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Original Article

Anatomy Section

Morphological and Morphometric Evaluation of Lumbar Vertebrae in Human Cadavers: A Cross-sectional Study

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ABSTRACT

Introduction: Awareness of the morphometry of vertebral elements is essential for the development of instruments related to the vertebral spine. It can be applied for the optimised design and advancement of spinal implants and instruments, particularly transpedicular screw more specifically, for robotic surgery.

Aim: To assess morphometric dimensions of the human lumbar vertebral bones in the Indian population.

Materials and Methods: A cross-sectional study was performed on dry-processed human lumbar vertebral bones procured from 14 cadavers of unspecified age and sex in the Department of Anatomy of MS Ramaiah Medical College, Bengaluru, Karnataka, India for a period of two years from March 2017 to March 2019. The lumbar vertebra morphometry of - body- height, antero-posterior, Transverse Diameter (TD); pedicle- length, width, height, interpedicular distance; vertebral foramen- transverse and Anteroposterior Diameters (APD); spine- length, height; lamina- length, height; Superior Articular Process (SAP)- height, width, distance between medial and posterior borders; Inferior Articular Process (IAP)- height, width, distance between IAP was described in terms of mean with standard deviation. Repeated measures of Analysis of Variance (ANOVA) using Generalised Linear Model (GLM) was used to compare different lumbar vertebrae in same cadavers. Pairwise comparison between any two combinations of vertebrae parameters, least significant difference was used to adjust the multiple comparisons.

Results: The vertebral body APD progressively increased from 26.4 mm at L1 to 32.4 mm at L5, while the TD increased from 37.5 mm to 48.2 mm. Analysis revealed statistically significant differences among the five lumbar vertebrae in vertebral body posterior height, anteroposterior and TDs, bilateral pedicle length and width, TD of the vertebral foramen, superior and Inferior Articular Process (IAP) height and width, distance between the medial and posterior borders of the SAP, and distance between the IAP (p-value <0.05).

Conclusion: Morphometric data of the lumbar vertebra can serve as additional information for higher-modality investigations such as Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). It is a prerequisite for the design and development of instruments and implants for vertebral surgery.

Keywords: Lumbar vertebra, Morphometry, Pedicle screws, Spinal implants

INTRODUCTION

The lumbar vertebrae with intervertebral discs in between them form the secondary curvature of the vertebral column (convex ventrally), which becomes apparent by one year of age when the child starts standing and walking. The formation of secondary curvatures helps transmit weight to the lower extremities in an erect posture. Each vertebra of any region presents a body in front and a vertebral arch made up of a pair of pedicles and laminae bearing seven processes: two transverse processes, two pairs of articular processes, and a single spinous process. The five lumbar vertebrae are identified by their massive reniform bodies, large triangular vertebral foramina, slender transverse process with the accessory tubercles postero-inferiorly except in the 5th where transverse process encroaches on the sides of the body from the junctions of the pedicles and laminae, concave superior articular facets directed backwards and medially with mammillary process in its posterior margin, convex inferior articular facets directed forwards and laterally and the spines which are broad, quadrilateral and horizontal in direction [1].

A proper understanding of the dimensions of vertebral elements is crucial for the development of instruments for the vertebral spine. It serves as a basis for the design and advancement of spinal implants and instruments, such as transpedicular screws, and, more specifically, in the context of robotic surgery. Ethnic variations have been reported in these dimensions [2,3].

The aim was to study the morphometry of the human vertebral bones of lumbar region in Indian population.

MATERIALS AND METHODS

A cross-sectional study was conducted in the Department of Anatomy, MS Ramaiah Medical College, Bengaluru, Karnataka, India from March 2017 to March 2019. Institutional Ethics Committee approval was obtained (MSRMC/EC/2016) for this study. Cadavers for the study were procured through the institute's voluntary body donation program. All the consecutive specimens of unspecified age and sex that were available were considered for the study. The sample size was 14 cadavers.

Inclusion criteria: All adult cadavers with intact lumbar vertebrae were included for the study.

Exclusion criteria: The lumbar vertebrae that were grossly damaged/deformed/with osteophytes/congenital anomalies were excluded from the study.

Study Procedure

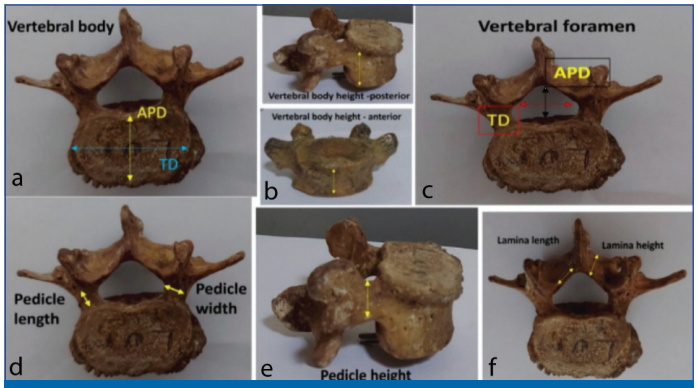
The soft-tissue covering the anterior and posterior aspects of lumbar vertebrae was removed completely in each cadaver. The lumbar vertebrae were identified from the proximal aspect of the first sacral vertebra, following which the lumbar vertebrae were sequentially labelled as L5, L4, L3, L2, and L1. All five lumbar vertebrae in each cadaver were disarticulated and dried. The morphometric parameters were measured with a digital stainless-steel Vernier caliper accurate to 0.01 mm. Each parameter was measured thrice, and the average was calculated. All observations were documented and specimens were photographed.

Parameters [Table/Fig-1,2] [4-6]: Vertebral body- APD- straight distance between the midpoints on the ventral and dorsal surface of the vertebral body in the midsagittal plane; TD- straight distance between the most laterally placed points on the margin of the cranial surface of the vertebral body; height (Ht) - Dorsal right and left- straight distance between the upper and lower surface of the vertebral body taken at the junction of body and root of pedicle; height -ventral - straight distance between the upper and lower surface of the vertebral body taken in the midsagittal plane on the ventral surface of the vertebra [Table/Fig-1].

Vertebral pedicle- length- distance from the tip of the pedicle to junction point of the body of vertebra; width - distance between the medial and lateral margins of the pedicle at its midpoint; height - distance between superior and inferior border of pedicle at midpoint [Table/Fig-1].

Vertebral lamina- length- a line connecting the medial borders of the superior and inferior articular facets to the midline of the interior aspect of the spinous process; height- distance from superior margin to the inferior margin of the lamina [Table/Fig-1].

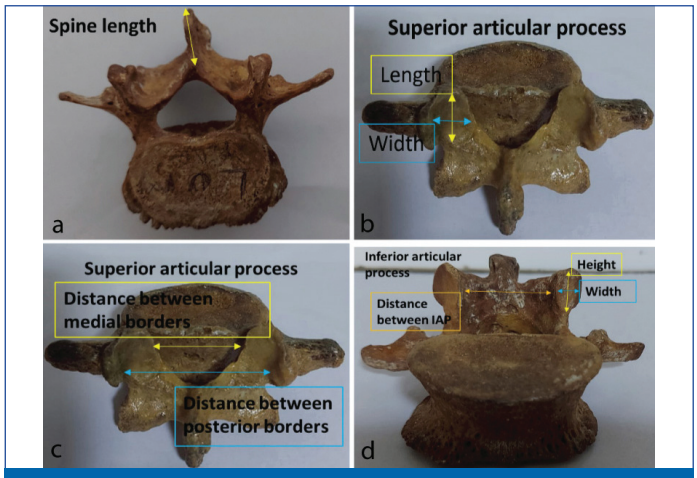
Vertebral foramen- APD- straight distance between the posterior upper margin of the body and the midpoint on the upper margin of the vertebral arch; TD- maximum distance between the medial points of the roots of the vertebral arch [Table/Fig-1].



[Table/Fig-1]: Morphometric parameters measured on a typical lumbar vertebra: (a) Vertebral body Anteroposterior Diameter (APD) and Transverse Diameter (TD); (b) Anterior and posterior vertebral body heights; (c) Vertebral foramen anteroposterior and Transverse Diameters (TD); (d) Pedicle length and width; (e) Pedicle height; (f) Lamina length and height.

Spinous process - Length - distance between the upper margin of the vertebral arch to the tip of the spine [Table/Fig-2].

Superior Articular Process (SAP)- Facetal height- maximum distance between superior and inferior end of the facetal surface; Width- maximum lateral diameter of the facetal surface; maximum distance between medial and posterior borders of SAP [Table/Fig-2].



[Table/Fig-2]: Morphometric parameters measured on a typical lumbar vertebra: (a) Spine length; (b) Superior Articular Process (SAP) measurements showing length and width; (c) Superior Articular Process (SAP) measurements showing the distance between the medial borders and the distance between the posterior borders; (d) Inferior Articular Process (IAP) measurements showing the distance between the Inferior Articular Processes (IAP), articular process height, and width.

IAP- Height- maximum distance between superior and inferior end of the facetal surface; Width- maximum lateral diameter of the facetal surface, maximal distance between IAP [Table/Fig-2].

STATISTICAL ANALYSIS

The data was analysed using IBM Corp (2020) IBM Statistical Package for the Social Sciences (SPSS) Statistics for windows (Version 27.0). The data of all the measurements of lumbar vertebrae were tested for normality using Shapiro-Wilk test. The values of all measurements of vertebrae have been presented with mean and standard deviation as the data was normally distributed. The intra-observer variation on all the measurements of lumbar vertebrae was analysed and found that that ICC >0.6 (p-value <0.05) for all the measurements. Repeated measures of ANOVA using GLM was used to compare different lumbar vertebrae in same cadavers. The sphericity was tested using Mauchly's test for the variance of difference between the repeated measures. Whenever Mauchly's test of Sphericity was not significant, the sphericity was assumed for comparing the tests of within subjects effects. While comparing the pairwise comparison between any two combinations of vertebrae parameters, least significant difference was used to adjust the multiple comparisons.

RESULTS

Vertebral body anteroposterior and TDs increased progressively from L1 to L5, with statistically significant differences among vertebral levels (p-value=0.001). Posterior vertebral body height decreased towards L5 and was significantly different bilaterally (p-value <0.01) [Table/Fig-3].

Superior and IAP dimensions, including height, width, and inter-articular distances, increased significantly towards the lower lumbar vertebrae, with the highest values observed at L5 (p-value <0.05) [Table/Fig-4].

The pairwise analysis demonstrated that L5 differs significantly from the other lumbar vertebrae for the majority of morphometric parameters, while adjacent vertebrae (e.g., L2 vs. L3 or L3 vs. L4) generally show fewer significant differences [Table/Fig-5].

DISCUSSION

The vertebral body APD increased from L1 to L5 in the present study, from 2.64±0.27 cm (L1) to 3.24±0.29 cm (L5). The present study findings demonstrated a progressive increase in vertebral body APD from the upper to the lower lumbar vertebrae, consistent with the caudal increase in vertebral body dimensions described by Berry JL et al., [2]. In contrast, posterior vertebral body height did not show a continuous increase across all lumbar levels, a pattern that was also consistent with Berry JL et al., who reported an initial increase followed by a decrease in the lower lumbar vertebrae.

Londhe BG et al., in a study on 45 sets of lumbar vertebrae from a Western Indian population, reported a gradual increase in pedicle length, height, and thickness from L1 to L4, with a marked increase in pedicle thickness at L5 [7]. They also observed a progressive increase in the transverse pedicle angle, with an abrupt increase at L5.

Nayak T et al., in a morphometric study of 125 lumbar vertebrae from a Western Indian population, also reported a progressive increase in pedicle width from L1 (6.30±0.87 mm) to L5 (15.79±1.82 mm), whereas pedicle height showed a gradual decrease from L1 (15.74±1.43 mm) to L5 (14.15±1.66 mm) [8]. A comparable trend was observed in the present study, where pedicle width increased and pedicle height decreased towards the lower lumbar vertebrae, but did not differ significantly among the levels.

The accurate knowledge of pedicle morphology and its relationship to vertebral body is essential for surgeons undertaking spinal stabilisation procedures [3]. In children aged 5 to 16 years, Computed Tomography (CT) scan study has reported that majority of pedicles of the lower lumbar spine are sufficiently large to accommodate the

S. No.	Parameter	L1 n=14; mean (in cm) ±SD	L2 n=14; mean (in cm) ±SD	L3 n=14; mean (in cm) ±SD	L4 n=14; mean (in cm) ±SD	L5 n=14; mean (in cm) ±SD	p-value
1	Vertebral body height- anterior	2.14±0.26	2.22±0.31	2.13±0.32	2.26±0.30	2.18±0.32	0.53
2	Vertebral body height- intermediate- right	2.16±0.24	2.17±0.32	2.05±0.24	2.12±0.30	2.16±0.37	0.62
3	Vertebral body height- intermediate- left	2.19±0.25	2.11±0.27	2.06±0.25	2.14±0.26	2.04±0.35	0.44
4	Vertebral body height- posterior- right	2.36±0.24	2.37±0.36	2.08±0.34	2.11±0.26	1.99±0.29	0.001
5	Vertebral body height- posterior- left	2.36±0.25	2.34±0.31	2.12±0.30	2.26±0.49	1.96±0.33	0.008
6	Vertebral body- APD	2.64±0.27	2.84±0.29	3.06±0.38	3.06±0.46	3.24±0.29	0.001
7	Vertebral body- TD	3.75±0.40	3.94±0.57	4.27±0.60	4.45±0.43	4.82±0.65	0.001
8	Vertebral pedicle- length- right	0.52±0.12	0.52±0.14	0.51±0.14	0.46±0.13	0.31±0.08	<0.001
9	Vertebral pedicle- length- left	0.59±0.29	0.61±0.30	0.52±0.13	0.51±0.22	0.31±0.08	<0.001
10	Vertebral pedicle- height- right	1.51±0.19	1.51±0.16	1.65±0.20	1.57±0.14	1.50±0.20	0.11
11	Vertebral pedicle- height- left	1.49±0.19	1.51±0.17	1.56±0.21	1.55±0.20	1.46±0.20	0.51
12	Vertebral pedicle- width- right	0.69±0.12	0.66±0.15	0.70±0.17	0.91±0.38	1.20±0.34	0.001
13	Vertebral pedicle- width- left	0.67±0.11	0.64±0.12	0.74±0.15	0.81±0.18	1.21±0.32	0.001
14	Inter-pedicular distance	2.15±0.25	2.09±0.24	2.16±0.27	2.06±0.40	2.34±0.35	0.11
15	Vertebral foramen- APD	1.52±0.15	1.62±0.25	1.44±0.24	1.48±0.22	1.51±0.29	0.20
16	Vertebral foramen- TD	1.95±0.09	2.05±0.21	2.05±0.16	2.01±0.19	2.21±0.26	0.001

[Table/Fig-3]: Mean values of various measurements of the body and pedicle of lumbar vertebrae.

S. No.	Parameter	L1 n=14; mean (in cm) ±SD	L2 n=14; mean (in cm) ±SD	L3 n=14; mean (in cm) ±SD	L4 n=14; mean (in cm) ±SD	L5 n=14; mean (in cm) ±SD	p-value
1	Vertebral spine- length	1.94±0.33	2.05±0.46	2.06±0.51	2.17±0.50	2.03±0.40	0.44
2	Vertebral spine- height	1.91±0.35	1.81±0.51	1.92±0.25	1.98±0.28	1.76±0.30	0.38
3	Lamina- transverse length- right	0.69±0.16	0.74±0.40	0.68±0.22	0.69±0.21	0.82±0.23	0.43
4	Lamina- transverse length- left	0.79±0.46	0.74±0.32	0.71±0.32	0.70±0.20	0.82±0.24	0.84
5	Lamina- height- right	1.99±0.40	1.96±0.63	2.0±0.55	2.19±0.39	1.98±0.43	0.64
6	Lamina- height- left	1.89±0.51	2.08±0.53	2.11±0.40	2.15±0.31	2.04±0.42	0.51
7	SAP- height- right	1.43±0.23	1.50±0.25	1.49±0.18	1.51±0.26	1.68±0.28	0.04
8	SAP- height- left	1.39±0.24	1.44±0.25	1.51±0.28	1.47±0.25	1.65±0.21	0.03
9	SAP- width- right	0.98±0.30	1.02±0.32	1.28±0.21	1.27±0.20	1.53±0.22	0.001
10	SAP- width- left	1.10±0.18	1.02±0.36	1.20±0.18	1.29±0.22	1.53±0.20	0.001
11	Distance between medial borders of SAP	1.61±0.27	1.69±0.46	1.79±0.35	1.80±0.34	2.01±0.53	0.04
12	Distance between posterior borders of SAP	2.34±0.59	2.46±0.42	2.69±0.45	2.90±0.58	3.46±0.80	0.001
13	IAP - height- right	1.56±0.29	1.69±0.29	1.67±0.17	1.60±0.24	1.86±0.24	0.011
14	IAP- height- left	1.53±0.29	1.57±0.28	1.66±0.16	1.54±0.22	1.80±0.27	0.014
15	IAP- width- right	1.09±0.22	1.18±0.25	1.23±0.16	1.24±0.18	1.38±0.27	0.019
16	IAP- width- left	1.10±0.22	1.12±0.16	1.26±0.12	1.30±0.16	1.46±0.51	0.008
17	Distance between IAP	1.61±0.23	1.81±0.39	1.95±0.52	2.20±0.48	2.83±0.54	0.001

[Table/Fig-4]: Mean values of various measurements of the posterior vertebral arch.

S. No.	Parameters	L1 *Vs L2	L1 Vs L3	L1 Vs L4	L1 Vs L5	L2 Vs L3	L2 Vs L4	L2 Vs L5	L3 Vs L4	L3 Vs L5	L4 Vs L5
		p-values									
1	Vertebral body height- posterior- right	-	0.007	0.02	0.001	0.02	0.03	0.003	-	-	-
2	Vertebral body height- posterior- left	-	0.020	-	0.001	-	-	0.008	-	-	-
3	Vertebral body- APD	0.02	0.005	0.011	<0.001	0.05	-	0.001	-	-	-
4	Vertebral body-TD	-	0.001	0.001	0.001	0.001	0.001	0.001	0.04	0.001	0.001
5	Vertebral pedicle- length- right	-	-	-	<0.001	-	-	<0.001	-	<0.001	0.001
6	Vertebral pedicle- length- left	-	-	-	0.003	-	-	0.002	-	<0.001	0.002
7	Vertebral pedicle- width- right	-	-	-	0.001	-	0.016	0.001	-	0.001	0.038
8	Vertebral pedicle- width- left	-	-	0.03	0.001	-	0.004	0.001	-	0.001	0.001
9	Vertebral foramen- TD	-	0.02	-	0.001	-	-	0.05	-	0.008	0.002
10	SAP- height- right	-	-	-	0.03	-	-	-	-	-	0.03
11	SAP- width- right	-	0.02	0.006	0.001	0.032	0.03	<0.001	-	0.001	0.001
12	SAP- width- left	-	-	0.02	0.001	-	0.02	0.001	-	0.001	0.001
13	Distance between medial borders of SAP	-	-	-	0.030	-	-	-	-	-	-

14	Distance between posterior borders of SAP	-	-	0.021	0.001	-	0.019	0.003	-	0.012	0.02
15	IAP- height- right	-	-	-	0.02	-	-	-	-	0.033	0.009
16	IAP- height- left	-	-	-	0.04	-	-	0.02	0.03	-	0.01
17	IAP- width- right	-	-	0.05	0.007	-	-	0.04	-	-	-
18	IAP- width- left	-	-	0.02	0.04	0.04	0.008	0.05	-	-	-
19	Distance between IAP	-	0.03	0.001	0.001	-	0.02	0.001	-	0.001	0.003

[Table/Fig-5]: Parameters showing statistically significant differences among the five different vertebrae.
*Vs-versus; Pairwise comparison between any two combinations of vertebrae parameters, least significant difference was used to adjust the multiple comparisons

smallest screw used in clinical practice. The pedicle width at L1 is smaller than that of T12 [9].

The SAP width increased from L1 to L5 in the present study and in that of Satoskar SR et al., [10]. The IAP width increased from L1 to L5 in the present study and in the study by Satoskar SR et al., [10]. Facet morphometry is important for understanding spinal dynamics and for planning spinal nerve root and spinal canal decompression [10].

The morphometric data of cadaveric lumbar vertebrae provides useful baselines for geometric modelling; planning orthopaedic and spinal surgeries.

Limitation(s)

This being a cadaveric study, the demographic data like age, sex, and ethnicity could not be included.

CONCLUSION(S)

The pairwise analysis demonstrated significant morphometric differences among lumbar vertebral levels, confirming a gradual cranio-caudal variation in lumbar vertebral morphology. These findings provide region-specific morphometric data that may serve as a useful anatomical reference for spinal surgeons, radiologists, and implant designers during the planning and execution of lumbar spinal procedures.

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