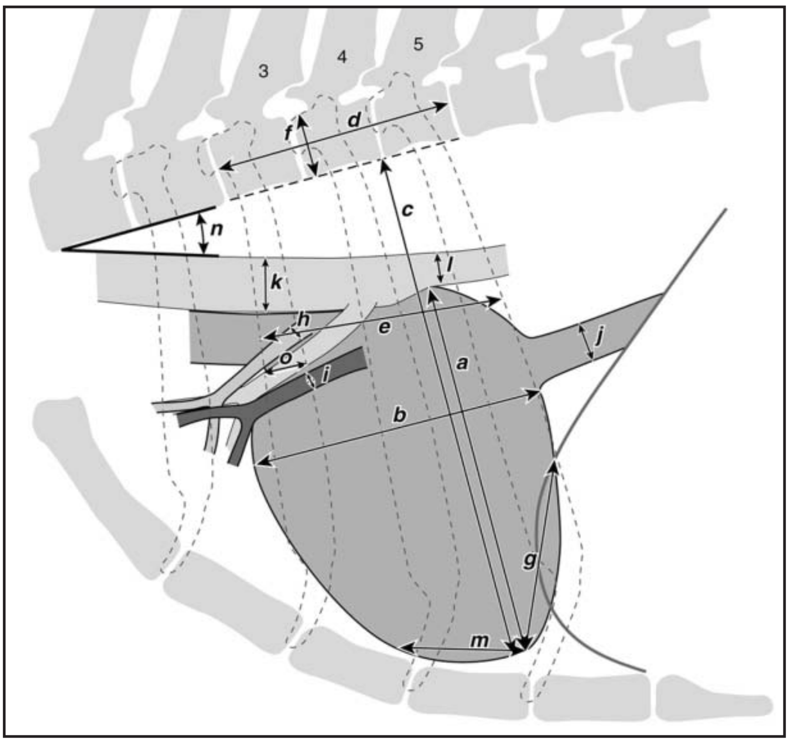

Figure 1—Diagram illustrating measurement of variables on a lateral radiographic projection of the thorax of an alpaca cria. a = Cardiac long axis, which is the distance from the apex of the heart to the ventral border of the origin of the mainstem bronchi. b = Cardiac short axis, which is the length of a line perpendicular to the cardiac long axis that originates at the junction of the caudal border of the heart and ventral margin of the CVC and extends to the cranial margin of the heart. c = Thoracic height measured from the cardiac apex to a line along the ventral margin of the thoracic vertebrae (dotted line). d = Length of T3 through T5 determined from the cranial end plate of the vertebral body of T3 to the caudal end plate of the vertebral body of T5. e = Distance between the third and fifth ribs measured from the cranial aspect of the third rib to the caudal aspect of the fifth rib at the level of the intersection with the cranial pulmonary artery. f = Height of the vertebral body of T4 measured perpendicular to a line along the ventral aspect of the vertebra. g = Cardiophrenic contact measured from the cardiac apex to the dorsal point of intersection of the heart and diaphragm. h = Diameter of the cranial pulmonary artery measured perpendicular to the long axis of the vessel at the level of the third rib. i = Diameter of the cranial pulmonary vein measured perpendicular to the long axis of the vessel at the level of the third rib. j = Diameter of the CVC measured perpendicular to the vessel at a point halfway between the heart and diaphragm. k = Tracheal height measured at the level of the third rib. l = Mainstem bronchus height measured just caudal to the carina at the level of the origin of the caudal mainstem bronchi. m = Cardiosternal contact measured from the cardiac apex to the point where the cranioventral cardiac margin diverges from the sternum. n = Tracheal angle, which is the angle between a line drawn along the ventral aspect of the cranial portion of the thoracic vertebral column and the dorsal margin of the trachea. o = Width of the third rib measured at its widest point at the intersection with the cranial pulmonary artery. 3, 4, and 5 = T3, T4, and T5, respectively.

craniventral and craniodorsal borders of the vertebral body. The distance between the third and fifth ribs was

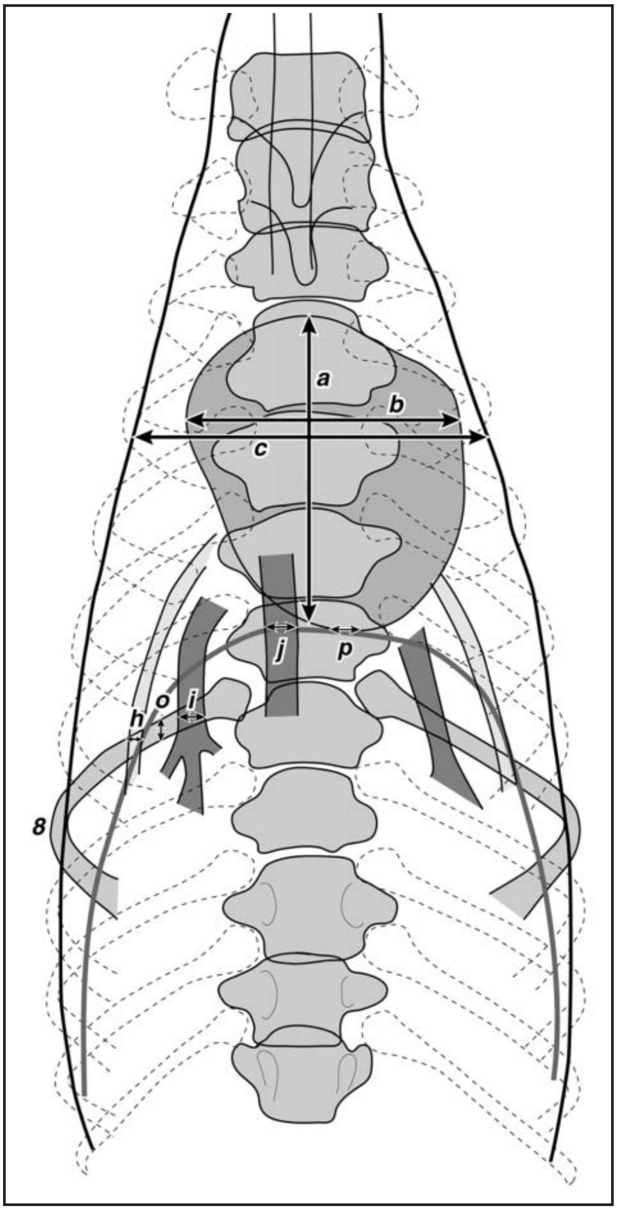

Figure 2—Diagram illustrating measurement of variables on DV and VD radiographic projections of the thorax of an alpaca cria. a = Cardiac long axis, which is measured as the distance from the cranial edge of the heart to the cardiac apex on a plane parallel to the thoracic vertebrae. b = Cardiac short axis measured along the widest portion of the heart on a line perpendicular to the long axis of the heart. c = Thoracic width measured at the level of the cardiac short axis from the most medial portions of the right and left thoracic walls. h = Width of the right caudal pulmonary artery measured perpendicular to the long axis of the vessel at the point of intersection with the right eighth rib and compared with the width of that rib; diameter of the left caudal pulmonary artery was measured in a similar manner and compared with the width of the left eighth rib. i = Width of the right caudal pulmonary vein measured perpendicular to the long axis of the vessel at the point of intersection with the right eighth rib and compared with the width of that rib; diameter of the left caudal pulmonary vein was measured in a similar manner and compared with the width of the left eighth rib. j = Diameter of the CVC measured perpendicular to the long axis of the vessel at its intersection with the diaphragmatic margin. p = Cardiophrenic contact measured between the left and right points of contact of the heart and diaphragm. 8 = The right eighth rib.

measured from the cranial aspect of the third rib to the caudal aspect of the fifth rib at the level of the intersection of the right cranial pulmonary artery with the third rib. When discrimination between right and left ribs could be made, the distance between the ribs on the right side was measured on LR projections and the distance between the ribs on the left side was measured on RL projections.

Measurements of cardiac long axis and short axis were used to calculate a vertebral heart scale. To calculate the vertebral heart scale on LR and RL projections, lengths of the long and short axis were measured in units of vertebral length; the measurement started at the cranial margin of the vertebral body of T4 and was estimated to the nearest 0.1 vertebra.[4] Values for the long and short axes were added to obtain a total score for each projection. The vertebral heart scale for DV and VD projections was determined similarly, with the long and short axes of the heart compared with those of the vertebrae; for the DV and VD projections, the measurement for the vertebral body of T4 was obtained from the LR projection.

To account for differences in size of the crias, the long and short axes of the heart were used as a ratio for other thoracic structures. On lateral projections, ratios of cardiac long and short axes were calculated by use of the length of T3 through T5, distance between the third and fifth ribs, and height of the thorax. On DV and VD projections, ratios of cardiac long and short axes were calculated by use of the length of T3 through T5 on the LR projection and with the width of the thorax measured on the corresponding DV or VD projection.

On LR and RL projections, the widths of the cranial pulmonary arteries and veins were measured perpendicular to the long axis of the vessels at the level of their intersection with the third rib. If the artery and vein bifurcated caudal to their intersection with the third rib, the widths of the artery and vein were measured immediately caudal to this bifurcation. The widths of the pulmonary artery and vein were then calculated as ratios to the width of the third rib at the level of the pulmonary artery. On DV and VD projections, the widths of the right and left caudal pulmonary artery and vein were measured perpendicular to their long axes at their intersection with the eighth rib. These widths were then calculated as ratios to the width of the eighth rib at the level of the pulmonary artery.

On lateral projections, height of the CVC was measured perpendicular to the long axis of the CVC at the midpoint between the cardiac and diaphragmatic silhouettes. The angle of the long axis of the CVC was recorded as parallel, divergent (caudal aspect of the CVC was closer to the vertebrae than was the cranial aspect), or convergent (caudal aspect of the CVC was farther from the vertebrae than was the cranial aspect) to the long axis of the midthoracic vertebrae. Finally, margination of the dorsal and ventral borders of the CVC was recorded as a subjective assessment (poor or good) for each cria. For lateral projections, ratio of the height of the CVC to the height of the vertebral body of T4 was determined. On DV and VD projections, the CVC margins were often not identified because of summation with other structures in the caudal portion of the thoracic cavity, but when possible, the width of the CVC was measured perpendicular to the long axis of the CVC at the intersection of the CVC with the diaphragmatic margin.

The angle of divergence of the trachea from the thoracic vertebrae was measured as the angle between the dorsal margin of the trachea at the thoracic inlet and the ventral margins of T3 through T5. Tracheal height and mainstem bronchus height on lateral projections were recorded. Tracheal height was measured (perpendicular to the tracheal wall) as the width of the lumen at the level of the third rib. Mainstem bronchus height was measured at the origin of the mainstem bronchus. Ratios of tracheal height to height of the vertebral body of T4 and tracheal height to mainstem bronchus height were determined.

Other miscellaneous thoracic variables were also recorded. On lateral projections, the position of the lumbodiaphragmatic recess was assessed relative to the adjacent vertebral body or intervertebral disk space. On DV and VD projections, the width of the mediastinum was assessed as wider or narrower than the width of the cranial portion of the thoracic vertebrae.

Statistical analysis—Statistical analyses were conducted by use of commercially available software.[c] For all measurements and ratios, mean and SD were calculated. Normality of the distribution of data was determined via a Kolmogorov-Smirnov test. Paired *t* tests were performed for cardiac and respiratory variables and selected vascular structures for LR versus RL projections and DV versus VD projections. When data were not normally distributed, a Wilcoxon signed rank test was performed. Crias were also classified into 2 age groups (< 60 days old and > 60 days old). For each projection, unpaired *t* tests were performed on mean cardiac, respiratory, and vascular variables between these 2 age groups. When data were not normally distributed, a Mann-Whitney *U* test was performed. Differences were considered significant at $P < 0.05$.

Results

Animals—Crias weighed between 8.1 and 25.5 kg (mean weight, 14.7 kg) and were between 2 and 238 days of age (mean age, 56 days). Fourteen crias were < 60 days old, and 7 crias were > 60 days old.

Cardiac variables—Mean measurements and ratios of all cardiac, vascular, and respiratory structures of interest were calculated for each projection **(Tables 1 and 2)**. The subjective appearance of the heart did not vary appreciably between LR and RL projections **(Figure 3)**. On both

Table 1—Mean ± SD and range values for cardiac, vascular, and respiratory variables measured on lateral radiographic projections obtained from 21 clinically normal alpaca crias.

Variable		Mean ± SD	Range
LR	Vertebral heart scale	9.36 ± 0.65	8.40–10.40
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	3.12 ± 0.22	2.71–3.52
	Ratio of cardiac long axis to length of T3 through T5	1.81 ± 0.16	1.54–2.14
	Ratio of cardiac short axis to length of T3 through T5	1.31 ± 0.11	1.07–1.57
	Ratio of cardiac long axis + cardiac short axis to thoracic height	1.31 ± 0.09	1.19–1.60
	Ratio of cardiac long axis to thoracic height	0.76 ± 0.04	0.65–0.84
	Ratio of cardiac short axis to thoracic height	0.55 ± 0.06	0.48–0.79
	Ratio of cardiac long axis + cardiac short axis to distance from the third to fifth ribs	3.42 ± 0.23	3.03–3.88
	Ratio of cardiac long axis to distance from the third to fifth ribs	1.99 ± 0.17	1.71–2.32
	Ratio of cardiac short axis to distance from the third to fifth ribs	1.43 ± 0.11	1.22–1.66
	Ratio of cardiophrenic contact to cardiac long axis	0.39 ± 0.10	0.20–0.53
	Cardiosternal contact (No. of sternebrae)	2.85 ± 0.30	2.50–3.50
	Intercostal spaces spanned by the heart	2.74 ± 0.30	2.00–3.00
	Ratio of left cranial pulmonary artery to width of the third rib	0.44 ± 0.13	0.24–0.65
	Ratio of the left cranial pulmonary vein to width of the third rib	0.46 ± 0.12	0.27–0.67
	Ratio of CVC height to T4 height*	0.84 ± 0.10	0.61–1.07
	Tracheal angle (°)	14.24 ± 3.57	9.00–22.00
	Ratio of trachea height to mainstem bronchi height	1.29 ± 0.22	0.98–1.75
	Ratio of trachea height to T4 height*	0.76 ± 0.09	0.63–0.95
RL	Vertebral heart scale	9.36 ± 0.59	8.60–10.40
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	3.12 ± 0.21	2.83–3.50
	Ratio of cardiac long axis to length of T3 through T5	1.80 ± 0.15	1.53–2.03
	Ratio of cardiac short axis to length of T3 through T5	1.31 ± 0.11	1.16–1.55
	Ratio of cardiac long axis + cardiac short axis to thoracic height	1.30 ± 0.08	1.17–1.59
	Ratio of cardiac long axis to thoracic height	0.72 ± 0.03	0.68–0.81
	Ratio of cardiac short axis to thoracic height	0.55 ± 0.07	0.46–0.78
	Ratio of cardiac long axis + cardiac short axis to distance from the third to fifth ribs	3.44 ± 0.26	2.91–3.89
	Ratio of cardiac long axis to distance from the third to fifth ribs	1.99 ± 0.19	1.68–2.30
	Ratio of cardiac short axis to distance from the third to fifth ribs	1.45 ± 0.11	1.31–1.62
	Ratio of cardiophrenic contact to cardiac long axis	0.38 ± 0.15	0–0.56
	Cardiosternal contact (No. of sternebrae)	2.81 ± 0.33	2.00–3.50
	Intercostal spaces spanned by the heart	2.76 ± 0.34	2.00–3.00
	Ratio of left cranial pulmonary artery to width of the third rib	0.41 ± 0.10	0.23–0.67
	Ratio of the left cranial pulmonary vein to width of the third rib	0.44 ± 0.10	0.23–0.61
	Ratio of CVC height to T4 height*	0.89 ± 0.15	0.55–1.14
	Tracheal angle (°)	13.2 ± 3.47	9.00–23.00
	Ratio of trachea height to mainstem bronchi height	1.29 ± 0.23	0.92–1.73
	Ratio of trachea height to T4 height*	0.80 ± 0.15	0.56–1.14

*Height of the vertebral body of T4.

Table 2—Mean ± SD and range values for cardiac, vascular, and respiratory variables measured on DV and VD radiographic projections obtained from clinically normal alpaca crias.

Variable		No of crias*	Mean ± SD	Range
DV	Vertebral heart scale	21	8.21 ± 0.51[a]	7.10–9.00
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5†	21	2.74 ± 0.19[b]	2.53–3.04
	Ratio of cardiac long axis to length of T3 through T5†	21	1.45 ± 0.10[c]	1.25–1.59
	Ratio of cardiac short axis to length of T3 through T5†	21	1.29 ± 0.11[d]	1.12–1.58
	Ratio of cardiac long axis + cardiac short axis to thoracic width	21	1.71 ± 0.12[e]	1.41–1.92
	Ratio of cardiac long axis to thoracic width	21	0.91 ± 0.07[f]	0.76–1.02
	Ratio of cardiac short axis to thoracic width	21	0.80 ± 0.06[g]	0.66–0.91
	Ratio of cardiophrenic contact to cardiac width	21	0.32 ± 0.18[h]	0–0.66
	Ratio of right caudal pulmonary artery to width of right eighth rib	17	1.27 ± 0.35	0.76–1.47
	Ratio of right caudal pulmonary vein to width of right eighth rib	1	1.15	NA
	Ratio of left caudal pulmonary artery to width of left eighth rib	9	1.33 ± 0.22	0.97–1.57
	Ratio of left caudal pulmonary vein to width of right eighth rib	4	1.14 ± 0.05	1.00–1.12
VD	Vertebral heart scale	21	8.65 ± 0.57[a]	7.70–9.60
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5†	21	2.89 ± 0.20[b]	2.55–3.24
	Ratio of cardiac long axis to length of T3 through T5†	21	1.57 ± 0.13[c]	1.30–1.82
	Ratio of cardiac short axis to length of T3 through T5†	21	1.32 ± 0.10[d]	1.14–1.55
	Ratio of cardiac long axis + cardiac short axis to thoracic width	21	1.89 ± 0.18[e]	1.58–2.19
	Ratio of cardiac long axis to thoracic width	21	1.03 ± 0.16[f]	0.84–1.28
	Ratio of cardiac short axis to thoracic width	21	0.86 ± 0.08[g]	0.71–1.00
	Ratio of cardiophrenic contact to cardiac width	21	0.20 ± 0.17[h]	0–0.51
	Ratio of right caudal pulmonary artery to width of right eighth rib	14	1.59 ± 0.36	0.93–2.40
	Ratio of right caudal pulmonary vein to width of right eighth rib	0	NA	NA
	Ratio of left caudal pulmonary artery to width of left eighth rib	11	1.4 ± 0.30	1.00–1.94
	Ratio of left caudal pulmonary vein to width of left eighth rib	8	1.67 ± 0.31	1.20–2.03

Width of the caudal pulmonary artery and caudal pulmonary vein between DV and VD projections was not statistically evaluated.
*Number of crias in which the cardiac, vascular, or airway structure could be measured. †Length of T3 through T5 measured on lateral projections.
[a–h]Values with paired superscript letters are significantly ($P < 0.05$) different between DV and VD projections.
NA = Not applicable.

lateral projections, the base of the heart was cranial to the apex so that the long axis of the heart was approximately parallel to the ribs and perpendicular to the vertebral column. The left atrium was not identified. No significant difference in the size of the heart (based on the long and short axis ratios and vertebral heart scale) was identified for LR versus RL projections.

The heart of each cria was assessed subjectively as having a rounded or angular shape on DV and VD projections (**Figure 4**). For those hearts considered to have a rounded shape, the cranial edge of the heart gently sloped between the area of the right atrium and pulmonary artery. This gentle rounding was maintained caudally such that the apex was blunted at the point of contact with or near the diaphragm. For those hearts considered to have an angular shape, the cranial edge of the heart appeared flattened, which then widened broadly into the area of the right atrium and pulmonary artery before tapering (with relatively straight margins) to form a distinct, pointed apex near the midline. The heart appeared rounded on 13 DV projections and 9 VD projections and angular on 8 DV projections and 12 VD projections. A rounded or angular shape on the DV projection did not necessarily imply a rounded shape on the VD projection and vice versa. Of 13 crias with a rounded shape on the DV projection, 6 had a rounded shape on the VD projection. Of 8 crias with an angular shape on the DV projection, 5 had an angular shape on the VD projection. On most DV and VD projections, the cardiac apex was on the midline near the point of cardiophrenic contact, although in some crias, the cardiac apex was directed slightly to the left of the midline. The cardiac long and short axis ratios and the vertebral heart scale were significantly larger for VD projections, compared with values for DV projections.

On lateral projections, the cranial border of the heart was located at the level of the third rib or third intercostal space and the caudal border of the heart was located at the level of the sixth rib or fifth intercostal space. On DV and VD projections, the cranial border of the heart was located at the level of the third rib or third intercostal space and the caudal border of the heart was located near the cranial margin of the diaphragm between the fifth and seventh intercostal spaces.

The heart more consistently contacted the diaphragm on lateral projections than on DV and VD projections. On all lateral projections, except for 2 RL projections, the heart contacted the diaphragm. In general, there was more separation between the heart and diaphragm on VD projections, compared with the separation on DV projections, with better aeration of the portion of the lung in this area on VD projections. On VD projections, the heart did not contact the diaphragm in 5 crias and only slightly (< 1 cm of total contact) contacted the diaphragm in 3 crias. On DV projections, the heart contacted the diaphragm in all crias, but this contact was < 1 cm in 4 crias.

The mean value for the vertebral heart scale in older (> 60 days old) crias was typically less than that in younger (< 60 days old) crias on all projections; on the RL projection, the mean value for the vertebral heart scale of older crias was significantly ($P = 0.01$) less than that of the younger crias (**Table 3**). A difference in relative cardiac size between older and younger crias could not be detected during qualitative evaluation; the cardiac silhouette subjectively was similarly proportioned to other thoracic structures for both groups.

Vasculature variables—On each RL and LR projection, only 1 set of cranial lobar arteries and veins could

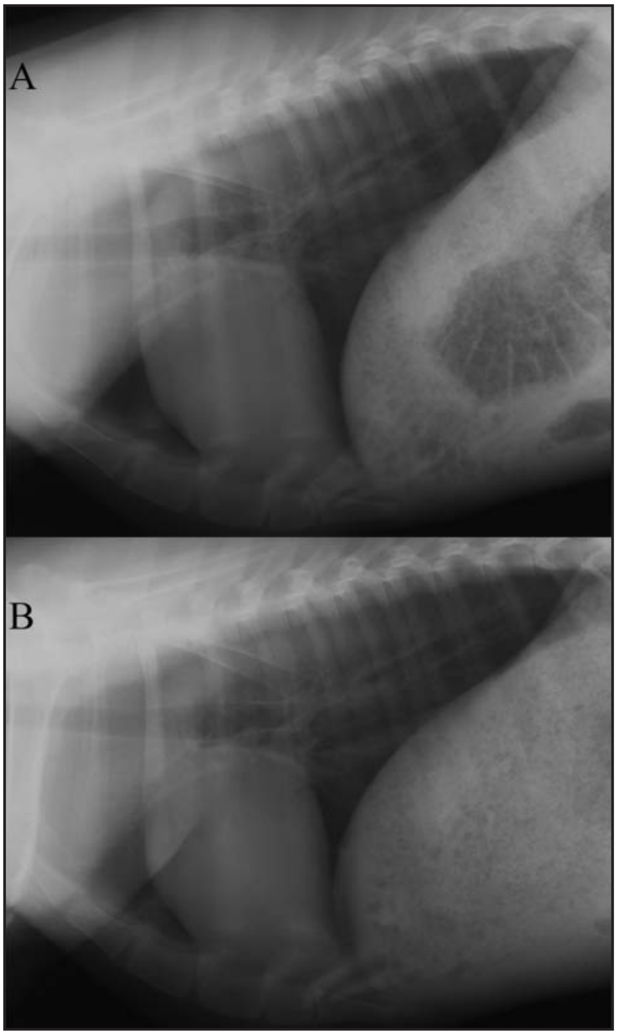

Figure 3—The RL (A) and LR (B) radiographic projections for a 105-day-old alpaca cria. Notice that the cardiac silhouette is generally of the same shape and size for both projections.

be easily identified (**Figure 5**). The cranial pulmonary vein was typically the same size or slightly larger than the corresponding artery, but the vein was occasionally slightly smaller than the artery. No significant difference in mean ratios of the cranial pulmonary artery or vein to rib width was identified between LR and RL projections, nor was a significant difference in ratios identified in older versus younger crias. A primary bifurcation of the artery, vein, or both was not visible in 6 crias on RL projections and 6 crias on LR projections. The artery and vein did not cross the third rib in 2 crias on LR projections and 1 cria on RL projections; instead, they curved ventrally just caudal to the third rib.

It was difficult to evaluate caudal pulmonary arteries and veins on DV and VD projections because of their medial location and summation with the ribs and vertebrae (**Figure 6**). In all crias, the ribs were narrow laterally but wide medially near the intersection with the caudal pulmonary vessels, which obscured the vessel margins. In several crias, the caudal pulmonary arteries and veins were seen near the carina, but the margins became indistinct just caudal to this region, which prevented evaluation at the level of the eighth rib.

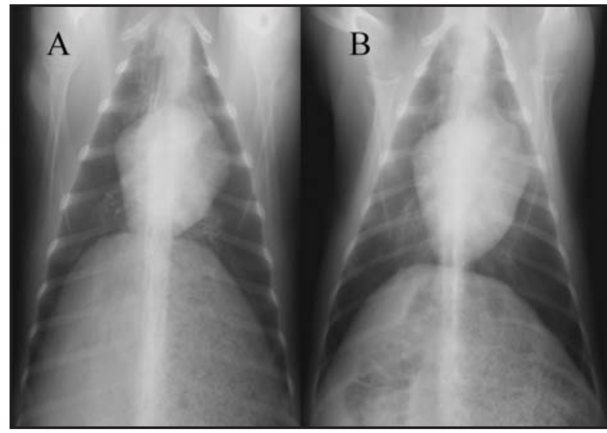

Figure 4—The DV (A) and VD (B) radiographic projections for a 15-day-old alpaca cria. The heart was considered to have a rounded shape on the DV projection and an angular shape on the VD projection.

Right caudal pulmonary arteries and veins were most frequently measured on DV projections, but left caudal pulmonary arteries and veins were most frequently measured on VD projections. Statistical evaluation of the caudal lobar arterial and venous diameter on the DV versus VD projections was not performed because vessels were not identified in all crias.

On lateral projections, the aortic arch and proximal portion of the descending aorta could be identified in all crias, but the midportion of the descending thoracic aorta became less distinct in the middle portion of the thorax and was only faintly visible just cranial to the diaphragm. Vessels could be seen extending to the periphery of the lung lobes in all crias.

On lateral projections, visibility of the dorsal margin of the CVC was considered good for 17 crias on LR projections and 12 crias on RL projections (**Figure 7**). The ventral margin was less clearly visible in most crias (visibility of the ventral margin was considered good for 7 crias on LR projections and 7 crias on RL projections). Mean ratio of CVC height to height of the vertebral body of T4 did not differ significantly between LR and RL projections. The angle of the CVC was divergent with the vertebral column in 8 crias on LR projections and 9 crias on RL projections. For all other crias, the CVC was parallel to the vertebral column. On DV and VD projections, CVC margins were often not seen because of summation with vasculature and the caudal portion of the thoracic vertebral column. The width of the CVC could be measured in 2 crias on DV projections and 7 crias on VD projections.

Respiratory variables—The cranial lung lobes extended to the level of the first rib in all crias. On lateral projections, the position of the lumbodiaphragmatic recess varied. In 2 crias, the lumbodiaphragmatic recess was located as far cranially as the vertebral body of T10, and 2 crias had a lumbodiaphragmatic recess located ventral to the body of T1. For the remainder of the crias, the position of the lumbodiaphragmatic recess was between the cranial edge of T11 and the caudal edge of T12. The diaphragm had a flattened shape dorsally, which transitioned to an abrupt rounded shape near the point of cardiophrenic contact.

Table 3—Comparison of mean values for selected cardiac variables between 14 younger and 7 older alpaca crias.

Projection	Variable	< 60 days old	> 60 days old	*P* value*
LR	Vertebral heart scale	9.54	9.01	0.08
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	3.20	2.96	< 0.05
	Ratio of cardiac long axis to length of T3 through T5	1.86	1.71	< 0.05
	Ratio of cardiac short axis to length of T3 through T5	1.33	1.26	0.13
RL	Vertebral heart scale	9.59	8.91	< 0.05
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	3.20	2.96	< 0.05
	Ratio of cardiac long axis to length of T3 through T5	1.87	1.67	< 0.05
	Ratio of cardiac short axis to length of T3 through T5	1.33	1.29	0.46
DV	Vertebral heart scale	8.34	7.94	0.10
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	2.77	2.67	0.25
	Ratio of cardiac long axis to length of T3 through T5	1.48	1.40	0.10
	Ratio of cardiac short axis to length of T3 through T5	1.18	1.19	0.99
VD	Vertebral heart scale	8.73	8.49	0.37
	Ratio of cardiac long axis + cardiac short axis to length of T3 through T5	2.91	2.85	0.51
	Ratio of cardiac long axis to length of T3 through T5	1.58	1.55	0.68
	Ratio of cardiac short axis to length of T3 through T5	1.33	1.30	0.25

For all projections, length of T3 through T5 was the distance measured on the lateral projections.
*Values were considered significant at $P < 0.05$.

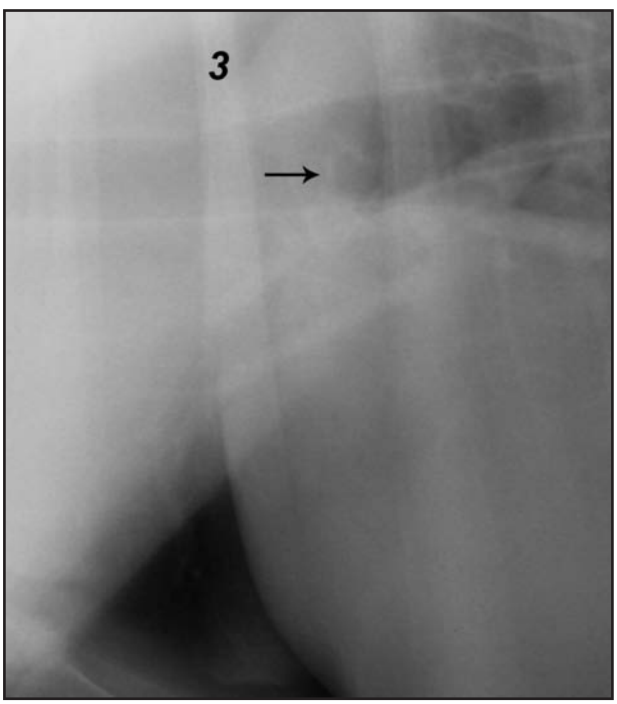

Figure 5—The RL radiographic projection of the cranioventral portion of the thorax of an alpaca cria. Notice the origin of the tracheal bronchus (arrow) to the right cranial lung lobe. The right cranial pulmonary artery and vein are distinctly evident as they cross the third ribs. 3 = Superimposed third ribs.

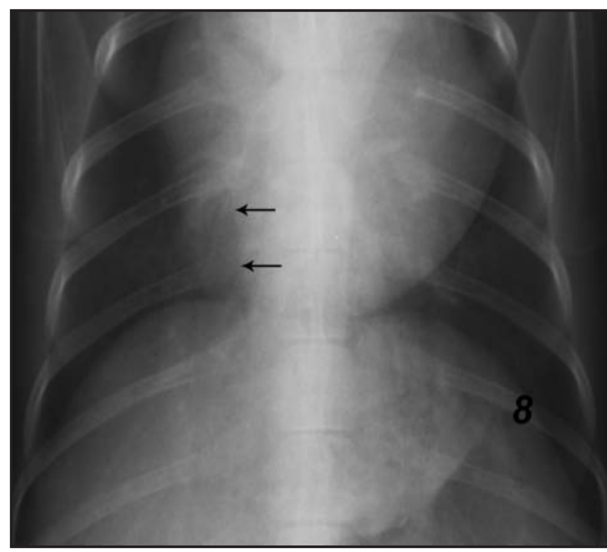

Figure 6—The DV radiographic projection of the caudal portion of the thorax in an alpaca cria. Notice the lateral margin of the CVC (arrows). The medial margin of the CVC cannot be seen because of summation with other thoracic structures. The left and right caudal pulmonary arteries and left caudal pulmonary vein can be seen at the level of the eighth ribs, but the right pulmonary vein cannot be seen at this level. 8 = Right eighth rib.

The trachea was evident as a straight thin-walled structure that extended from the thoracic inlet to the carina, without ventral or dorsal curvature. On the DV and VD projections, the trachea entered the thorax immediately to the right of midline, just medial to the head of the right first rib. The carina was located on the midline in all crias. On lateral projections, a slight bulge in the trachea was detected at the level of the fourth rib, which in some crias extended cranially to the level of the third intercostal space. This bulge was detected at the point where the bronchus to the right cranial lung lobe arose from the trachea. This bulge was slight in some crias but more pronounced in others **(Figure 8)**. Mean ratios of tracheal diameter to height of the body of T4 were not significantly different between LR and RL projections; similarly, these ratios did not differ significantly in younger versus older crias.

Other variables—In all crias, the width of the cranial mediastinum was less than the width of the thoracic vertebrae on DV and VD projections. A thymic silhouette (a triangular-shaped soft tissue opacity visible to the cranial and left side of the heart) was seen on the DV projection in a 105-day-old cria.

Discussion

The study reported here provided qualitative and quantitative radiographic descriptions of the thorax of

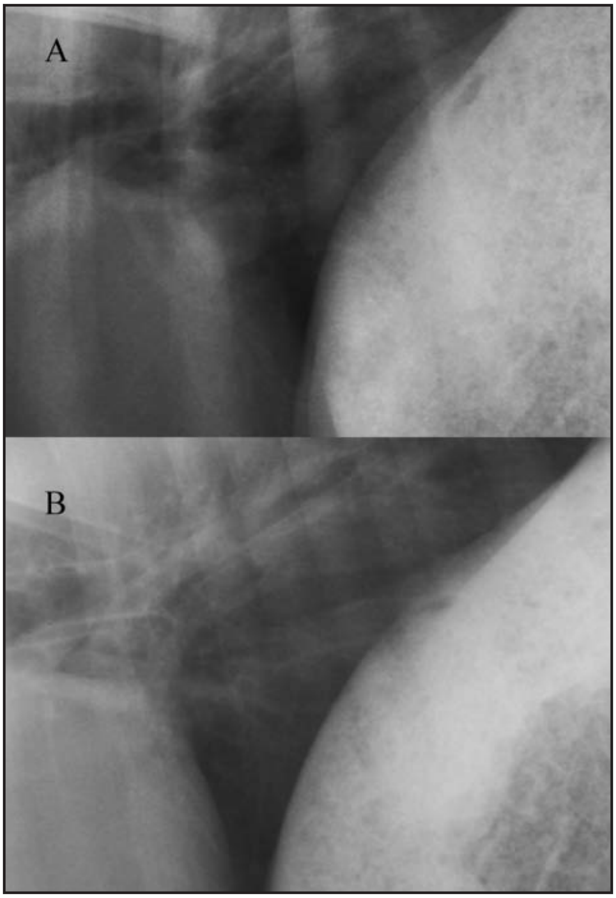

Figure 7—The LR radiographic projections of 2 alpaca crias (A and B). In panel, A, the dorsal and ventral margins of the CVC are considered to have good margination, whereas those in panel B have poor margination.

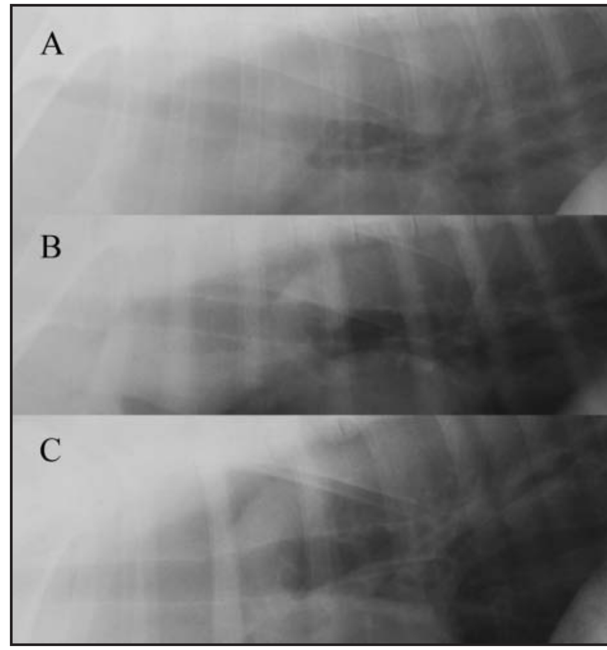

Figure 8—The LR radiographic projections of 3 alpaca crias (A, B, and C) in the region of the origin of the tracheal bronchus. In panel A, only a slight increase in diameter of the trachea is evident at the origin of the tracheal bronchus. In panels B and C, notice the moderate and large, respectively, increase in tracheal diameter at the origin of the tracheal bronchus.

alpaca crias. Measurement of thoracic structures is often not performed by experienced clinicians, who instead rely on subjective impressions formed via their practice experiences; however, measurement of thoracic structures may be helpful to those who are inexperienced, when a novel species is encountered, or when questions arise about a particular animal.[5] When evaluating particular thoracic structures in young animals, the utility of absolute measurements is limited because the older and therefore larger subjects are expected to have larger body components. In the present study, crias of various ages (2 to 238 days old) and body weights (8.1 to 25.5 kg) were radiographed. To account for the range in size for this population, ratios between structures of interest and other standard, internal anatomic landmarks were used.

The vertebral heart scale is a method for measuring cardiac size in units of thoracic vertebral length, with ranges established for clinically normal cats,[6] dogs,[7,8] and ferrets.[9] In the alpaca crias of the present study, mean vertebral heart scales for LR and RL projections were similar, which is not surprising given the similar qualitative appearance of the heart for these 2 projections. Values for the mean vertebral heart scale were significantly higher on VD projections than on DV projections, which was likely attributable to a greater distance of the heart from the radiographic cassette on VD projections that resulted in greater magnification of the heart.

Ratios of heart measurements were made with several other thoracic structures, including the length of vertebral bodies T3 through T5, thoracic height and width, and distance between the third and fifth ribs. The same ratios were reported[3] for adult llamas, which are generally similar to alpacas with regard to body conformation and size. For all of these ratios, the mean cardiac measurements were greater for alpaca crias, compared with results for adult llamas. Although alpacas and llamas are morphologically similar, this discrepancy may be explained by slight differences in cardiac size between these 2 species. Differences in age of the study populations (crias vs adults) may also account for differences in cardiac size between these 2 groups.

Cardiac dimensions were compared with thoracic height on lateral projections, whereas they were compared with thoracic width on DV and VD projections. Although these ratios provide an additional method to assess the heart, pulmonary inflation should be considered during interpretation of these values. These ratios depend on careful acquisition of radiographs during inspiration and would likely increase if radiographs were obtained during expiration or when pulmonary disease prevented full pulmonary inflation. Subjective assessment reveals that alpaca crias tend to inflate their thorax laterally rather than dorsoventrally during breathing. Thus, it is more likely that thoracic width, rather than thoracic height, would change during respiration, which indicates that measurements of thoracic width may be less reliable; however, this has not been thoroughly investigated.

Finally, the dimensions of the heart were compared with the distance between the third and fifth ribs on lateral projections.[3] Similar to comparisons for thoracic height and width, distance between ribs may change during pulmonary inflation, which likely makes this method of cardiac assessment less reliable than comparison with the length of T3 through T5. Of all the methods that can be used to evaluate cardiac size, the vertebral heart scale and comparison with the length of T3 through T5 are likely the most reliable methods. The vertebral heart scale has the added advantage of ease of use and does not rely on an equation to determine cardiac size ratios.

Because crias differed in age, radiographs were evaluated quantitatively and qualitatively relative to age. For statistical purposes, crias were categorized as those < 60 days old and those > 60 days old because most crias in the study were younger than 60 days of age and the distribution of age for crias > 60 days old was wide. Overall cardiac size (as reflected in the mean vertebral heart scale) was generally smaller in older alpacas, compared with cardiac size in younger alpacas. For this analysis, the mean value for the vertebral heart scale was significantly ($P = 0.01$) less only on the RL projection (8.9 in older crias vs 9.6 in younger crias). The mean values for the vertebral heart scale were less on other projections as well, but those differences were not significant. A difference in relative cardiac size was not detected during subjective evaluation of radiographs, which likely reflected the relatively small magnitude of difference in heart sizes. Additionally, within each age group, there was overlap in relative cardiac sizes, with some younger crias having relatively smaller values for the vertebral heart scale and some older crias having relatively larger values for the vertebral heart scale. As a result, this finding likely has little clinical relevance, and the range of values for the vertebral heart scale is thought to be sufficient for clinical use in both younger and older crias (Tables 1 and 2). No qualitative or significant quantitative differences in size were detected for any vascular or respiratory structure.

The CVC was always evident on lateral projections, but there was variation in the clarity of its borders among crias. The ventral margin of the CVC was seen clearly only in approximately one-third of the LR and RL projections; clear margination of the dorsal margin was seen more frequently. The margins of the mid and caudal portions of the descending thoracic aorta were always indistinct. These observations are similar to those for adult llamas, where the descending aorta typically has indistinct margins and the dorsal CVC margin is clear more often than is the ventral margin.[3] Therefore, poor visualization of the CVC and aorta margins does not indicate pulmonary pathological changes in alpaca crias.

Visualization of the pulmonary vasculature of alpaca crias varied, with the cranial pulmonary artery and veins easily seen on lateral projections but the caudal vessels not as easily identified on DV and VD projections. On each lateral projection, 1 set of cranial pulmonary arteries and veins was easily identified, and it was assumed that the right cranial pulmonary vessels were identified on RL projections and the left cranial pulmonary vessels were identified on LR projections. In alpacas, the primary bronchus to the right cranial lung lobe (also called the tracheal bronchus) arises from the trachea more cranially than do other bronchi, which makes it difficult to determine associations with pulmonary vessels on LR or RL projections.[1,10] Although caudal pulmonary vessels are more easily seen near the base of the heart where they are widest, these vessels were often difficult to see on DV and VD projections at the level of the eighth rib. Because the thorax of crias has little thoracic width, relative to the thoracic height, the caudal pulmonary vessels frequently summated with the diaphragm and cranial portion of the abdomen, CVC, and heart. Additionally, ribs of crias widen medially near the vertebral column, which obscures the more medially located pulmonary veins.

An abnormal position of the trachea can be an important indicator of disease, with dorsal displacement of the base commonly seen with cardiomegaly and focal deviations caused by adjacent masses.[11] In the present study, the trachea diverged from the thoracic vertebrae in all crias, appearing as a straight structure that extended from the thoracic inlet to the carina. Focal deviations of the thoracic portion of the trachea were not observed. When obtaining radiographs of these crias, their neck was usually in a neutral position; thus, the effect that neck flexion may have on tracheal position in this species is not known. On DV and VD projections, the cranial aspect of the thoracic portion of the trachea deviated slightly to the right before extending toward the carina and midline more caudally. This should not be confused with pathological changes, such as a cranial mediastinal mass. Given the repeatable position of the trachea in alpaca crias, displacement is likely a reliable indicator of cardiac or mediastinal pathological changes when patients are carefully positioned for diagnostic imaging.

Height of the thoracic portion of the trachea was uniform, except at the level of the origin of the right cranial lobar bronchus where a bulge-like increase in tracheal height was detected in all crias. A similar widening has been described in adult llamas[3]; however, this widening was not always present (in only 7/16 llamas). As alpacas reach maturity, this increase in tracheal height may disappear in some animals. Alternatively, this bulge may be detected with greater frequency in alpacas, compared with the frequency in llamas. The thoracic portion of the trachea was of uniform diameter on DV and VD projections. This indicated that in alpaca crias, the trachea is a round tubular structure until the level of the tracheal bronchus, where it elongates ventrodorsally, but not laterally, to form an oblong tubular structure.

Thoracic radiography, including DV and VD projections, is easily performed on alpaca crias. Establishment of quantitative and qualitative thoracic radiographic variables for alpaca crias may prove useful in assessment of cardiac and noncardiac thoracic disease in neonates and juveniles. Although it is expected that the appearance of the thorax of llama crias would be similar to that of alpaca crias, studies conducted to compare the thoracic radiographic appearance of these 2 species would be helpful.

a. Kodak X-Sight intensifying screens, Eastman Kodak Co, Rochester, NY.
b. Kodak X-Sight L/RA film, Eastman Kodak Co, Rochester, NY.
c. SigmaStat, version 3.11, Systat Software, San Jose, Calif.

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