Comparative radiographic morphometry of thorax in up to one month old healthy buffalo and cow calves

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SUMMARY
The study was aimed to record the radiographic morphometry of thorax in buffalo and cow calves of up to one month of age and to compare them between the two species.
The study included 17 buffalo and 13 cow calves (5 local breeds and 8 crossbred exotica). All the calves were subjected to lateral chest radiography in a recumbent position, without sedation or anesthesia. For evaluation purposes, the parameters were divided into the thoracic wall (thoracic inlet diameter, thorax dimensions, number and size of each sternebra, thoracic depth), airway (tracheal lumen diameter, carina diameter, tracheal inclination angle, tracheal lumen, and thoracic inlet diameter ratio, thoracic inlet, and thoracic depth ratio), major vessels (aorta and caudal vena cava at various level and their ratios), cardiac (length, width, vertebral length, rib 4 diameter, heart size in relation to the number of sternebrae, rib and intercostal space, vertebral left atrial score, sternal contact of heart, cardiac inclination angle and their various ratio) and the diaphragm (cupula height and placement in relation to rib, sternum, caudal vena cava height at diaphragm, diaphragm crus placement in relation to vertebrae) region.
In 94% of buffalo calves the number of sternebrae was 7 while, one calf had 8 sternebrae with the 7th smaller in length. However, 69.23% of cow calves (9 out of 13) had 7 sternebrae, and 4 calves had only 6 sternebrae (all exotic crossbred) with S6 missing. Out of 9 calves with 7 sternebrae, the S6 was very small in 66.67% (6/9) of the calves and the S6 was a block vertebra with no/little joint space with adjoining S5 or S7 in 4 calves (30.76%). The thoracic depth, sternal length, diagonal thorax measurements, body weight, and length of the S1, S2, S3, and S6 sternebra of buffalo calves were significantly more than that of cow calves. However, the thoracic inlet to thoracic depth ratio of buffalo calves was significantly less than the cow calves. The maximum tracheal diameter, the tracheal inclination angle, and the ratio of trachea to thoracic inlet diameter of buffalo calves were significantly more in comparison to cow calves. The cardiac inclination angle and the thoracic depth of the buffalo calves were significantly more than the cow calves; however, the heart length to thoracic depth ratio was more in cow calves. The vertebral left atrial score recorded by two described methods in dogs was found to be significantly different for bovine calves. The cupula height from the sternum was found to be significantly more in buffalo calves compared to cow calves.
In conclusion, a normal radiographic morphometry database of the thorax of buffalo and cow calves of up to one month of age was generated. Statistical anatomical differences in the thorax of cow and buffalo calves exist.

KEY WORDS
Axial, Bovine, Buffalo, Calves, Congenital, Radiography, Thorax.

INTRODUCTION

The calves of up to one month of age may be suspected of congenital heart diseases, especially the one presented with respiratory signs, and poor growth, weakness or exercise intolerance[1] or with some external congenital deformity (< 3%)[2]. Thoracic radiography is the primary and the most accessible modality for the evaluation of heart and other thoracic structures[3]. Though, echocardiography is the gold standard for the diagnosis of heart affection but is a specialized field with less availability.
Cows and buffaloes belong to the same family *bovidae*, but differences in the physiology, anatomy, and disease patterns exist[4-12]. Thoracic radiography of very young calves can be done in a single lateral view (recumbent position). Thoracic radiography in small animals like dogs and cats has been developed but the literature lacks objective information on the normal chest radiographic parameters in young buffalo and cow calves. So, this study was designed to record the radiographic morphometry of the thorax in apparently healthy buffalo and

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cow calves of up to one month of age and to compare them between the two species.

MATERIAL AND METHODS

The study included 17 buffalo (Figure 1a, Group 1) and 13 cow calves (5 local breeds and 8 crossbred exotica) (Figure 1b and c, Group 2) of up to one month of age, presented with their dam to the Teaching Veterinary Hospital. The study was duly approved by the Institutional Animal Ethics committee. All the calves were clinically and apparently healthy as assessed through physical examination and thorax auscultation. The calves were subjected to single lateral chest radiograph in a recumbent position and inspiratory phase, without sedation or anesthesia. The calves were casted with both forelimbs and hind limbs pulled cranially and caudally, respectively.

Out of 17 buffalo calves (Group 1), 7 had radiographs obtained in the right lateral, and 10 in the left lateral recumbency. A student t-test was run between the objective parameters in the two recumbency (right and left lateral) and no significant difference was recorded in any of the objective thoracic parameters, therefore, all the buffalo calves (n=17) irrespective of the recumbency were considered in Group 1. However, for the purpose of measuring the distance between two crura in Group 1, only the radiographs obtained in the right lateral recumbency were considered. In Group 2, all the radiographs were made in right lateral recumbency.

The radiographs were made using a ceiling-mounted movable X-ray machine (ProRad) of Prognosis make, with 1000mA and 125 KVP. The radiographic exposure factors used were 60 KVP, 20mAs, and 100-120 FFD for Kodak computerized radiography system, and 50-55KVP, 12-16mAs and 100-120FFD for the digital radiography system.

Figure 1 - Representative photographs of the Dam and calf of the buffalo (a), Native breed Sahiwal (b) and Jersey cross bred (c) included in the study.

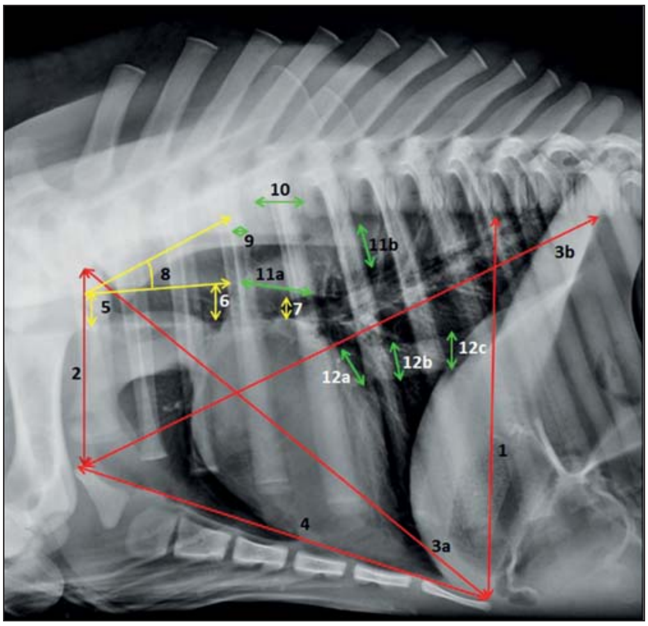

Figure 2 - Radiograph of the chest of a calf showing thoracic cavity, airway and great vessels measurements; the thoracic depth (1), Thoracic inlet diameter (2), diagonal size of the thorax (3a and b), length of the sternum (4), the trachea diameter at thoracic inlet (5), the maximum trachea diameter (6), the carina (7) and the trachea inclination angle (8), the diameter of 4th rib (9), the length of vertebra above carina (10), the diameter of Aorta at base (11a), diameter of Aorta in alignment with CVC (11b), the diameter of CVC at base (12a), diameter of CVC in alignment with Aorta (12b), diameter of CVC at diaphragm (12c).

The body weight, age, and gender of all the calves were recorded. The radiographs were then evaluated for the measurement of the following parameters using the inbuilt digital caliper of the software.

I. Thoracic Cavity parameters (Figure 2)

The thoracic depth (TD in cm) was measured from the dorsal-caudal margin of the xiphoid process to the ventral margin of the vertebral body, aligned perpendicular to the vertebral column[13].

Thoracic inlet length/diameter (cm) (ThID) was measured from the dorso-cranial margin of the manubrium to the ventral margin of the caudal end of the C7 vertebra. The ThID: TD ratio was calculated as the division of thoracic inlet diameter to the thoracic depth length.

The size of the chest (cm) was taken as two diagonal measurements as: The diagonal length measured from the caudo-ventral aspect of C7 to the most caudo-dorsal point on the xiphoid (C7-X) and the diagonal length measured from the most cranio-dorsal aspect of the manubrium to the ventral margin of the vertebra where the caudal crus of the diaphragm merge (M-D).

The number of sternebrae, the length and width of each sternebra (cm) was recorded. The length of the sternum (cm) was measured as a straight line from the most cranio-dorsal aspect of the first sternebra to the most caudo-dorsal point of the xiphoid. The subjective shape of the sternum was also recorded. The alignment of respective ribs with the sternebrae was recorded.

II. Airway parameters in Chest (Figure 2)

The tracheal diameter at the thoracic inlet (cm) (TrD at ThI) was measured as the diameter of the trachea on the line of measuring the ThID[14]. The TrD ratio with ThI and the ThID were calculated.[14] The tracheal diameter maximum (cm) (TrD max) was measured cranial to carina[14]. The size of the carina (cm) was defined as the radiolucent circular or ovoid structure within the trachea that represented the bifurcation of the left and right mainstem bronchi[16.] The maximum diameter of the carina was recorded.

The tracheal inclination angle (TrI°) was determined by drawing lines along the dorsal border of the trachea and the ventral margin of the cranial thoracic vertebra. But, since these two lines intersect far cranially in calves, another parallel line was made above the line drawn along the dorsal border of the trachea so that it intersects (and forms the angle) the line on the ventral margin of the cranial thoracic vertebra at the cranial end. Then the angle was measured using digital calliper[15].

III. Great vessels parameters (Figure 2)

The diameter of the Aorta (Ao) (cm) was measured at the base of the aorta (Ao_b) and at the intercostal space (ICS) where both caudal vena cava (CVC) and Ao were seen (6[th] ICS) (Ao_{CVC}). The diameter of CVC (in cm) was taken at the base (CVC_b), in the ICS with Aorta (CVC_{Ao}), and at the entry to the diaphragm (CVC_d). The various ratios of great vessels; CVC_{Ao} : Ao_{CVC}, CVC_{Ao} : VL, CVC_{Ao} : R4, CVC_b : Ao_b, Ao_{CVC} : VL, Ao_{CVC} : R4, Ao_b : Ao_{CVC}, CVC_b : CVC_{Ao}, CVC_b : CVC_d, and CVC_{Ao} : CVC_d were calculated.

The length of the vertebra (VL) (cm) above the carina was measured. The rib 4 diameter (R4) (cm) was measured dorsally at the ventral margin of the vertebra.

IV: Cardiac Parameters (Figure 3)

The heart was measured in reference to ribs, sternebrae, ICS etc which is explained as below:

- *Heart in sternebrae (HS):* Two straight lines were drawn from the broadest part of the heart on the sternum. The numbers of sternebrae falling in the lines were calculated.
- *Heart in the n^{th} number of sternebra (HNS):* the n^{th} number of sternebra involved in the measurement of HS was recorded.
- The heart falling in the number of ICS, and ribs was recorded. If half or more than half of the rib diameter falls over the heart, it was included.
- *Heart in the n^{th} number of ribs*: The serial number of the rib was counted from the start and the ribs falling over the heart were recorded.
- The cardiac inclination angle (CI°) was determined by measuring the angle formed between the cranial cardiac border and the sternum.
- The heart length/long axis (HL)(cm) was measured from the ventral border of the Carina to the most ventral point of the heart apex[17]. The heart width/short axis (HS) (cm) was determined as the length at the broadest point of the heart starting underneath the caudal vena cava and at the right angle to the HL[17].
- *Vertebral heart score (VHS):* Both HL and HS were positioned/aligned separately with the vertebral column starting at the beginning of the T4 vertebra and the number of vertebrae falling in each was counted and added[17].

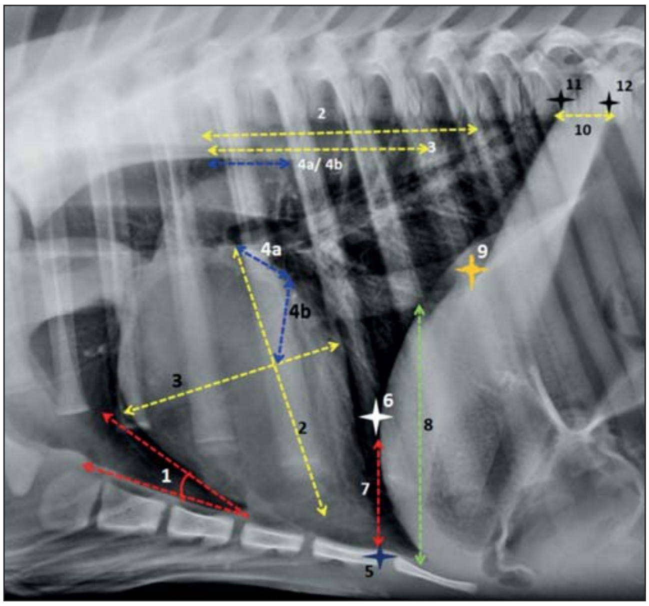

Figure 3 - Radiograph showing cardiac and diaphragm parameters measurements; the cardiac inclination angle (1), the heart length in long axis (2), the heart width/short axis (3), the measurement for $VLAS_a$ and $VLAS_b$ (4a and b), the cupula at sternum (5), the rib at cupula (6), the height of cupula from sternum (7),), the height of CVC when it enters diaphragm from sternum (8), the rib where the CVC enters diaphragm (9), the distance between crura (10), the cranial crus at thoracic vertebra (11), the caudal crus and thoracic vertebra (12).

- *Vertebral left atrial score (VLAS):* VLAS was measured by two techniques described in the literature for dogs. The score from the two techniques was also compared statistically.
  - A line was drawn from the centre of the most ventral aspect of the carina to the most caudal aspect of the left atrium where it intersected with the dorsal border of the caudal vena cava. A second line that was equal in length to the first was drawn beginning at the cranial edge of the T4 and extending caudally just ventral and parallel to the vertebral column. The VLAS was defined as the length of the second line expressed in vertebral body units to the nearest 0.1 vertebra[16, 18] (**VLASa**).
  - A line was drawn at 45° from the intersection of heart length and heart width up to the dorsal border of the left atrium. A second line that was equal in length to the first was drawn beginning at the cranial edge of T4 and extending caudally just ventral and parallel to the vertebral column. The VLAS was defined as the length of the second line expressed in vertebral body units to the nearest 0.1 vertebra[17, 19] (**VLASb**).
- The sternal contact of the heart was the number of sternebrae in contact with the heart ventrally. The subjective shape of the heart was also recorded
- The ratio between *VLASa*/ $VLAS_b$, $VLAS_a$/VHS, $VLAS_b$/VHS, and HL/TD were calculated.

V. Diaphragm (Figure 3)

The cupula at the n^{th} sternebrae was determined by drawing a straight line from cupula to down on the sternebra and the sternebra number was recorded. The N^{th} rib on Cupula was determined by counting the rib from start and recording the number of the rib which coincides with the cupula. The height of Cupula (cm) was measured by drawing a straight line from the

cupula to the dorsal margin of the sternebra underneath it[8]. The Cranial and caudal crus of the diaphragm at the thoracic vertebra was counted and recorded in radiographs done in the right lateral view. The distance between two crus (cm) was measured just at the ventral border of the vertebrae.
The number of the rib at which the CVC enters the diaphragm was counted from the start to the point where CVC enters the diaphragm, and was recorded. The height of the CVC from the sternum at the point it enters the diaphragm (cm) was measured from the point CVC touching the diaphragm on the ventral aspect to down on the dorsal margin of the sternum.
The merging of the diaphragm on the sternum was counted from start to the point where the diaphragm ends ventrally.

Statistical Analysis

The data generated were subjected to statistical analysis using Microsoft Office Excel, 2007. The mean and the standard deviation of all the numerical parameters were calculated in all the calves. The quantitative data was tested for normality before statistical analysis. The student t-test was applied to test the significance of differences in the radiographic parameters in the two species at 5% or 1%. The subjective data were compared using percentage, absolute and relative. Pearson's correlation coefficients were calculated and analysed for the test of significance to check the influence of age, weight, gender, and a few other parameters.

RESULTS

The body weight of the Group 1 calves (33.86 Kg ± 4.62) was significantly higher than those of Group 2 calves (20.85 ± 2.15) at ($p \leq 0.05$) irrespective of gender.
The breed of buffalo calves was a cross of Murrah and Nili-Ravi. Among cows, out of 13, 6 were Holstein Friesian cross (46.15%), 3 indigenous Sahiwal (23.07%), 2 each of Jersey cross, and indigenous Hariana Breed (15.38%) calves.

I. Thoracic Cavity Parameters (Table 1)

The TD and the length of the chest C7-X, in Group 1 was significantly higher ($p \leq 0.01$) as compared to Group 2.

Table 1 - Table showing the thoracic cavity parameters (Mean ± SD) (range) in Group 1 and 2.

	Group 1 (n=17)	Group 2 (n=13)
Body weight (kg)	33.86 ± 4.62** (27-40)	20.85 ± 2.15** (16-25)
Age (days)	18.75 ± 9.02 (3-30)	12.54 ± 10.95 (1-30)
TD (cm)	21.14 ± 1.33** (18.27 - 23.17)	18.41 ± 2.24** (16.28-23.26)
ThID (cm)	9.67 ± 1.11 (7.47-11.49)	10.36 ± 1.71 (8.36-13.45)
C7-X (cm)	26.64 ± 1.67** (23.7-29.3)	23.43 ± 2.64** (20.6-29.7)
M-D (cm)	32.82 ± 2.59* (27.7-36.5)	29.52 ± 4.24* (24.5-38.0)
No Sternebrae	7.06 ± 0.25* (7-8)	6.69 ± 0.48* (6-7)
L S1 (cm)	3.23 ± 0.38* (2.7-3.7)	2.79 ± 0.41* (2.1-3.3)
L S2 (cm)	2.65 ± 0.40** (2.2-3.3)	2.19 ± 0.35** (1.7-2.9)
L S3 (cm)	3.05 ± 0.32* (2.6-3.3)	2.76 ± 0.29* (2.3-3.4)
L S4 (cm)	2.93 ± 0.22 (2.4-3.3)	2.97 ± 0.28 (2.7-3.3)
L S5 (cm)	2.81 ± 0.23 (2.5-3.1)	3.02 ± 0.33 (2.5-3.6)
L S6 (cm)	3.06 ± 0.34** (2-3.3)	1.89 ± 0.95** (0.9-3.6)
L S7 (cm)	3.84 ± 0.62 (1.9-4.3)	3.62 ± 0.47 (3.1-4.3)
L S8 (cm)	4.8	-
W of S1 (cm)	2.10 ± 0.22 (1.7-2.3)	1.9 ± 0.54 (1.2-2.5)
W S2 (cm)	2.4 ± 0.36* (1.6-2.9)	2.05 ± 0.43* (1.3-2.7)
W S3 (cm)	1.95 ± 0.35 (1.5-2.5)	1.72 ± 0.43 (1.2-2.7)
W S4 (cm)	1.4 ± 0.41 (1-2.4)	1.43 ± 0.42 (1.0-2.5)
W S5 (cm)	1.14 ± 0.48 (0.6-1.3)	1.31 ± 0.47 (0.8-2.4)
W S6 (cm)	1.03 ± 0.50 (0.6-2.3)	0.95 ± 0.47 (0.6-2.0)
W S7 (cm)	0.83 ± 0.20 (0.6-1.4)	0.93 ± 0.32 (0.7-1.3)
W S8 (cm)	0.6	-
L of Sternum (cm)	22.36 ± 1.67** (19.4-25.21)	18.89 ± 2.20** (16.4-24.6)
Shape of Sternum	Cigar shape in all with a dip at S2 level	Cigar shape in all with less dip at S2 level in comparison to Group1
ThID: TD	0.46 ± 0.05** (0.35-0.52)	0.57 ± 0.054** (0.47-0.62)

*Similar asterisks represents significant differences between the groups (** at p≤0.01 and * at p≤0.05)*
*(**Expansion of abbreviations:** TD=thoracic depth, ThID=thoracic inlet diameter, C7-X= The diagonal length measured from the caudo-ventral aspect of C7 to the most caudo-dorsal point on the xiphoid in cm, M-D= The diagonal length measured from the most cranio-dorsal aspect of the manubrium to the ventral margin of vertebra where the caudal crus of diaphragm merge, L= length, W=width)*

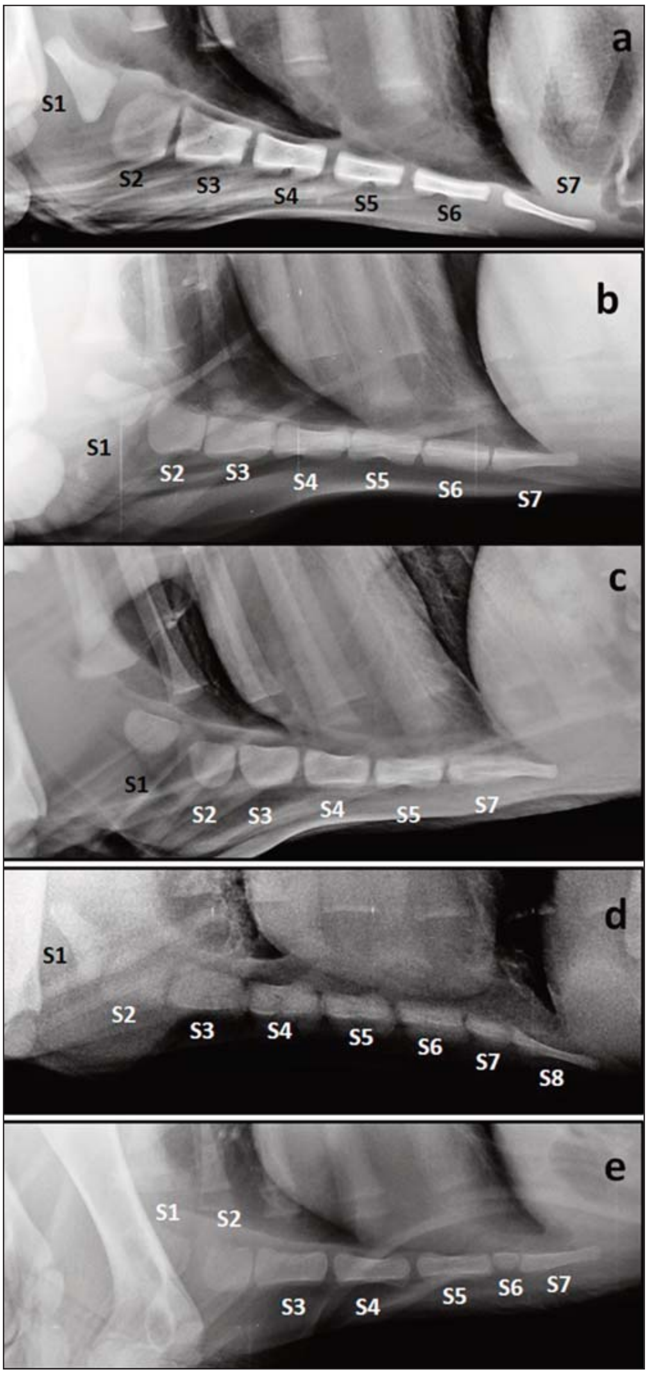

Figure 4 - Radiographs of the sternum in a buffalo calf with normal 7 sternebrae (a), in a cow calf with normal 7 sternebrae (b), in a cow calf with 6 sternebrae (c), in buffalo a calf with 8 sternebrae and S7 small (d), in a cow calf with 7 sternebrae but S6 small (e).

In Group 1, 94% (n=16) of the calves had 7 sternebrae (Figure 4a) and one calf had 8 sternebrae, however, in Group 2, 69.23% of calves (9 out of 13) had 7 sternebrae (Figure 4b), but 4 calves had only 6 sternebrae (all exotic crossbred). The number of sternebrae was identified by their shape. While comparing the shape of the individual sternebra in cow calves, it was observed that S6 was missing in calves with six sternebrae (Figure 4c). The one calf of Group 1 with eight sternebrae had the 7th sternebra smallest with a length of 1.9cm (Figure 4d). Out of 9 calves with seven sternebrae in Group 2, the S6 was very small in 66.67% (6/9) and was a block sternebra with no/little joint space with the adjoining S5 or S7 in 4 calves (44.44%, 4/6) (Figure 4e).

In, general, the length of the sternebra was recorded to be increasing while moving from S1 to S7 and the width was decreasing. The width of S1 was thinner cranially and thicker caudally (which was more distinct in Group 1 in comparison to Group 2). The S2 sternebra was more of a square shape with length and width almost equal and the length smaller than the S1 or S3 and could be distinctly identified on the radiograph. Next to S2, the sternebrae had more width cranially and less caudally (Figures 4a & b). The S7 was the longest sternebra and the S2 was the widest (Figure 4a & b). The space between the sternebra was highest in S1 and S2, which kept on reducing caudally. The S6-S7 had the lowest space between them. The length of S1, S2, S3, and S6 sternebra were significantly more in Group 1 than Group 2.

The length of the sternum in Group 1 was significantly ($p \leq 0.01$) more than that in Group 2. The calf of Group 1 with 8 sternebrae had the maximum sternal length of 25.21cm.

The shape of the sternum was cigar shape with a dip at the level of S2. This dip was more pronounced in buffalo calves in comparison to cow calves, where sometimes the sternum appeared rather a straight line (Figure 4a & b). The dip in S2 was topographically at the place of the brisket (Figure 4a).

In Group 2 calves with 6 sternebrae, the first rib was subjectively seen aligned slightly cranial to S1 in comparison to that in buffalo or cow calves with 7 sternebrae. In the calves with 7 sternebrae, the first 4 ribs were seen aligned to the first 4 sternebrae, and later the ribs were seen aligned slight caudal to the respective sternebrae, leading to the 7th rib aligned caudal to S7. However, in calves with 6 sternebrae or S6 very small, the 6th rib was seen aligned caudal to Xiphoid (as 6th sternebra was the xiphoid). The ThID: TD ratio of Group 2 was significantly ($p \leq 0.01$) more in comparison to Group 1.

II. Airway Parameters in the chest

The TrD at the thoracic inlet was non-significantly higher in Group 1 (1.63cm ± 0.19) in comparison to Group 2 (1.42cm ± 0.52), however, the average of the TrD max was recorded significantly ($p \leq 0.01$) more in Group 1(1.95cm ± 0.31) in comparison to Group 2 (1.48cm ± 0.49).

The TrI° in Group 1 (14.98°± 2.79) was significantly ($p \leq 0.01$) more than that in Group 2 (10.34°± 2.71). The maximum diameter of carina in both the groups was almost similar (1.22 ± 025 and 1.24 ± 0.24 respectively in Group 1 and 2). The carina in calves was not well defined as in dogs and the shape may vary from round to oval.

The TrD: ThID was significantly ($p \leq 0.01$) more in Group 1(0.17 ±0.018) in comparison to Group 2 (0.13 ± 0.03).

III. Great vessels parameters (Table 2)

The diameter of the Ao was significantly ($p \leq 0.01$) higher at the base in comparison to at 6th ICS (in alignment with the CVC) in both the Groups. However, no significant difference in the diameter of the Aorta at the base, and CVC was recorded between the two Groups/species. Both the Aorta and the CVC were seen clear, complete and perpendicular at the 6th ICS.

The diameter of CVC was significantly ($p \leq 0.01$) higher at the base and then kept on decreasing as the vessel moves caudally towards the diaphragm in both Groups. However, no significant difference in the diameter of CVC at the base, in alignment with the aorta, or at the entry into the diaphragm was recorded between the two Groups/species.

The length of the vertebra above the carina was almost simi-

Table 2 - Table showing the great vessels parameters (Mean ± SD) (range) in cm in Group 1 and 2.

	Group 1 (n=17)	Group 2 (n=13)
Ao_b (cm)	3.6 ± 0.61^{aa} (2.92-5.2)	3.22 ± 0.52^{bb} (2.31-3.99)
Ao_{cvc} (cm)	2.65 ± 0.38^{aa} (2.1-3.2)	2.49 ± 0.31^{bb} (2.03-2.96)
CVC_b (cm)	2.02 ± 0.35^{ccdd} (2.1-3.2)	2.18 ± 0.51^{eeff} (1.16-3.05)
CVC_{Ao} (cm)	1.74 ± 0.34^{cc}(1.28-2.38)	1.55 ± 0.28^{ee} (0.95-1.87)
CVC_d (cm)	1.65 ± 0.31^{dd} (1.1-2.08)	1.5 ± 0.44^{ff} (0.57-1.92)
VL (cm)	2.66 ± 0.22 (2.26-3.05)	2.49 ± 0.36 (2.08-3.21)
R4 dia (cm)	0.82 ± 0.11* (0.6-1.0)	0.7 ± 0.18* (0.52-1.15)
CVC_{Ao}/Ao_{cvc}	0.66 ± 0.15 (0.46-0.87)	0.63 ± 0.15 (0.39-0.92)
CVC_{Ao}/VL	0.66 ± 0.15 (0.43-1.02)	0.63 ± 0.13 (0.38-0.81)
CVC_{Ao}/R4	2.13 ± 0.44 (1.6-3.01)	2.3 ± 0.6 (1.53-3.37)
CVC_b/Ao_b	0.57 ± 0.15 (0.33-0.84)	0.68 ± 0.15 (0.36-0.92)
CVC_b/CVC_{Ao}	1.17 ± 0.13* (0.83-1.41)	1.45 ± 0.38* (0.63-2.11)
CVC_b/CVC_d	1.24 ± 0.21 (0.91-1.68)	1.61 ± 0.66 (0.67-3.15)
CVC_{Ao}/CVC_d	1.07 ± 0.15 (0.87-1.29)	1.11 ± 0.34 (0.72-1.18)
Ao_{cvc}/VL	0.99 ± 0.14 (0.76-1.23)	1.01 ± 0.15 (0.69-1.28)
Ao_{cvc}/R4	3.25 ± 0.55 (2.2-4.08)	3.69 ± 0.65 (2.35-4.67)
Ao_b/Ao_{cvc}	1.37 ± 0.21 (0.97-1.68)	1.3 ± 0.24 (0.95-1.50)

*Similar asterisks represents significant differences between the groups * at p≤0.05)*
Similar superscripts (alphabets) represents significant difference between the them (double at ≤0.01 & single at p≤0.05)
(Ao_b=Aorta diameter at base, Ao_{cvc}=Aorta diameter in 6th ICS where it is in alignment with the CVC, CVC_b=CVC diameter at base, CVC_{Ao}=diameter of CVC at 6th ICS where it is in alignment with the Aorta, CVC_d= diameter of CVC at diaphragm where it is seen entering the diaphragm, VL=vertebra length, R4= rib 4 diameter)

lar in both Groups, however, the diameter of rib 4 at the proximal end was significantly ($p \leq 0.05$) higher in Group 1 in comparison to Group 2.
The ratio calculated for CVC_{Ao} and Ao_{cvc} and CVC_{Ao} and VL was similar in both the Groups, indicating the diameter of the Aorta in alignment with CVC was similar to the length of the vertebra above the carina which is mostly 5th Thoracic vertebra. The other combinations of ratios calculated between the aorta and the CVC at various levels, or with vertebral length, or rib diameter were not significantly different in the two Groups.

IV. Cardiac parameters (Table 3)

The heart was almost equally distributed when compared with respect to the number of sternebrae in both species. In the maximum number of buffalo (64.71%) and cow (38.46%) calves the heart was distributed between S4-S7 sternebrae, while in cow calves, it was almost equally distributed between S3-S7 and S3-S7 (23.07%) sternebrae. The number of ICS in which the heart width falls was 2-3 for buffalo calves and 2-4 for cow calves, but otherwise the average was almost similar in both the species and did not show any significant difference. The heart width was recorded to fall between 3-3.5 ribs in Group 1 and 3-4 in Group 2, however, the average was almost similar with no significant difference between the species. In maximum buffalo calves (64.71%), the width of the heart fell between R4-R6 rib, while it was equally distributed between R3-R5 and R4-R6 and slightly less between R3-R6 among the cow calves.
The cardiac inclination angle was significantly more ($p<0.05$) in Group 1 in comparison to Group 2. The $VLAS_a$ and $VLAS_b$ showed a significant difference between themselves in both the species. The shape of the heart was round at the base with maximum width below the caudal vena cava. The apex was narrower in buffalo calves, in comparison to cow calves. The caudal border of the heart was mostly straight in cow calves while it had a pot-like, caudal border in buffalo calves.
The ratio between $VLAS_a$/ $VLAS_b$ was similar in both the species with no significant difference. The ratio of $VLAS_b$ and VHS was significantly higher in both species in comparison to $VLAS_a$/VHS. The ratio of HL: TD was significantly ($p<0.01$) less in Group 1 in comparison to Group 2.

V. Diaphragm parameters (Table 4)

In maximum calves of Group 1 (76.47%) the cupula fell on S7 sternebra, while it was on S6 in Group 2. While counting the ICS on which the cupula fell, it was recorded that in buffalo calves with 7 sternebrae, the cupula was seen slight caudal in comparison to cow calves with 6 sternebrae.
In maximum number of buffalo calves (70.59%), the 6th rib was seen at the cupula of the diaphragm and similar was in cow calves (84.61%), though variation was seen in the portion (cranial or the caudal part) of 6th rib touching the cupula. The height of the cupula was significantly ($p<0.05$) more in Group 1 in comparison to Group 2.
In most of the buffalo calves (71.43%) the cranial crus of the diaphragm fell on the 11th thoracic vertebra while in cow calves, it is on the 10th. The caudal crus of the diaphragm was seen to fall on the 11th or 12th thoracic vertebra with almost equal distribution, while in cow calves, it was distributed from T10 to T13 with more variation compared to buffalo calves. The distance between the two crus of the diaphragm was significantly more in buffalo calves (1.81cm) than the cow calves (1.52cm).
In most of the buffalo (52.94%) and cow calves (69.23%) the

Table 3 - Table showing the Cardiac parameters (Mean ± SD) (range) in cm in Group 1 and 2.

	Group 1 (n=17)	Group 2 (n=13)
Heart in No. of sternebrae	3.29 ± 0.25 (3-3.8)	3.33 ± 0.41 (2.8-4)
n^{th} sternebra for heart	S3-S6=3/17=17.65% S4-S6=2/17=11.76% S4-S7=11/17=64.71% S3-S7=1/17=5.88%	S3-S6=3/13=23.07% S4-S7=5/13=38.46% S3-S7=3/13=23.07% S4-S6=2/13=15.38%
Heart in no. ICS	2.69 ± 0.48 (2-3)	2.77 ± 0.6 (2-4)
Heart in No. of rib	3.03 ± 0.13 (3-3.5)	3.08 ± 0.28 (3-4)
Heart in rib no.	R3-R5=5/17=29.41% R4-R7=1/17=5.88% R4-R6=11/17=64.71%	R3-R5=5/13=38.46% R4-R6=5/13=38.46% R3-R6=3/13=23.07%
CrI°	21.92 ± 5.36* (13.11-27.97)	17.49 ± 3.94* (12.24-24.82)
TD	21.14 ± 1.29** (18.27-23.17)	18.41 ± 2.25** (16.28-23.26)
HL	13.19 ± 0.79 (12.31-15.18)	12.89 ± 1.69 (10.82-16.28)
HW	10.4 ± 0.67 (9.27-15.18)	9.73 ± 1.56 (7.9-12.73)
VHS	9.13 ± 0.42 (8.2-10.1)	8.87 ± 0.61 (7.3-10)
Carina to CVC length	3.35 ± 0.64 (2.1-4.7)	3.28 ± 0.67 (2.3-4.2)
$VLAS_a$	1.26 ± 0.21^{aa} (1.0-1.7)	1.35 ± 0.29^{b} (1.0-1.9)
Length b	3.91 ± 0.5 (3.16-4.7)	3.83 ± 0.67 (3.2-5.12)
$VLAS_b$	1.45 ± 0.16^{aa} (1.2-1.7)	1.55 ± 0.2^{b} (1.2-2.0)
Sternal contact Heart	1.93 ± 0.49 (1-3)	2.28 ± 0.5 (1.5-3.0)
Sternal no. contact Heart	S5-S6=13/17=76.47% S7=1/17=5.88% S5-S7=2/17=11.76% S4-S6=1/17=5.88% S4-S7=1/17=5.88%	S5-S6=6/13=46.15% S4-S6=4/13=30.77% S5-S7=2/13=15.38% S4-S7=1/13=7.69%
$VLAS_a$/ $VLAS_b$	0.88 ± 0.15 (0.68-1.21)	0.88 ± 0.18 (0.58-1.21)
$VLAS_a$/VHS	0.14 ± 0.02^{cc} (0.11-0.19)	0.15 ± 0.03^{d} (0.11-0.19)
$VLAS_b$/VHS	0.16 ± 0.01^{cc} (0.13-0.20)	0.17 ± 0.02^{d} (0.14-0.22)
HL/TD	0.62 ± 0.03** (0.58-0.67)	0.7 ± 0.03** (0.65-0.75)

*Similar asterisks represents significant differences between the groups (** at p≤0.01 and * at p≤0.05)*
Similar superscripts (alphabets) represents significant difference between the them (double at ≤0.01 & single at p≤0.05)
(n^{th} sternebrae for Heart: the n^{th} sternebrae in which the heart anterior and posterior border falls, ICS= intercostal space, CrI°= cardiac angle of inclination, TD= thoracic depth, HL=heart length, HW= heart width, VHS= vertebral Heart Score, CVC= caudal Vena Cava, VLAS= vertebral left atrial score, length b= A line was drawn at 45° from the intersection of heart length and heart width up to the dorsal border of left atrium in cm)

CVC enters the diaphragm at the 7^{th} Rib, while almost 3% were also seen entering at the 8^{th} rib. The CVC enters at a non-significantly more height from the sternum in Group 1 in comparison to Group 2. The CVC was recorded to enter the diaphragm at almost the double the height of the cupula. The diaphragm was seen inserting at the last sternebra (S7 or 8), i.e. the xiphoid in the buffalo calves and S6 or S7 vertebra in the cow calves.

Effect of age, weight, and gender on the quantitative parameters in both the Groups

No parameter had any significant correlation with the gender in both species. In Group 1, the body weight of buffalo calves had a negative correlation (r=-0.542, p=0.030) with the diameter of the aorta at the level of CVC. No significant correlation existed for the age and gender with the chest parameters.
In Group 2, the body weight had a positive correlation with the age (r=0.572, p=0.041), thoracic depth (r=0.657, p=0.015), Heart length (r=0.572, p=0.040), heart width (r=0.564, p=0.045) and the height of CVC at the Diaphragm (r=0.590, p=0.034). The age of the cow calves had a positive correlation with the diameter of the aorta at the base (r=0.606, p=0.028) and the length of the sternum (r=0.827, p=0.002).

DISCUSSION

Congenital heart conditions are not common in bovines, but calves with other multiple visible congenital defects or respiratory problems in the early days of life or stunted growth might be affected with heart defects. Radiography of the chest is the primary and feasible non-invasive tool to assess the status of the heart or lungs. Standard data on the radiography of the heart and the thorax in healthy bovine calves is lacking in the literature.
The body weight of healthy buffalo calves (at birth) has been reported to be significantly higher than those of the cow calves, for both male and female gender[20]. A few of the chest and heart parameters in cow calves were correlated with the age and the weight that may be because of the less variability in the body weight of the calves as all the calves were aged less than one

Table 4 - Table showing the Cardiac parameters (Mean ± SD) (range) in cm in buffalo and cow calves.

	Buffalo calves (n=17)	Cow calves (n=13)
Cupula on sternum	S6=3/17=17.65 S7=13/17=76.47 S8=1/17=5.88	S7=3/13=23.0 S6=10/13=76.92
Cupula on rib	R6=12/17=70.59 R7=5/17=29.41	R5=1/13=7.69 R6=11/13=84.61 R7=1/13=7.69
Cupula height from S	5.11 ± 0.83* (4.1-6.69)	4.41 ± 0.57* (3.6-5.36)
Cranial crus D at V (RL)	T11=5/7=71.43 T10=2/7=28.57	T9=2/13=15.38 T10=7/13=53.84 T11=3/13=23.0 T12=1/13=7.69
Caudal crus D at V (RL)	T11=4/7=57.14 T12=3/7=42.85	T10=5/13=38.46 T11=5/13=38.46 T12=2/13=15.38 T13=1/13=7.69
Distance between two crus (RL)	1.81 ± 1.22 (0.8-3.0)	1.52 ± 0.87 (0-2.6)
CVC at Diaphragm and rib	R7=9/17=52.94 R8=6/17=35.29 R9=2/17=11.76	R7=9/13=69.23 R8=4/13=30.76
CVC at diaphragm height from sternum	12.09 ± 0.99 (10.0-13.57)	11.16 ± 1.79 (9.1-15.35)
Diaphragm insertion	S7 or 8/xiphoid=17	Last sternebra S6 or 7

*Similar asterisks represents significant differences between the groups (** at p≤0.01 and * at p≤0.05)*
(S=Sternum, D=diaphragm, V=vertebra, RL=right lateral recumbency, CVC=Caudal vena cava).

month. The calves in the region of study are usually fed little milk and are weaned early, thus showing reduced growth rate[20]. The majority of differences in the buffalo and cow calves were noticed in the wall of the thoracic cavity. The thoracic depth, size, sternum length, number of sternebrae, etc were found different in the two species. In many cow calves, the number of sternebrae was 6 with S6 missing or very small in size. Due to the missing or small S6 in cow calves, the overall length of the sternum was significantly reduced. The number of sternebrae may be of importance in adult bovine radiography. The sternebra is the primary bony structures visible on a reticular or ventral thoracic radiograph and the cranial ribs are aligned with the respective sternebrae. The ultrasonography of the bovine abdomen or chest also defines the topography as per the ICS[6]. So, if the number of sternebrae is less or S6 is small, the ICS will be maligned, compared to normal and the topography may vary[6].

The ThID: TD ratio depicted that the thoracic inlet of cow calves was more while the thoracic depth of buffalo calves was more. The higher ThID in cow calves was subjectively observed to be because the S1 in cow calves was placed slightly caudal in the thoracic wall as compared to S1 in buffalo calves.

The measurement of tracheal diameter, thoracic inlet diameters, and their ratio has been used in previous studies to know the tracheal collapse, coughing status, and relation of respiratory pathology in relation to tracheal diameter change[21]. The ratio of tracheal diameter to thoracic inlet diameter was significantly more in buffalo calves in comparison to cow calves. This could be related to the higher thoracic inlet diameter and lower tracheal diameter in cow calves in comparison to buffalo calves.

The diameter of the aorta and CVC was recorded to be broadest at the base and decreased as the vessel moved caudally in the chest in both the species. This could be due to the oblique placement of the vessel at the base as compared to the perpendicular at the 6th ICS. However, the diameter of the aorta was always greater than the CVC. Slight variation in diameter of CVC was recorded in a few calves, which was correlated to the thin wall of CVC which changes shape and diameter with a pulse.

The size of the heart was assessed with respect to sternebrae, rib, and ICS as these bony structures are visible on the radiograph of the chest in young bovines. The heart size in dogs has been reported to be 2.5-3.5 ICS for normal-sized hearts in deep or broad-chested dog's respectively[22] but was less in bovine calves with the buffalo calves having even lesser than the cow calves also. The cardiac inclination angle was higher in buffalo calves in comparison to cow calves, making the heart more uplifted in buffalo calves. The sternal contact of the heart in buffalo calves was also less than the cow calves, which may also be related to the higher cardiac inclination angle in buffalo calves, making it more upright and hence, less sternal contact. The reduced cardiac inclination angle in unhealthy animals is related to the right ventricle enlargement[23]. The VHS in buffalo and cow calves was less than that reported in young puppies of 3-9 months of age[24] but was similar to that reported in adult goats of the Zariabi breed[25].

A variation in the distribution of the heart in relation to the sternebra between the buffalo and the cow calves could be due to the variation in the number, size, and anatomical defect (block sternebra) in the sternebra of cow calves. Therefore, the parameters related to the sternebra cannot be relied upon for the assessment of heart size in cow calves. Similar variation was also recorded when comparing the heart size with ribs as the cranial ribs are aligned with the sternebra when they join at the costochondral junctions.

The two methods reported for the assessment of left atrial size in dogs[16-19] were found to be significantly different among themselves for the same calves, with the $VLAS_b$ showing higher values than $VLAS_a$. It suggested that the $VLAS_a$ and $VLAS_b$ cannot be used vice-versa in bovine calves and further studies are required to correlate the more appropriate one.
In maximum buffalo calves, the cupula fell on S7 sternebra, while it was on S6 in cow calves however, in adult bovines in most of the healthy cows and buffaloes it had been reported at S6[5]. Since in adult bovines all the sternebrae are not visible in one view, the sternebrae are counted from back considering the last one as S7, however, in this study it was found that the sternebrae may be less in few cows. The height of the cupula was more in buffalo calves in comparison to cow calves, as also reported in adult bovines making the diaphragm subjectively straight in buffaloes and dome-shaped in cattle[5].

CONCLUSIONS

The study concludes that:
1. A normal radiographic morphometry data-base of the thorax of buffalo, and cow calves of up to one month of age was generated.
2. Statistical anatomical differences in the thorax of buffalo, and cow calves exist:
   - The radiographic thoracic parameters; the thoracic depth, thoracic size, number and length of individual sternebra, the length of sternum, the maximum diameter of trachea, the size of vessels, the trachea, and cardiac inclination angles, and the height of Cupula are higher in buffalo calves than the cow calves.
   - The two methods of VLAS, described in dogs, differ significantly in bovine calves, so cannot be used vice-versa.

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