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Gross morphological and sex wise morphometrical studies on the first, second and third thoracic vertebrae of blue bull (*Boselaphus tragocamelus*)

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Abstract
The present study was carried out on the first, second and third thoracic vertebrae of six specimens of adult Blue bull (*Boselaphus tragocamelus*) of either sex. The first, second and third thoracic vertebrae were characterized by a long supraspinous process, cylindrical, but shorter centrum. The arch presented shallow notches and was perforated by intervertebral foramina at its caudal aspect. They also presented cranial and caudal facets on their bodies. The length and breadth of supra spinous processes was observed to increase up to T_3. The transverse process was reported to be thick, strong that presented a rounded non-articular mammillary process and a facet ventrally that articulated with the facet of the tubercle of the corresponding rib. The dorsal supraspinous process presented two surfaces, two borders and a summit. The costal facets were placed on either side at the end of the articular extremities of the centrum. The cranial articular processes were represented by oval facets on the anterior part of the arch and faced upwards, whereas the caudal ones spring from the base of the dorsal supraspinous process. The Biometrical observations on different parameters of first, second and third thoracic vertebrae reflected significance ($P<0.05$) differences between the sexes of this species.

Keywords: Blue bull, morphology, morphometry, thoracic vertebrae

Introduction
The Blue bull (*Boselaphus tragocamelus*) is known to be one of the biggest antelopes in Asia and is widely found in both the forests and adjoining villages with enough green grass [14]. Blue bull is considered sacred as per Hindu religion since Vedic period (1500-500 BC) and it is considered as religious. The Blue bull belongs to the family Bovidae and comes under the genus *Boselaphus* [14]. The German Zoologist Scientist Peter Simon Pallas explained this species for the first time in 1766. English Zoologist Scientist Philips for the first time in 1833 narrated the binomial combination of the Blue bull. It is quite prevalent in northern and central parts of India especially in the foothills of the Himalayas, eastern part of Pakistan and southern part of Nepal, but has vanished from Bangladesh [15]. The adult male appears like ox and so called as Blue bull. They are usually seen in day times in the meadow pasture, timberland areas and agricultural land area. It prefers mostly plain or grassy plain and low hilly areas with shrubs, small bushes, scrub forests with scattered trees and does not usually found in dense forest areas, dense compact wood, etc. The Blue bulls are safeguarded beneath the IUCN since 2003 and also under safeguard of 'Schedule III' of the Indian Wildlife Protection Act, 1972[1]. The Blue bull is safeguarded in various parts of India such as Gir National Park (Gujarat), Kumbhalgarh sanctuary (Rajasthan) and Panchamarahi Biosphere Reserve, India. The massive body of the Blue bull can be attributed to the large skeleton of the antelope. Further, the skeleton comprises of large and massive bones of the axial and appendicular skeleton that not only protects the viscera, but also provides shape and support to the heavy musculature of the Blue bull [16]. The present osteo-morphological study developed a baseline data on the first, second and third thoracic vertebrae of adult Blue bull that would immensely help the wild life anatomists and Veterinarians in species identification and solving forensic and vetero-legal cases as no previous work has been done in this field on the Blue bull.

Materials and methods
The present study was carried out on the first, second and third thoracic vertebrae of six specimens of adult Blue bulls (*Boselaphus tragocamelus*) of either sex.

The permission for the collection of bones was acquired from the Principal Chief Conservator of Forests (PCCF), Government of Rajasthan. The bones were possessed from the Jodhpur zoo, Rajasthan getting authentic confirmation from the Principal Chief Conservator of Forests (PCCF), Government of Rajasthan. The skeletons were taken out from the burial ground that was located in the premises of the office of the Deputy Conservator of Forest Wildlife (WL), Jodhpur. Afterwards, the specimens were processed as per standard technique given by Snedecor and Cochran [18]. The gross study was conducted under the supervision of the Zoo Authority, Jodhpur, India. The different parameters of first, second and third thoracic vertebrae were measured and subjected to routine statistical analysis and independent samples t-Test with Systat Software Inc, USA and SPSS 16.0 version software.

Results

The thoracic vertebrae were thirteen in number in the Blue bull irrespective of sex (Fig. 1). The first, second and third thoracic vertebrae were characterized by long supraspinous process, cylindrical, but shorter centrum (Fig. 2). The centrum was distinctly constricted in the middle. It presented a thin-edged ventral crest. The arch presented shallow notches and was perforated by intervertebral foramina at its caudal aspect. They also presented cranial and caudal facets on their bodies. The length and breadth of supra spinous processes was observed to increase up to T_3. The transverse process was reported to be thick, strong that presented a rounded non-articular mammillary process and a facet ventrally that articulated with the facet of the tubercle of the corresponding rib. The dorsal suprasinous process presented two surfaces, two borders and a summit. The lateral surfaces were found to be convex and the borders were nearly straight. The present findings obeyed the observations made by Getty *et al.* [5] in ox and sheep, Brelend [2] in cat, Raghavan [12] in ox, Miller *et al.*[9], Dyce *et al.* [3] in dog, Ozkan [10] in mole-rats and Meena [8] in chital, while according to Getty *et al.* [5], there were eighteen numbers of thoracic vertebrae, according to Smuts and Bezuidenhout [17] there were twelve numbers of thoracic vertebrae in camel, according to Yilmaz [19] there were fifteen numbers in porcupine, and according to Yilmaz *et al.* [20] fourteen numbers thoracic vertebrae were present in otters. The costal facets were placed on either side at the end of the articular extremities of the centrum. Each articular facet was a demi-facet that articulated with the half the part of the head of the rib. The cranial vertebral notches were found to be shallower and smaller, but the caudal ones were deeper. The caudal arch was perforated by an additional intervertebral foramen on either side. The cranial articular processes were represented by oval facets on the anterior part of the arch and faced upwards, whereas the caudal ones spring from the base of the dorsal supraspinous process.

Biometrical observation

The biometrical observations revealed characteristic differences between the sexes of the Blue bull.

First thoracic vertebra

The biometrical studies revealed that the average length of the body was found to be 2.57±0.09 cm in adult Blue bull. Further, it was measured to be 2.40±0.06 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 2.73±0.09 cm. The average width of the body at the middle was found to be 2.05±0.07 cm in adult Blue bull. Further, it was measured to be 1.97±0.09 cm and 2.13±0.09 cm in females and males respectively. Pandey *et al.* [11] in tiger (*Panthera tigris*) reported that the average widths of the body of T1 at the anterior, middle and posterior aspects were 4.48±0.06 cm, 3.52±0.11 cm and 4.14±0.08 cm respectively.

The average vertical diameter of vertebral canal was found to be 2.05±0.02 cm in adult Blue bull. Further, it was measured to be 2.02±0.02 cm and 2.08±0.02 cm in females and males respectively. The average transverse diameter of vertebral canal found to be 2.90±0.01 cm in adult Blue bull. Further, it was measured to be 2.87±0.01 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 2.92±0.01 cm. The average width of dorsal supraspinous process at the middle was found to be 2.28±0.02 cm in adult Blue bull. Further, it was measured to be 2.26±0.02 cm and 2.31±0.01 cm in females and males respectively. The average height of the dorsal supraspinous process was found to be 7.42±0.10 cm in adult Blue bull. Further, it was measured to be 7.23±0.09 cm and 7.60±0.12 cm in females and males respectively. The average length of transverse process was found to be 2.17±0.04 cm in adult Blue bull. Further, it was measured to be 2.13±0.06 cm and 2.20±0.06 cm in females and males respectively.

The average length of cranial articular facet was found to be 1.97±0.04 cm in adult Blue bull. Further, it was measured to be 1.94±0.05 cm and 2.00±0.05 cm in females and males respectively. Similarly, the average width of cranial articular facet was found to be 0.79±0.03 cm in adult Blue bull. Further, it was measured to be 0.76±0.04 cm and 0.82±0.04 cm in females and males respectively. The average length of caudal articular facet was found to be 1.16±0.01 cm in adult Blue bull. Further, it was measured to be 1.13±0.01 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 1.19±0.01 cm. Similarly, average width of caudal articular facet was found to be 0.64±0.01 cm in adult Blue bull. Further, it was found to be 0.61±0.01 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 0.67±0.01 cm. The average diameter of tubercular facet was found to be 1.31±0.03 cm in adult Blue bull. Further, it was measured to be 1.28±0.05 cm and 1.34±0.05 cm in females and males respectively. Similarly, the average distance between the tubercular facet and costal facet was found to be 1.62±0.03 cm in adult Blue bull. Further, it was measured to be 1.59±0.04 cm and 1.65±0.05 cm in females and males respectively (Table 1).

Second thoracic vertebra

The biometrical studies revealed that the average length of the body was found to be 3.33±0.11 cm in adult Blue bull. Further, it was measured to be 3.13±0.09 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 3.53±0.09 cm. Similarly, the average width of the body at the middle was found to be 2.86±0.02 cm in adult Blue bull. Further, it was measured to be 2.81±0.02 cm in females that was significantly lesser ($P<0.05$) than that of males, where it was found to be 2.91±0.01 cm. Pandey *et al.* [11] in tiger (*Panthera tigris*) reported that the widths of the body of T_2 at the anterior, middle and posterior aspects were 3.08±0.04 cm, 3.34±0.08 cm and 4.26±0.06 cm respectively. The average vertical diameter of vertebral canal was found to be 1.44±0.02 cm in adult Blue bull. Further, it was measured

to be 1.41±0.02 cm and 1.47±0.03 cm in females and males respectively. Similarly, the average transverse diameter of vertebral canal found to be 1.91±0.02 cm in adult Blue bull. Further, it was measured to be 1.87±0.02 cm and 1.94±0.04 cm in females and males respectively. The average width of dorsal supraspinous process at the middle was found to be 2.82±0.02 cm in adult Blue bull. Further, it was measured to be 2.77±0.02 cm and 2.86±0.02 cm in females and males respectively.

The average height of the dorsal supraspinous process was found to be 8.88±0.07 cm in adult Blue bull. Further, it was measured to be 8.77±0.09 cm and 9.00±0.06 cm in females and males respectively. The average length of transverse process was found to be 1.63±0.01 cm in adult Blue bull. Further, it was measured to be 1.60±0.01 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 1.65±0.01 cm. The average length of cranial articular facet was found to be 1.55±0.04 cm in adult Blue bull. Further, it was measured to be 1.53±0.05 cm and 1.57±0.05 cm in females and males respectively. The average width of cranial articular facet was found to be 0.56±0.01 cm in adult Blue bull. Further, it was measured to be 0.54±0.02 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 0.58±0.02 cm. The average length of caudal articular facet was found to be 2.66±0.03 cm in adult Blue bull. Further, it was measured to be 2.63±0.03 cm and 2.69±0.04 cm in females and males respectively. Similarly, the average width of caudal articular facet was found to be 0.98±0.04 cm in adult Blue bull. Further, it was measured to be 0.95±0.06 cm and 1.00±0.06 cm in females and males respectively.

The average diameter of tubercular facet was found to be 1.42±0.02 cm in adult Blue bull. Further, it was measured to be 1.38±0.03 cm and 1.45±0.03 cm in females and males respectively. The average distance between the tubercular facet and costal facet was found to be 1.36±0.02 cm in adult Blue bull. Further, it was measured to be 1.33±0.02 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 1.40±0.02 cm (Table 2).

Third thoracic vertebra

The biometrical studies revealed that the average length of the body was found to be 3.03±0.07 cm in adult Blue bull. Further, it was measured to be 2.93±0.07 cm and 3.13±0.09 cm in females and males respectively. The average width of the body at the middle was found to be 3.01±0.02vcm in adult Blue bull. Further, it was measured to be 2.98±0.01 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 3.05±0.02 cm. Pandey *et al*. [11] in tiger (*Panthera tigris*) reported that the average widths of the body of T_3 at the anterior, middle and posterior aspects were 3.10±0.04 cm, 2.48±0.06 cm and 4.34±0.03 cm respectively. The average vertical diameter of vertebral canal was found to be 1.44±0.02 cm in adult Blue bull. Further, it was measured to be 1.41±0.01 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 1.47±0.01 cm. Similarly, the average transverse diameter of vertebral canal found to be 2.06±0.02 cm in adult Blue bull. Further, it was measured to be 2.02±0.01 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 2.10±0.01 cm.

The average width of dorsal supraspinous process at the middle was found to be 2.46±0.02 cm in adult Blue bull. Further, it was measured to be 2.42±0.02 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 2.49±0.01 cm. The average height of the dorsal supraspinous process was found to be 12.57±0.11 cm in adult Blue bull. Further, it was measured to be 12.40±0.12 cm and 12.73±0.12 cm in females and males respectively. The average length of transverse process was found to be 1.45±0.01 cm in adult Blue bull. Further, it was measured to be 1.42±0.02 cm in females that was significantly lesser (P<0.05) than that of males, where it was found to be 1.48±0.02 cm.

The average length of cranial articular facet was found to be 2.63±0.06 cm in adult Blue bull. Further, it was measured to be 2.60±0.09 cm and 2.66±0.09 cm in females and males respectively. Similarly, the average width of cranial articular facet was found to be 0.87±0.03 cm in adult Blue bull. Further, it was measured to be 0.85±0.05 cm and 0.90±0.05 cm in females and males respectively. The average length of caudal articular facet was found to be 2.85±0.07 cm in adult Blue bull. Further, it was found to be 2.80±0.09 cm and 2.90±0.11 cm in females and males respectively. Similarly, the average width of caudal articular facet was found to be 1.11±0.02 cm in adult Blue bull. Further, it was found to be 1.08±0.03 cm and 1.14±0.03 cm in females and males respectively. The average diameter of tubercular facet was found to be 1.00±0.02 cm in adult Blue bull. Further, it was measured to be 0.97±0.03 cm and 1.04±0.03 cm in females and males respectively. The average distance between the tubercular facet and costal facet was found to be 1.75±0.02 cm in adult Blue bull. Further, it was measured to be 1.72±0.02 cm and 1.77±0.02 cm in females and males respectively (Table 3).

Table 1: Measurements of first thoracic vertebra of Blue bull in cm

Parameters			Range	Mean	SD	SE	Female (Mean±SE)	Male (Mean±SE)
Body	Length		2.3-2.9	2.57	0.22	0.09	2.40*±0.06	2.73±0.09
	Width at middle		1.8-2.3	2.05	0.16	0.07	1.97±0.09	2.13±0.09
	Height		2.0-2.7	2.37	0.25	0.10	2.23±0.15	2.50±0.12
Dorsal supraspinous process	Width	Summit	0.70-0.81	0.75	0.04	0.02	0.71*±0.01	0.79±0.01
		Middle	2.22-2.33	2.28	0.04	0.02	2.26±0.02	2.31±0.01
		Base	3.18-3.29	3.24	0.04	0.02	3.21*±0.01	3.27±0.01
	Height		7.1-7.8	7.42	0.26	0.10	7.23±0.09	7.60±0.12
Cranial articular facet	Length		1.80-2.14	1.97	0.13	0.04	1.94±0.05	2.00±0.05
	Width		0.64-0.93	0.79	0.11	0.03	0.76±0.04	0.82±0.04
Caudal articular facet	Length		1.10-1.23	1.16	0.04	0.01	1.13*±0.01	1.19±0.01
	Width		0.58-0.70	0.64	0.04	0.01	0.61*±0.01	0.67±0.01
Length of transverse process			1.98-2.36	2.17	0.14	0.04	2.13±0.06	2.20±0.06
Diameter of tubercular facet			1.15-1.47	1.31	0.11	0.03	1.28±0.05	1.34±0.05
Distance between tubercular facet and costal facet			1.46-1.77	1.62	0.10	0.03	1.59±0.04	1.65±0.05

Diameter of intervertebral foramen		0.09-0.22	0.16	0.04	0.01	0.14*±0.01	0.19±0.01
Distance between two costal facets	Cranial	2.18-2.28	2.23	0.04	0.01	2.20*±0.01	2.25±0.01
	Caudal	2.02-2.17	2.10	0.06	0.02	2.06±0.03	2.13±0.03
Distance between two cranial articular facets		2.63-2.79	2.71	0.05	0.02	2.68±0.03	2.75±0.02
Distance between two caudal articular facets		0.28-0.38	0.33	0.04	0.02	0.31±0.02	0.36±0.01
Diameter of vertebral canal	Vertical	1.99-2.11	2.05	0.04	0.02	2.02±0.02	2.08±0.02
	Transverse	2.85-2.94	2.90	0.03	0.01	2.87*±0.01	2.92±0.01

Values bearing superscript (*) differ significantly in column $P< 0.05$

Table 2: Measurements of second thoracic vertebra of Blue bull in cm

Parameters			**Range**	**Mean**	**SD**	**SE**	**Female (Mean±SE)**	**Male (Mean±SE)**
Body	Length		3.0-3.7	3.33	0.26	0.11	3.13*±0.09	3.53±0.09
	Width at middle		2.78-2.93	2.86	0.06	0.02	2.81*±0.02	2.91±0.01
	Height		3.08-3.30	3.15	0.08	0.03	3.11±0.01	3.20±0.05
Dorsal supraspinous process	Width	Summit	1.10-1.16	1.13	0.02	0.01	1.12±0.01	1.14±0.01
		Middle	2.73-2.90	2.82	0.06	0.02	2.77*±0.02	2.86±0.02
		Base	2.49-2.61	2.55	0.04	0.02	2.52*±0.02	2.58±0.01
	Height		8.6-9.1	8.88	0.17	0.07	8.77±0.09	9.00±0.06
Cranial articular facet	Length		1.39-1.71	1.55	0.13	0.04	1.53±0.05	1.57±0.05
	Width		0.48-0.63	0.56	0.05	0.01	0.54*±0.02	0.58±0.02
Caudal articular facet	Length		2.53-2.77	2.66	0.09	0.03	2.63±0.03	2.69±0.04
	Width		0.80-1.17	0.98	0.14	0.04	0.95±0.06	1.00±0.06
Length of transverse process			1.57-1.71	1.63	0.04	0.01	1.60*±0.01	1.65±0.01
Diameter of tubercular facet			1.29-1.51	1.42	0.08	0.02	1.38±0.03	1.45±0.03
Distance between tubercular facet and costal facet			1.29-1.46	1.36	0.06	0.02	1.33*±0.02	1.40±0.02
Diameter of intervertebral foramen			0.39-0.54	0.46	0.05	0.01	0.43*±0.01	0.50±0.01
Distance between two costal facets	Cranial		1.69-1.81	1.75	0.04	0.02	1.72*±0.02	1.78±0.01
	Caudal		1.60-1.71	1.65	0.04	0.02	1.62*±0.01	1.68±0.01
Distance between two cranial articular facets			0.65-0.75	0.69	0.04	0.01	0.67±0.01	0.71±0.02
Distance between two caudal articular facets			0.58-0.71	0.67	0.06	0.02	0.62*±0.02	0.71±0.01
Diameter of vertebral canal	Vertical		1.39-1.52	1.44	0.05	0.02	1.41±0.02	1.47±0.03
	Transverse		1.83-2.01	1.91	0.06	0.02	1.87±0.02	1.94±0.04

Values bearing superscript (*) differ significantly in column $P< 0.05$

Table 3: Measurements of third thoracic vertebra of Blue bull in cm

Parameters			**Range**	**Mean**	**SD**	**SE**	**Female (Mean±SE)**	**Male (Mean±SE)**
Body	Length		2.8-3.3	3.03	0.16	0.07	2.93±0.07	3.13±0.09
	Width at middle		2.98-3.08	3.01	0.05	0.02	2.98*±0.01	3.05±0.02
	Height		3.02-3.20	3.12	0.06	0.02	3.08±0.03	3.15±0.03
Dorsal supraspinous process	Width	Summit	1.81-1.96	1.89	0.05	0.02	1.84*±0.02	1.93±0.02
		Middle	2.39-2.52	2.46	0.05	0.02	2.42*±0.02	2.49±0.01
		Base	2.60-2.71	2.65	0.04	0.02	2.61*±0.01	2.68±0.02
	Height		12.2-12.9	12.57	0.26	0.11	12.40±0.12	12.73±0.12
Cranial articular facet	Length		2.37-2.87	2.63	0.21	0.06	2.60±0.09	2.66±0.09
	Width		0.71-1.01	0.87	0.12	0.03	0.85±0.05	0.90±0.05
Caudal articular facet	Length		2.55-3.17	2.85	0.24	0.07	2.80±0.09	2.90±0.11
	Width		1.0-1.23	1.11	0.07	0.02	1.08±0.03	1.14±0.03
Length of transverse process			1.36-1.53	1.45	0.05	0.01	1.42*±0.02	1.48±0.02
Diameter of tubercular facet			0.90-1.12	1.00	0.07	0.02	0.97±0.03	1.04±0.03
Distance between tubercular facet and costal facet			1.64-1.84	1.75	0.06	0.02	1.72±0.02	1.77±0.02
Diameter of intervertebral foramen			0.23-0.37	0.30	0.04	0.01	0.26*±0.01	0.33±0.01
Distance between two costal facets	Cranial		1.02-1.13	1.08	0.04	0.02	1.06±0.02	1.10±0.02
	Caudal		1.05-1.14	1.10	0.03	0.01	1.08±0.01	1.12±0.01
Distance between two cranial articular facets			1.01-1.13	1.08	0.04	0.02	1.04*±0.02	1.11±0.01
Distance between two caudal articular facets			1.11-1.22	1.17	0.04	0.02	1.14*±0.02	1.20±0.01
Diameter of vertebral canal	Vertical		1.39-1.50	1.44	0.04	0.02	1.41*±0.01	1.47±0.01
	Transverse		2.0-2.12	2.06	0.05	0.02	2.02*±0.01	2.10±0.01

Values bearing superscript (*) differ significantly in column $P< 0.05$

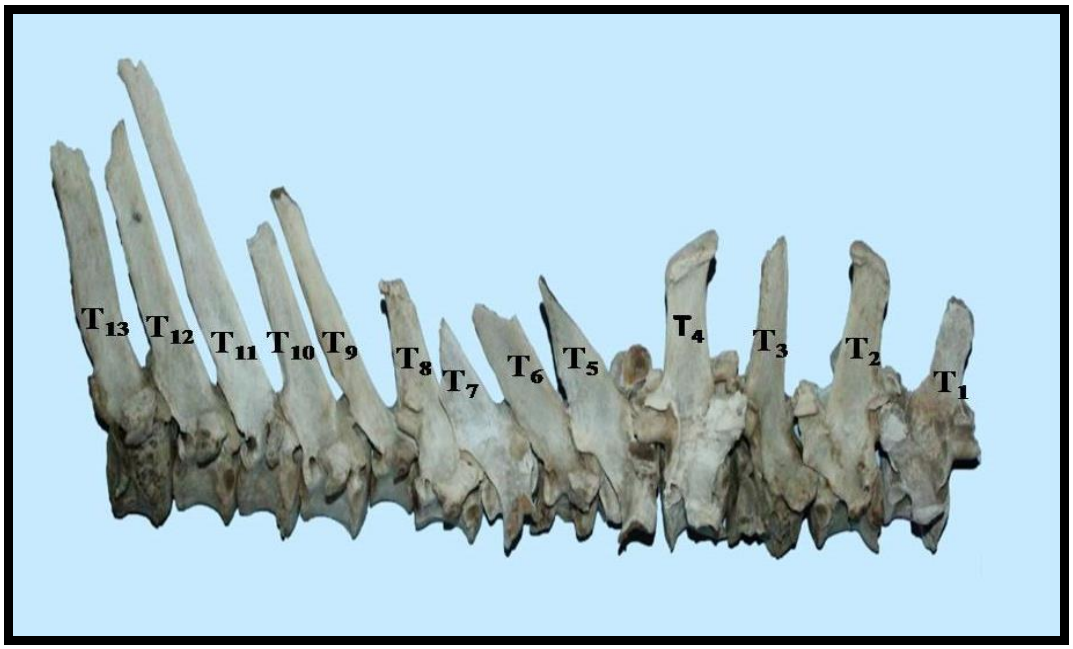

Fig 1: Lateral view of thoracic vertebrae ($T_1 – T_{13}$) of adult female Blue bull (*Boselaphus tragocamelus*)

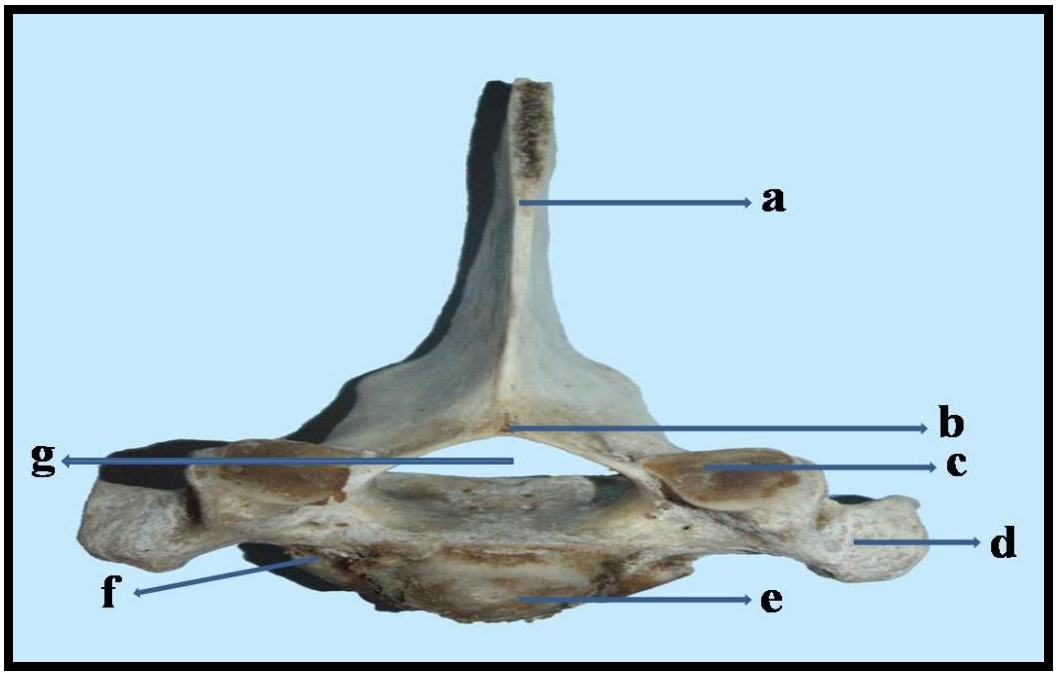

Fig 2: Cranial view of first thoracic vertebra of adult male Blue bull (*Boselaphus tragocamelus*) showing a) Dorsal supraspinous process, b) Laminae, c) Cranial articular facet, d) Transverse process, e) Cranial surface of body, f) Facet on cranial surface of body for head of first rib and g) Thoracic vertebral foramen

Conclusion

The first, second and third thoracic vertebrae of Blue bull were characterized by long supraspinous process, thick transverse process, cranial and caudal articular facets and cylindrical, but shorter centrum. Further, the various parameters of the first, second and third thoracic vertebrae like average length, width and height of body, average width and height of dorsal supraspinous process, average length and width of cranial and caudal articular facets, average length of transverse process, average diameter of tubercular facet, average diameter of intervertebral foramen, average distance between cranial and caudal costal facets and articular facets, average transverse and vertical diameters of vertebral canal showed characteristic sexual variations in the Blue bull.

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