ACTA ZOOLOGICA BULGARICA

ACTA ZOOLOGICA BULGARICA

Zoomorphology
Research Article

Acta zool. bulg., 74 (3), 2022: 455-463
Published online 07 September 2022
http://www.acta-zoologica-bulgarica.eu/2022/002578

Morphology of the Lumbar Vertebrae of Adult Chinkara *Gazella bennettii* (Sykes, 1831) (Mammalia: Bovidae)

***Din Salahud*[1,*], *Masood Saima*[2], *Zaneb Hafsa*[2], *Sajid Hameed*[1], *Masood Ayesha*[1], *Hafiz Muhammad Ali*[1] & *Sikandar* Arbab[3]**

[1] Department of Anatomy and Histology, Faculty of Veterinary and Animal Sciences, Islamia University of Bahawalpur, Bahawalpur, Pakistan; E-mail: dr.salahuddin@iub.edu.pk; sajid.hameed@iub.edu.pk
[2] Department of Anatomy and Histology, University of Veterinary and Animal Sciences, Lahore, Pakistan; E-mail: saima.masood@uvas.edu.pk, hafsa.zaneb@uvas.edu.pk; jasmeen83@hotmail.com
[3] Department of Anatomy and Histology, College of University of Veterinary and Animal Sciences, Jhang, UVAS, Campus; E-mail: arbab.sikandar@uvas.edu.pk

Abstract: Lumbar vertebrae morphology in adult chinkara is not studied yet. We hypothesised that the lumbar vertebrae morphology of the chinkara would be a typical example of fast running ungulates. This study was designed to study gross morphological and basic osteometric features of the lumbar vertebrae of chinkara. The study was conducted on the lumbar vertebrae of ten male and ten female adults. The gross morphological features of each lumbar vertebra were studied thoroughly, and the osteometric measurements were done using a digital Vernier calliper. The craniocaudal lengths of the vertebral bodies were similar among the first five vertebrae. However, in the sixth lumbar vertebra, the vertebral body length decreased and its width increased. The height and breadth of the extermitas cranialis of the vertebral body, as well as the breadth of extermitas caudalis, increased from L1 to L6. The pediculus arcus vertebrae were connected perpendicularly with the dorsal surface of the vertebral body and their dorsal margins projected laterally. The ventral margins of the left and right Lamina arcus vertebrae attached with the pedicles at 45°. The spinous processes were mostly rectangular and similar in height except for L6, which was lower in height. Length of spinous processes decreased from L1-L6 in both sexes. Sharp bony projections existed on the cranial border on the tips of both transverse processes. The dimensions of the spinal canal increased craniocaudally. Considerable morphological differences in the cranial and caudal articular processes, vertebral arch, transverse processes, spinous processes and vertebral bodies were observed.

Key words: chinkara, lumbar vertebrae, morphology, osteometrics

Introduction

The lumbar region bridges the thorax with the sacrum and provides support for the abdominal region. In domestic animals, the lumbar region has no ribs and the lumbar vertebrae have longer and stronger transverse processes. Thoracic vertebrae usually fluctuate from 12 to 15 vertebrae, whereas lumbar vertebrae are between three and seven (Narita & Kuratani 2005). That is the presacral vertebrae (cervical, thoracic and lumbar vertebrae) are considered to be more conserved in fast-running

*Corresponding author: dr.salahuddin@iub.edu.pk

mammals due to pleiotropic effects on the lumbosacral transition (Galis et al. 2014). The mammalian vertebral column is highly variable, reflecting adaptations to a wide range of lifestyles (Galis 2014). The different segments of the trunk cope differently with a different form of gaits, in symmetric gaits (e.g., walking, trotting) the trunk bends laterally (Schilling & Carrier 2010). In contrast, the lumbar region during asymmetric gaits undergoes sagittal flexion and extension (Schilling & Carrier 2010, Schilling 2011). Some mammals use a larger sagittal plane (flexion and extension) during running than other mammals (Bertram & Gutmann 2009). These species are described as 'dorsomobile'. In contrast, those mammals which limit sagittal bending or restrict it to the lumbosacral joint are referred to as 'dorsostable' (Nakatsukasa 2008, Wood et al. 2011, Williams 2012). The large herbivorous mammals have been characterised as dorsostable lumbar regions. The characteristic features of the lumbar vertebrae are associated with sagittal mobility and locomotor function (Koob & Long 2000, Pierce et al. 2011, Molnar et al. 2014, Jones 2015a). Dorsomobile species typically have craniocaudally elongate lumbar regions. We hypothesised that the lumbar vertebral morphology of the chinkara *Gazella bennettii* (Sykes, 1831) (Mammalia: Bovidae) will be a typical example of fast running ungulates.

To our knowledge, there is no literature on the specific anatomical characteristics of chinkara deer lumbar vertebrae. The purpose of the present study is to establish a preliminary anatomical and osteometric database on the adult chinkara lumbar vertebrae.

Materials and Methods

In this study, lumbar vertebrae from twenty (20) specimens of homogeneous groups of adult male and female chinkara (*Gazella bennettii*) from the same locality were studied, to reduce differences due to sampling from dissimilar races and sources to a minimum (Guintard & Lallemand 2003, Clutton et al. 1990). The lumbar vertebrae for morphological studies were collected after natural mortality from the Manglot Wildlife Park and Ungulate Breeding Centre, Nizampur, Khyber Pakhtunkhwa, Pakistan. Age and sex of all the studied chinkara were noted at the time of post mortem examination and carcasses of males and females were buried separately in a designated location within the park premises to obtain lumbar vertebrae. After a period of approximately 4 to 5 months, the

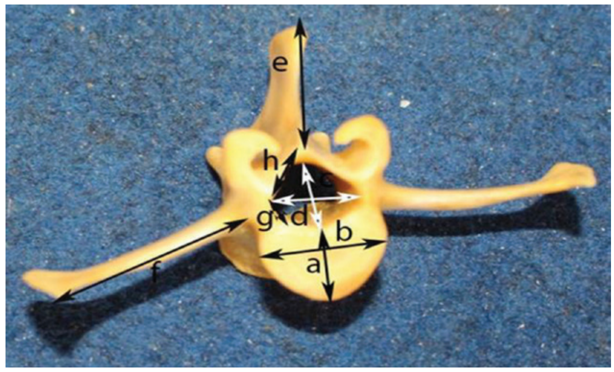

Fig. 1. Cranial vertebra. a. Cranial vertebral body height; b. Cranial vertebral body breadth; c. Cranial vertebral canal breadth; d. Cranial vertebral canal height; g. Pedicle depth; h. Lamina depth; e. Spinous process length; f. Cranial transverse process length.

lumbar vertebrae of each male and female chinkara were unearthed. The gross morphological features of the vertebrae were described using the terminology given in Nomina Anatomica Veterinaria (2017, 6th Edition). The gross morphological and osteometric readings were obtained as mentioned in human and veterinary literature (McLain et al. 2002, Mageed et al. 2013) at the University of Veterinary and Animal Sciences, Lahore, Pakistan. Each measurement was repeated three times by two independent observers and the mean values were recorded.

The lumbar parameters analysed were as follows:

Vertebral body (*Corpus vertebrae*) dimensions (Fig. 1): 1) Cranial vertebral body (*Caput vertebrae or extremitas cranialis*) breadth (CVBB); 2) Cranial vertebral body (*Caput vertebrae or extremitas cranialis*) height (CVBH); 3) Caudal vertebral body breadth (*Fossa vertebrae, extremitas caudalis*) (CDVBB); 4) Caudal vertebral body height (*Fossa vertebrae, extremitas caudalis*) (CDVBH).

Vertebral canal (*Canalis vertebralis*) dimensions (Fig. 1): 1) Cranial Vertebral canal breadth (CVCB); 2) Cranial Vertebral canal height (CVCH); 3) Caudal Vertebral canal breadth (CDVCB); 4) Caudal Vertebral canal breadth (CDVCH).

Vertebral arch dimensions (Fig. 1): 1) Pedicle (*Pediculus arcus vertebrae*) width (PW); 2) Pedicle depth (PD); 3) Lamina (*Lamina arcus vertebrae*) width (LW); 4) Lamina depth (LD).

Spinous process length measurements (Fig. 1): 1) Spinous process (*Processus spinosus*) length (SPL).

Transverse process length (*Proccessus transversus, processus costalis*) dimensions (Fig. 1): Cranial transverse process length (CTPL); 2) Caudal transverse process length (CDTPL).

All anatomic values were expressed as the mean ± standard deviation (SD) and means between male and female chinkara were compared with the Student t-test. Analysis of data was conducted with SPSS version 20.0 (SPSS, Inc., Chicago, IL) and differences were considered significant at $P < 0.05$.

Results

There were a total of six lumbar vertebrae (*Vertebrae lumbales*) in chinkara. Each anatomical feature of the vertebrae explained in detail.

The vertebral bodies (*Corpus vertebrae*) of the lumbar vertebrae were cylindrical, distinctly constricted in the centre and expended on either end. The vertebral bodies were craniocaudally lengthy and dorsoventrally shorter. The vertebral bodies were opisthocoelous means extremitas cranialis convex and extremitas caudalis concave throughout the lumbar vertebrae (Fig. 2). The ventral crest (*Crista ventralis*) was in the form of a thin clearly visible median ridge and present in all lumbar vertebrae. The ventral surface of the body was wider and flatter caudally from L1 to L6.

The diameter of the vertebral canal was uniform up to the 3rd lumbar vertebra and then caudally to L3 increases both at the cranial and caudal aspect in width and height up to the last lumbar vertebra. The caudal vertebral notches (*Incisurae vertebrales caudales*) were larger than the cranial (Incisurae vertebrales craniales) ones. The intervertebral foramen (*Foramen intervertabrale*) was larger between the lumbar vertebrae and sometimes forms complete lateral vertebral foramen (*Foramen vertebrale laterale*) in the cranial part of the series. The vertebral bodies (*Corpus vertebrae*) were cordiform shaped cranially while caudally it was elongated sagittally (Fig. 2). The craniocaudal lengths of the vertebral bodies were uniform in the first five vertebrae but in the sixth lumbar vertebrae, the length decreases and width increased.

The osteometric measurements estimated in the present study for the CVBB, CVBH, CDVBB and CDVBH of the vertebral body for L1 to L6 in males and females are presented in Table 1. The values of the cranial vertebral (*Caput vertebrae or extremitas cranialis*) body breadth (CVBB), cranial vertebral body height (CVBH) and caudal vertebral (*Fossa vertebrae, extremitas caudalis*) body breadth (CDVBB) increased from L1 to L6 in both males and females. The osteometric measurements estimated in the present study for the cranial vertebral canal breadth (CVCB), cranial vertebral canal height (CVCH), caudal vertebral canal breadth (CDVCB) and caudal vertebral canal height (CDVCH) of the spinal canal for L1 to L6 in males and females are presented in Table 1. The values of CVCB, CVCH, CDVCB and CDVCH increased from L1 to L6 in both males and females, showing that the dimensions of the spinal canal increased caudally. The values of the CVCH and CDVCH of the first lumbar vertebrae were significantly higher in males ($P<0.05$) compared to females. The values of the CVCB and CDVCB of the second lumbar vertebrae were significantly lesser in females ($P<0.05$) than in males. The values of the CVCH of the third lumbar vertebrae were significantly higher in males ($P<0.05$) than in females. The val-

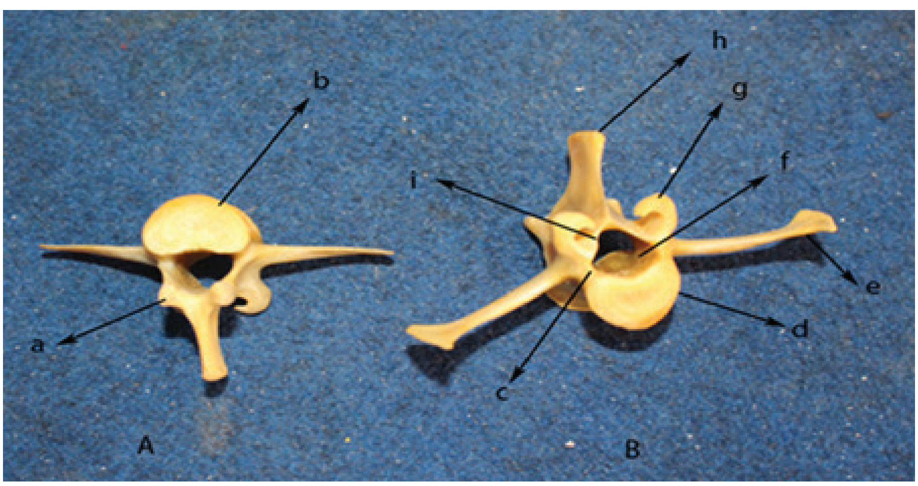

Fig. 2. Caudal (A) and cranial (B) view of the chinkara fourth lumbar vertebrae (L4). a. Caudal articular process; b. Vertebral body; c. Pedicle; d. Vertebral body; e. Transverse process, f. Vertebral canal; g. Cranial articular process; h. Spinous process; i. Lamina.

Table 1. Osteometric measurements of lumbar vertebrae (vertebral body and vertebral canal) of adult chinkara. Differences considered significant at P < 0.05. Legend: P - P-value.

		Male	Female	P-value	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value
		L1±SD	L1±SD		L2±SD	L2±SD		L3±SD	L3±SD		L4± SD	L4±SD		L5±SD	L5±SD		L6±SD	L6±SD	
Vertebral body	CVBB	1.65±0.03	1.42±0.04	.00	1.59±0.05	1.36±0.06	.01	1.65±0.04	1.42±0.05	.04	1.59±0.04	1.36±0.04	.03	1.70±0.04	1.47±0.05	.01	1.98±0.04	1.75±0.04	.02
	CVBH	0.94±0.02	0.82±0.03	.03	0.97±0.04	0.85±0.03	.02	1.07±0.03	0.95±0.07	.09	1.66±0.03	1.54±0.03	.42	1.65±0.07	1.53±0.04	.22	1.07±0.03	0.95±0.03	.31
	CDVBB	1.72±0.04	1.57±0.04	.03	1.68±0.04	1.53±0.04	.30	1.66±0.04	1.51±0.03	.40	1.77±0.04	1.62±0.04	.40	2.01±0.03	1.69±0.04	.14	1.77±0.04	1.62±0.04	.08
	CDVBH	1.09±0.03	0.99±0.04	.19	0.94±0.04	0.84±0.03	.19	1.11±0.04	1.01±0.05	.01	0.97±0.04	0.87±0.04	.29	1.05±0.05	0.95±0.04	.09	1.04±0.03	0.94±0.04	.07
Vertebral canal	CVCB	1.11±0.04	0.97±0.05	.43	1.34±0.03	1.20±0.04	.05	1.41±0.04	1.27±0.09	.53	1.45±0.05	1.31±0.05	.34	1.44±0.09	1.30±0.03	.53	1.84±0.04	1.70±0.04	.04
	CVCH	0.94±0.03	0.83±0.03	.04	0.98±0.04	0.87±0.03	.86	0.90±0.06	0.79±0.05	.04	1.06±0.03	0.95±0.03	.04	1.30±0.05	1.19±0.04	.17	1.36±0.03	1.25±0.06	.02
	CDVCB	1.2±0.02	1.05±0.04	.07	1.38±0.03	1.23±0.04	.03	1.42±0.05	1.27±0.05	.08	1.64±0.04	1.49±0.04	.04	1.61±0.05	1.46±.03	.11	2.05±0.04	1.90±0.05	.03
	CDVCH	1.18±0.04	1.06±0.32	.03	1.12±0.04	1.00±0.04	.04	0.94±0.06	0.82±0.09	.10	1.26±0.32	1.14±0.32	.03	1.33±0.09	1.21±0.04	.03	1.32±0.04	1.20±0.06	.05

Table 2. Osteometric measurements of the vertebral arch, spinous process length and transverse length of lumbar vertebrae of adult chinkara. Differences considered significant at P < 0.05. Legend: P - P-value.

		Male	Female	P	Male	Female	P	Male	Female	P	Male	Female	P	Male	Female	P	Male	Female	P
		L1±SD	L1±SD		L2±SD	L2±SD		L3±SD	L3±SD		L4± SD	L4±SD		L5±SD	L5±SD		L6±SD	L6±SD	
Pedicle	PW	0.31±0.04	0.22±0.04	.40	0.31±0.03	0.22±0.06	.43	0.39±0.04	0.30±0.02	.02	0.45±0.04	0.31±0.04	.02	0.29±0.02	0.32±0.03	.40	0.43±0.06	0.34±0.04	.43
	PD	0.57±0.03	0.49±0.03	.19	0.55±0.04	0.47±0.08	.16	0.41±0.04	0.33±0.07	.03	0.47±0.03	0.39±0.03	.04	0.61±0.07	0.53±0.04	.19	0.48±0.08	0.40±0.04	.10
Lamina	LW	0.23±0.02	0.19±0.02	.53	0.29±0.03	0.25±0.05	.59	0.18±0.05	0.24±0.04	.02	0.27±0.02	0.23±0.02	.04	0.24±0.04	0.20±0.03	.53	0.18±0.05	0.14±0.05	.09
	LD	0.95±0.04	0.84±0.05	.86	0.74±0.04	0.63±0.06	.79	0.84±0.04	0.73±0.03	.05	0.95±0.05	0.84±0.05	.04	1.09±0.03	0.98±0.04	.86	1.68±0.06	1.57±0.04	.86
Spinous process length	SPL	2.42±0.03	2.26±0.05	.03	1.87±0.04	1.71±0.04	.04	2.42±0.02	2.26±0.04	.19	2.22±0.05	2.06±0.05	.19	1.95±0.04	1.79±0.04	.03	2.00±0.04	1.84±0.02	.04
Transverse process length	CTPL	2.25±0.02	2.14±0.04	.04	3.27±0.06	3.16±0.04	.59	4.18±0.03	4.07±0.04	.53	4.29±0.04	4.18±0.04	.63	3.96±0.04	3.85±0.06	.03	3.94±0.04	3.83±0.03	.04
	CDT-PL	2.43±0.06	2.33±0.04	.05	3.50±0.08	3.40± 0.05	.39	4.50±0.06	4.40±0.03	.19	4.49±0.04	4.39±0.04	.09	4.48±0.03	4.38±0.08	.57	4.19±0.05	4.09±0.06	.03

ues of the CVCH and CDVCB of the fourth lumbar vertebrae were significantly ($P<0.05$) greater in males than in females. The values of the CDVCH fifth lumbar vertebrae were significantly ($P<0.05$) higher in males. The average values of the CVCB, CVCH, CDVCB and CDVCH of the sixth lumbar vertebrae were significantly ($P<0.05$) higher in males, too.

The vertebral arch (*Arcus vertebrae*) consisted of right and left pedicles (*Pediculus arcus vertebrae)* and right and left laminae *(Lamina arcus vertebrae)*. The pedicles were placed ventrally and the laminae dorsally. The pedicles were connected perpendicularly with the dorsal surface of the vertebral body and its dorsal margins were projected laterally in chinkara. The ventral margins of the left and right laminae attached at 45^{O} with the pedicles. This type of articulation of the pedicle and laminae of the right and left side gave a roughly circular outline to the vertebral canal (Fig. 2). The pedicles were thicker than the laminae.

The osteometric measurements estimated for the vertebral arch (pedicle and lamina) from L1 to L6 in both male and female adult chinkara are presented in Table 2. The pedicle parameters estimated were pedicle width (PW) and pedicle depth (PD). The average values of the PW and PD of the first lumbar vertebrae in males and females were 0.31 ± 0.04 cm and 0.22 ± 0.04 cm and 0.57 ± 0.03 cm and 0.49 ± 0.03 cm, respectively. However, the average values of both studied parameters were higher in males than in females but this difference was not significant ($P>0.05$). The lamina parameters estimated were lamina width (LW) and lamina depth (LD) (Table 2).

The spinous processes (*Processus spinosus*) notified in these animals were mostly rectangular and similar in height except for L6, which was low in height (Fig. 2). The craniocaudal width of the spinous processes of the first four lumbar vertebrae was almost similar but diminishes in the last two. The dorsal summits of the spinous processes were pointed cranially (Fig. 3). The cranial border of the spinous process of all lumbar vertebrae was sharp and deeply concave. However, the caudal border was slightly concave except in the L6, in which it was straight. Such type of morphological arrangements between the cranial and caudal border of the spinous processes forming an oval space between the adjacent vertebrae. A wide space was present between the spinous process of L5 and L6. Cranially the spinous process was thinner than in its caudal aspect. The spinous processes were thicker at the base and tapered towards the tip (Fig. 2). The angle between the spinous process and transverse process (*Processus transversus*) were almost 90^{o} in all lumbar vertebrae. The osteometric measurements estimated in the present study for the spinous process length (SPL) for L1 to L6 in both males and females are presented in Table 2. It was noticed in the present study that the mean values of the SPL decrease from L1-L6 in both males and females. The average values of the SPL of the L1, L2, L3, L4, L5 and L6 in males and females were found to be 2.42 ± 0.03 cm and 2.26 ± 0.05, 1.87 ± 0.04 cm and 1.71 ± 0.04 cm, 2.42 ± 0.02 cm and 2.26 ± 0.04 cm, 2.22 ± 0.05 cm and 2.06 ± 0.05 cm, 1.95 ± 0.04 cm and 1.79 ± 0.04 cm and 2.00 ± 0.04 cm and 1.84 ± 0.02 cm, respectively.

The transverse processes (*Processus transversus*) were a long plate of the bone of each vertebra expanding mediolaterally at right angles from the vertebral body, flattened dorsoventrally, projects laterally and usually tilt slightly cranially and ventrally (Fig. 2). Their mediolateral length increased to the L3 and L4 and then decreases to the last one, which is the shortest. Sharp bony projections on both sides (left and right) were present on the cranial border on tips of the transverse process (Fig. 3). Near the vertebral bodies, the transverse processes were wider and became tapper towards the tip (Fig. 3). Its cranial borders were comparatively thick than the caudal ones (Fig. 2).

The osteometric measurements estimated in the present study for the transverse process length were the cranial transverse process length (CTPL) and caudal transverse length (CDTPL) from L1 to L6 in both males and females (Table 2). The values of the CTPL and CDTPL of the first lumbar

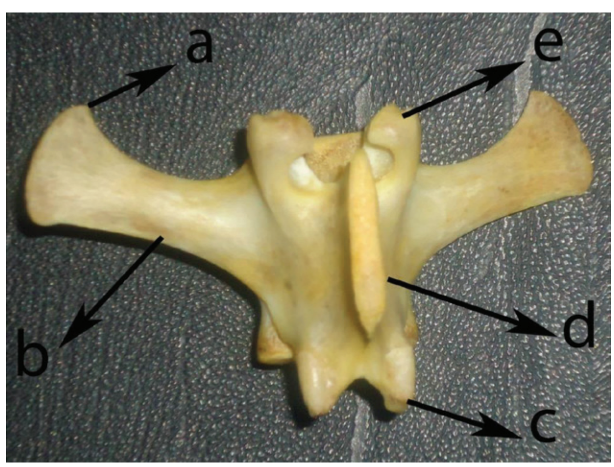

Fig. 3. Dorsal view of the chinkara third lumbar vertebra (L3). a. Cranial end of the transverse process; b. Caudal border of the transverse process; c. Caudal articular process; d. Spinous process; e. Cranial articular process.

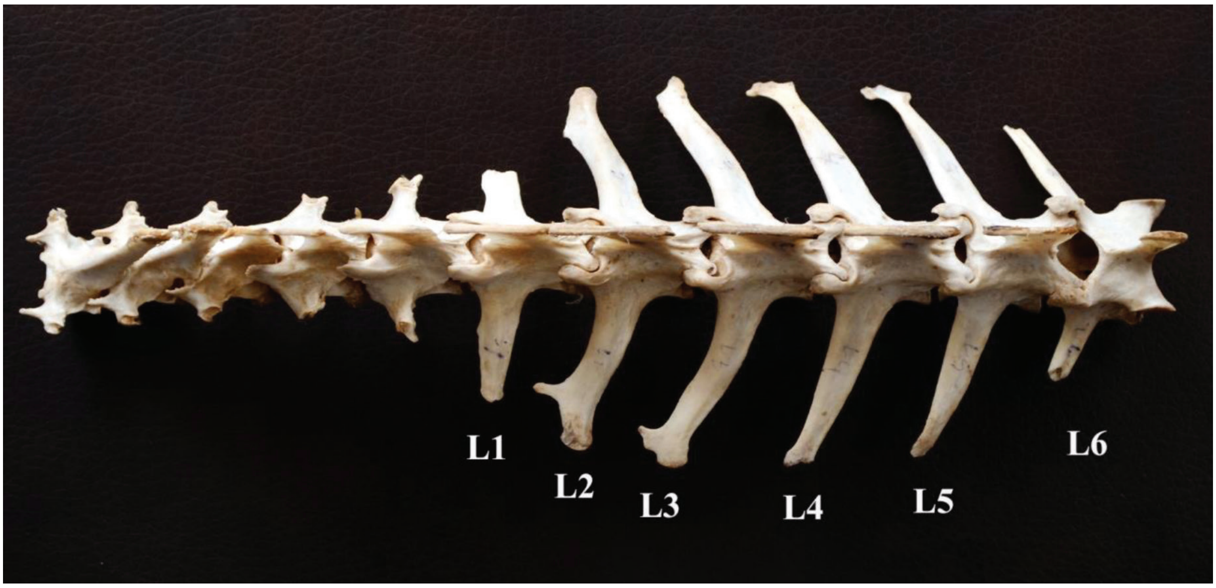

Fig. 4. Dorsal views of the lumbar vertebrae of the adult chinkara.

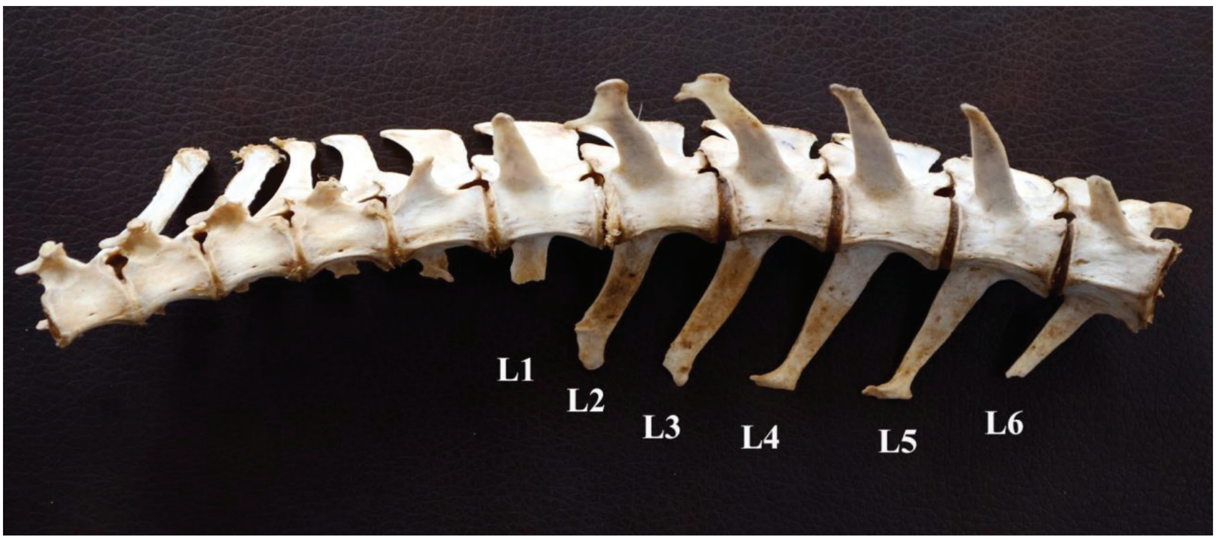

Fig. 5. Lateral view of the lumbar vertebrae of adult chinkara.

vertebrae were significantly higher in males than in females ($P<0.05$). The values of the CTPL and CDTPL of the second lumbar vertebrae were significantly higher in males ($P<0.05$) than in females. The values of the CTPL and CDTPL of the fourth lumbar vertebrae are significantly lesser in female ($P<0.05$). The average values of the CTPL and CDTPL of the fifth lumbar vertebrae were significantly lesser in females ($P<0.05$). The values of the CTPL and CDTPL of the sixth lumbar vertebrae were significantly higher in males ($P<0.05$).

The articular processes (*Processus articulares*) include cranial articular processes (*Processus articularis cranialis*) and caudal articular processes (*Processus articularis caudalis*). The space between the left and right cranial and left and right caudal articular process grossly increased caudally. The cranial articular processes had concave articular surfaces for the caudal articular processes of the preceding vertebrae (Fig. 2). The articular surfaces of the cranial articular processes were elongated craniocaudally and lie sagittally (Fig. 2). The articular surfaces of the caudal articular processes were convex, faces laterally and slightly dorsally and lie dorsally from the level of the cranial articular processes on the same vertebrae. Its convex articular surfaces fit into the grooved surfaces of the cranial pair of the succeeding vertebra.

Discussion

To our best knowledge, the present study is the first comprehensive examination of the morphology and osteometry of the lumbar vertebrae in adult chinkara. Therefore, it provides thoroughly gross anatomic details and osteometric measurements as reference values for the lumbar vertebrae of a healthy adult animals of this species.

It was observed that an increase in the body size of an animal put mechanical stresses on its skeleton (Biewener 2005). The animal's appendicular skeleton is adapted according to its requirements, i.e. structural allometry of long bones and soft tissue anatomy (Day & Jayne 2007, Doube et al. 2009). The lumbar region is exposed more to the mechanical stress of the increased abdominal weight; however, its response to the increasing size is less well studied in animals. The lumbar region of chinkara consists of six vertebrae. However, this number varies in different animals: six lumbar vertebrae are reported by Kumar et al. (2000) in red deer *(Cervus elaphus)*, Choudhary et al. (2015a) in blackbuck (*Antilope cervicapra*), Rajani & Chungath (2012) in Indian muntjac (*Muntiacus muntjak*). Levine et al. (2007) reported six lumbar vertebrae in the horse. Smuts & Bezuidenhout (1987) reported seven lumbar vertebrae in camels. In previous literature, it has been claimed that a comparatively long and flexible vertebral column can contribute significantly to increase stride length and provides an additional source of forwarding propulsion (Sargis 2001, Flores 2009). The lumbar region in chinkara comprised of six vertebrae and, therefore, being considered as a longer lumbar region, it may help in its fast running. This is supporting the hypothesis that the increased lumbar size may lead to increased stabilization of the lumbar region in the sagittal plane (Preuschoft & Franzen 2012).

In chinkara, the lumbar vertebral body was cordiform; this type of shape provides a more patent area for attachment of the ventral longitudinal ligament (VLL) (Sisson 1975a, b). This ligament (VLL), along with other spinal ligaments, provides regional stability (Zaneb et al. 2013) to the vertebral column. The stronger the attachment of the ligament is, the more stability it provides for the vertebral column. The transverse processes extend mediolaterally and provide attachment for intertransverse ligaments, epaxial and hypaxial muscles (Flower 1885). The length and orientation of the transverse processes of the lumbar vertebrae influence the stability and sagittal movements of the vertebral column. The lumbar vertebrae having straighter transverse processes are associated with more stabilised lumbar regions (Argot 2003). The morphology of the transverse processes elaborated in the present study in chinkara is similar to the reports of Jones (2015) on bovine. In bovines, the transverse processes are craniocaudally wider, mediolaterally longer and cranioventrally inclined in all lumbar vertebrae. These features support the functions of the longissimus dorsi muscle (Halpert et al. 1987). In chinkara, the transverse processes of the lumbar vertebrae are cranially and ventrally inclined. These morphological features (shape of the vertebral body and transverse processes) are interpreted as an adaptation in chinkara. It allows the sagittal mobility of the vertebral column easily in these animals because such type of anatomical features synergises the actions of the parallel component of the epaxial muscles on both sides (Ward & Latimer 1993).

The last seven presacral joints in fast running animals allow sagittal bending of the trunk during running (Schilling & Hackert 2006). The articular processes (zygapophyses) in fast running animals in this region are sagittally-oriented; such type of orientation permits bending and the movement is controlled by paraxial muscles (Schilling 2011). The anatomical features of the lumbar vertebrae are linked to sagittal flexibility and locomotor functions (Koob & Long 2000, Pierce et al. 2011, Molnar et al. 2014, Jones 2015a). In chinkara, anatomical features are evolved similar to those reported in dorsomobile animals. The articular surfaces of the cranial articular processes are elongated craniocaudally and lie sagittally in chinkara. These morphometric features of the cranial articular processes of the lumbar vertebrae allow chinkara to run fast, jump and leap. These findings of our study are also supported by the previous findings of Harty (2010) and Bebej et al. (2012) who stated that the sagittally-oriented and relatively planar zygapophyseal articular facets allow maximum sagittal bending. Dorsomobile animals naturally have craniocaudally lengthen lumbar regions. In contrast, in dorsostable animals, the facets of the cranial articular processes face laterally, dorsally and ventrally, forming a c-shaped joint restricting movement altogether (Boszczyk et al. 2001, Argot 2003, Wood et al. 2011).

Towards the sacrum, the distance between the caudal articular processes of the vertebrae varies in different quadrupedal animals; this distance is increased in order to provide increased torsion to these animals in this region (Bronek et al. 2001). Similar morphological trends are also observed in the chinkara. This is also an important feature that makes chinkara a dorsomobile animal. The role of caudal articular process in the range of vertebral movements are less understood. However, in chinkara, the articular surfaces of the caudal articular processes are convex, faces laterally and slightly dorsally and lie dorsally to the level of the cranial articular processes of the same vertebra.

The spinous processes protrude dorsally to provide attachment for nuchal, supraspinous and interspinous ligaments as well as for epaxial muscles (Bogduk 1980). The spinous processes of the lumbar vertebrae in chinkara are inclined cranially. This feature also assists chinkara in fast running. In slow-moving animals, the dorsal spinous processes of all vertebrae are backwards-pointing (Galis et al. 2014). In contrast, in fast-running animals, the spine is flexible dorsoventrally and laterally, the thorax is rather short and narrow and the lumbar spine is relatively long and slender (Halpert et al. 1987, Spoor et al. 1988). In bovines, slow running animals, the spinous processes are craniocaudally long and have square spinous processes (Jones 2015).

The values of the vertebral bodies parameters studied in the current research are fairly uniform from L1 to L6. Similar descriptions are devised in red deer (Kumar et al. 2000) and sheep (*Ovis aries*) (Mageed et al. 2013). However, higher values have been reported for the same measurements in red deer (Kumar et al. 2000) and sheep (Mageed et al. 2013).

The vertebral canal values calculated in the current study for both male and female chinkara gradually increases from L1 to L6. The analogous pattern is reported (Bai et al. 2012) in deer and sheep for the spinal values; however, they used only two measurements values (SCTD and SCSD). Higher values from the present study for the same parameters have been reported in deer (Cervidae) and sheep *(Ovis aries)* (Bai et al. 2012). The PW values showing a gradually increasing trend toward L6 except for L5. A similar description is reported by (BAI et al. 2012) in deer and sheep, the PDW gradually increased from L1 to L5. The PD and LW values are fairly uniform with minor increase and decrease from L1 to L6; however, the values of LH are increasing from L1 to L6. The same pattern for the pedicle parameters in deer and sheep are reported (Kumar et al. 2000).

Conclusion

The main purpose of this study was to provide a complete morphological and osteometric description of the lumbar vertebrae of adult chinkara. Significant morphological adaptations were found in the lumbar vertebrae in these animals. The morphological difference observed in the lumbar vertebrae of the adult chinkara may be an adaptation in these animals for fast running and long jumping in comparison to other related ungulates and small domestic ruminants. This study will serve as a baseline source for studying comparative morphology of other similar animals, especially anatomical features of fast-running mammals.

Conflict of interest: The authors do not have any conflicts of interest to declare.

References

Argot C. 2003. Postcranial functional adaptations in three South American Miocene borhyaenoids (Mammalia, Metatheria): *Cladosictis*, *Pseudonotictis*, and *Sipalocyon*. Alcheringa 27 (4): 303–356.

Bai X., Liu G., Xu C., Zhuang Y., Zhang J., Jia J. & Liu Y. 2012. Morphometry research of deer, sheep, and human lumbar spine: feasibility of using deer and sheep in spinal animal models. *International Journal of Morphology 30* (2): 510–520.

Bertram J. E. A. & Gutmann A. 2009. Motions of the running horse and cheetah revisited: fundamental mechanics of the transverse and rotary gallop. Journal of the Royal Society Interface 6: 549–559.

Biewener A. A. 2005. Biomechanical consequences of scaling. Journal of Experimental Biology 208: 1665–1676.

Boszczyk B. M., Boszczyk A. A. & Putz R. 2001. Comparative and functional anatomy of the mammalian lumbar spine. Anatomical Record 264 (2): 157–168.

Choudhary O. P., Ishwer S., Balwinder S., Sanjay K. B., Khan I. M., Srinivas S. & Nishant K. 2015. Osteomorphological studies on the thoracic vertebrae of Indian blackbuck (*Antelope cervicapra*). *Journal of Veterinary Anatomy* 8 (1): 31–36.

Chrószcz A., Janeczek M., Onar V., Pazvant G. & Pospieszny N. 2007. The shoulder height estimation in dogs based on the internal dimension of cranial cavity using mathematical formula. Anatomia, Histologia, Embryologia 36: 269–271.

Clutton-Brock J., Dennis-Bryan K. Armitage P. L. & Jewell P. A. 1990: Osteology of the Soay sheep. Bulletin of the Natural History Museum. Zoology 56: 1–56.

Day L. M. & Jayne B. C. 2007. Interspecific scaling of the morphology and posture of the limbs during the locomotion of cats (Felidae). Journal of Experimental Biology 210: 642–654.

Doube M., Conroy A. W., Christiansen P., Hutchinson J. R. & Shefelbine S. 2009. Three-dimensional geometric analysis of felid limb bone allometry. PLoS ONE 4: e4742

Driesch von Den A. 1976. A guide to the measurement of animal bones from archaeological sites. Peabody Museum Bulletin, Harvard University, Massachusetts.

Galis F., Carrier D. R., Alphen J. V., Van Der Mije S. D., Van Dooren T. J. M., Metz J. A. J. & Ten Broek C. M. A. 2014. Fast running restricts evolutionary change of the vertebral column in mammals. Proceedings of the National Academy of Sciences. 111 (31): 11401–11406.

Guintard C. & Lallemand M. 2003. Osteometric study of metapodial bones in sheep (*Ovis aries* L., 1758). Annals of Anatomy 185: 573–583.

Hafsa Z., Christian P. & Christian S. 2013. Functional anatomy and biomechanics of the equine thoracolumbar spine: a review. Turkish Journal of Veterinary Animal Sciences 37: 380–389.

Halpert A. P., Jenkins F. A. & Franks Jr H. 1987. Structure and scaling of the lumbar vertebrae in African bovids (Mammalia, Artiodactyla). Journal of Zoology 211: 239–258.

Jones K. E. 2015. Evolutionary allometry of lumbar shape in Felidae and Bovidae. Biological Journal of the *Linnean* Society 116: 721–740.

Koob T. J. & Long J. H. 2000. The vertebrate body axis: Evolution and mechanical function. American Zoologist 40: 1–18.

Kumar N., Kukreti S., Ishaque M. & Mulholland R. 2000. Anatomy of deer spine and its comparison to the human spine. Anatomical Record 260 (2): 189–203.

Levine J. M., Levine G. J., Hoffman A. G., Mez J. & Bratton G. R. 2007. Comparative Anatomy of the Horse, Ox and Dog: The Vertebral Column and Peripheral Nerves. CE article 1: 279–281.

Mageed M., Berner D., Jülke H., Hohaus C., Brehm W. & Gerlach K. 2013. Is sheep lumbar spine a suitable alternative model for human spinal researches? Morphometrical comparison study. Laboratory Animal Research 29 (4): 183–189.

Mageed M., Berner D, Jülke H., Hohaus C., Brehm W. & Gerlach K. 2013. Morphometrical dimensions of the sheep thoracolumbar vertebrae as seen on digitised CT images. Laboratory Animal Research 29 (3): 138–147.

McLain R. F., Yerby S. A. & Moseley T. A. 2002. Comparative morphometry of L4 vertebrae: comparison of large animal models for the human lumbar spine. Spine 27: 200–206.

Molnar J. L., Pierce S. E. & Hutchinson J. R. 2014. An experimental and morphometric test of the relationship between vertebral morphology and joint stiffness in Nile crocodiles (*Crocodylus niloticus*). Journal of Experimental Biology 217: 758–768.

Nakatsukasa M. & Hirose Y. 2003. Scaling of lumbar vertebrae in anthropoids and implications for evolution of the hominoid axial skeleton. Primates 44: 127–135.

Narita Y. & Kuratani S. 2005. Evolution of the vertebral formulae in mammals: A perspective on developmental constraints. The Journal of Experimental Zoology Part B: Molecular and Developmental Evolution 304 (2): 91–106.

Nomina Anatomica Veterinaria. 2017. Prepared by the International Committee on Veterinary Gross Anatomical Nomenclature and Authorized by the General Assembly of the World Association of Veterinary Anatomists, Sixth Edition.

Pierce S. E., Clack J. A. &. Hutchinson J. R. 2011. Comparative axial morphology in pinnipeds and its correlation with aquatic locomotory behaviour. Journal of Anatomy 219: 502–514.

Rajani C. V. & Chungath J. J. 2012. Studies on the Lumbar, Sacral and Coccygeal Vertebrae of Indian Muntjac (*Muntiacus muntjak*). Indian Journal of Veterinary Anatomy 24 (2): 78–79.

Schilling N. & Carrier D. R. 2010. Function of the epaxial muscles in walking, trotting and galloping dogs: implications for the evolution of epaxial muscle function in tetrapods. Journal of Experimental Biology 213: 1490–1502.

Schilling N. 2011. Evolution of the axial system in craniates: Morphology and function of the perivertebral musculature. Frontiers in Zoology 8: 4–23.

Sisson S. 1975. Ruminant, Porcine and Carnivore Osteology. In: Sisson and Grossman's the Anatomy of the Domestic Animals, Getty R. 5th Edition. W.B. Sounder's Co., Philadelphia, pp. 105–109.

Smuts M. S. & Bezuidenhout A. J. 1987. Anatomy of Dromedary. Oxford: Oxford Science Publications.

Spoor C. F. & Badoux D. M. 1988. Descriptive and functional myology of the back and hindlimb of the striped hyena (*Hyaena hyaena* L. 1758). Anatomisher Anzeiger 167 (4): 313–321.

Ward C. V. & Latimer B. 1993. The thoracic and lumbar vertebrae. In: Walker A. (Ed.): The Nariokotome *Homo erectus* skeleton. Cambridge: Cambridge University Press.

Williams S. A. 2012. Placement of the diaphragmatic vertebra in catarrhines: Implications for the evolution of dorsostability in hominoids and bipedalism in hominins. American Journal of Physical Anthropology. 148: 111–122.

Wood A. R., Bebej R. M., Manz C. L., Begun D. L. & Gingerich P. D. 2011. Postcranial functional morphology of *Hyracotherium* (Equidae, Perissodactyla) and locomotion in the earliest horses. Journal of Mammalian Evolution 18: 1–32.

Received: 26.08.2021
Accepted: 10.12.2021