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Assessment of Lumbar Vertebrae Morphometry Across Different Age Groups: A Computed Tomographic Study

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ABSTRACT

Background: Lumbar vertebral morphometry plays a critical role in spinal biomechanics, radiological interpretation, and surgical planning. Although several studies have evaluated lumbar vertebral dimensions, data on age-related morphometric changes in the Indian population remain limited.

Aim: To establish age-specific morphometric standards for lumbar vertebrae (L1–L5) and to assess age-related changes using computed tomography (CT).

Materials and Methods: This multicentric, cross-sectional study included 1000 CT scans of the lumbar spine from individuals aged 18–50 years. Thin-slice (1 mm) CT images were analyzed using a DICOM viewer to measure pedicle dimensions, vertebral body dimensions, canal parameters, disc-related indices, and interlaminar angles at levels L1–L5. Participants were categorized into four age groups. Statistical analysis was performed using ANOVA, with $p < 0.05$ considered significant.

Results: Significant age-related differences were observed across most morphometric parameters at all lumbar levels ($p < 0.001$). Transverse dimensions, interpedicular distance, and disc parameters increased progressively from L1 to L5, while vertebral heights showed a relative decline with advancing age. The greatest remodeling was observed at L4 and L5.

Conclusion: Lumbar vertebral morphometry demonstrates significant age- and level-dependent variation, with maximal structural adaptation at the lower lumbar levels. These findings provide valuable normative data for the Indian population and have important implications for radiological evaluation, implant design, and spinal surgery.

Introduction:

Owing to its complex anatomical structure, the vertebral column has been extensively studied for many years.[1] The complex biomechanical and anatomical interplay between the axis and the spinal column renders this region susceptible to congenital, traumatic, infectious, and degenerative conditions, leading to increased emphasis on its fixation for precise diagnosis and effective treatment of spinal disorders.[2] Many studies have been carried out to examine the morphometry of lumbar vertebrae in a Western population using fresh cadavers or

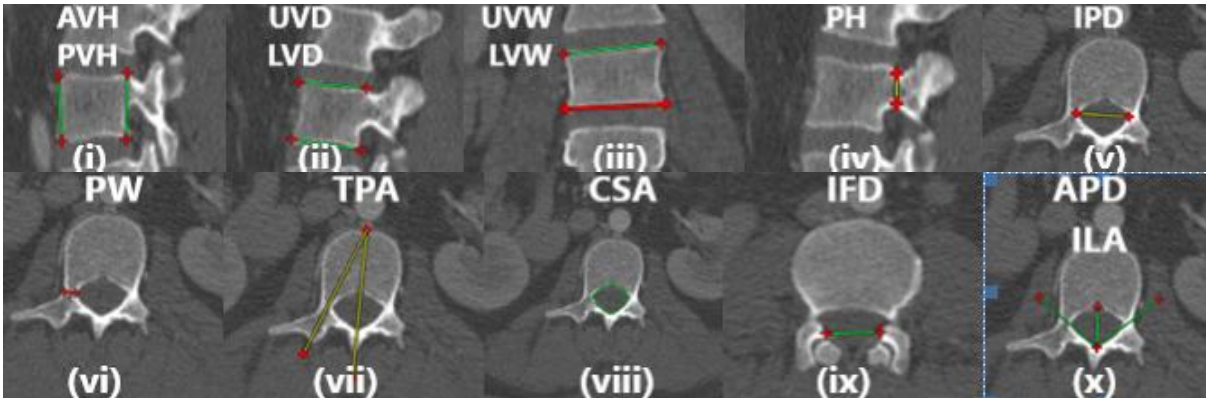
osteological collections.[3–5] these studies had adequate sample sizes but lacked demographic data including race, age and sex.[6] Computed tomographic (CT) imaging has increasingly been utilized in recent studies of lumbar vertebrae.[7,8] The recent application of CT for measuring various vertebral dimensions, including canal diameter and overall vertebral size, has resulted in improved evaluation of vertebral morphometry compared to X-ray and cadaver studies.[9] Intervertebral disk degeneration, often linked to the natural aging process, can lead to a forward shift of the vertebra. This displacement increases strain and may cause the pedicles, laminae, and articular processes to enlarge.[10]
This study was aimed to establish morphometric standards for all lumbar vertebrae across different age groups and to identify age-related changes in vertebral body shape and dimensions.

Materials and methods:

This study was conducted in the Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut. Study participants were recruited from the Departments of Radiology at Chhatrapati Shivaji Subharti Hospital, Meerut; Sri Venkateshwara Medical College, Ariyur, Puducherry; and Virk Hospital, Karnal, Haryana. Ethical clearance was obtained from the Institutional Ethics Committee, along with approval from the Professor and Head of the Department of Anatomy, Subharti Medical College. Demographic details including age, sex, and region were recorded for all participants. Individuals aged below 18 years or above 50 years, as well as those with a history of spinal surgery, vertebral fractures, deformities, osteoporosis, pre-existing spinal pathology, or congenital anomalies, were excluded from the study.

Morphometric measurements were obtained using the Digital Imaging and Communications in Medicine (DICOM) viewer, PACS version 3.0.11.5 (INFINITT Healthcare Co., Ltd., South Korea). Thin-slice abdominal computed tomography (CT) images were acquired using a 64-slice multidetector CT scanner (Brilliance 190P, Philips Healthcare). Scanning was performed from the level of the diaphragm to the pubic symphysis, with the field of view encompassing vertebral levels L1 to L5. Images were acquired with a slice thickness of 3 mm, followed by reconstruction of 1-mm-thick images in the bone window setting. The reconstructed images were reformatted in axial, sagittal, and coronal planes for analysis. In the present study, various morphometric parameters(pedicle height,pedicle width, trans pedicular angle and interpedicular distance,anterior and posterior vertebral height, upper and lower width and depth, canal area, anteroposterior diameter, of each vertebra from L1 to L5 were measured**.**

Measurements of anterior and posterior vertebral height(AVH,PVH); upper and lower vertebral width(UVW,LVW), upper and lower vertebral depth(UVD, LVD), transpedicular angle(TPA), leftand right pedicle height(PH) and width(PW); canal cross sectional area(CSA), canal anteroposterior diameter(APD), intralaminar angle(ILA), interfacet distance(ILA) were made at each lumbar level (Figure i-x). Left and right pedicle measurements were averaged, and the mean values used for statistical analysis once statistical analysis determined absence of significant side-to- side variation.



Statistical Analysis

Data was entered in excel spreadsheet. Data cleaned, validated and analyzed using SPSS software (V-20). All the categorical variables were expressed as frequencies and percentages. Quantitative data were expressed by mean and standard deviation. All numerical variables were tested for normality using Kolmogorov Smirnov test. Statistical difference between age groups were tested using Analysis of Variance (ANOVA) test. Correlation between the parameters were measured using Pearson's correlation coefficient. P-value <0.05 was considered statistically significant.

Table 1: Number Of Complete Lumbar Spine Specimens - Age distribution

Age (in years)	Frequency	Percent
<=20	56	5.6
21-30	238	23.8
31-40	294	29.4
41-50	400	40.0
>50	12	1.2
Total	1000	100.0

The age distribution shows that the majority of participants fall within the 41–50 years group (40%), followed by those aged 31–40 years (29.4%). Only a small proportion are older than 50 years (1.2%).

Figure 1: Age distribution

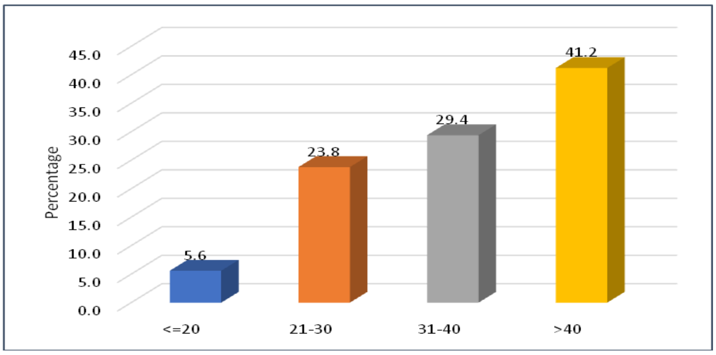


Table 2: Comparison of vertebral parameters between age groups at the level of L1

L1	Age (in years				F	P-value
	<=20	21-30	31-40	>40		
L1-PW	0.73±0.13	0.77±0.12	0.74±0.11	0.68±0.14	27.503	<0.001
L1-PH	1.16±0.16	1.49±0.36	1.16±0.19	1.34±0.18	93.187	<0.001
L1-IPD	1.98±0.23	2.14±0.23	2.15±0.16	2.17±0.19	15.980	<0.001
L1-TPA	21.44±2.37	22.99±2.48	22.22±2.93	21.39±3.93	13.211	<0.001
L1-AVH	2.39±0.24	2.61±0.19	2.36±0.17	2.46±0.22	72.172	<0.001
L1-PVH	2.71±0.26	2.87±0.19	2.53±0.19	2.71±0.20	130.828	<0.001
L1-UVW	3.84±0.51	4.06±0.32	3.87±0.37	4.09±0.35	27.334	<0.001
L1-LVW	4.06±0.54	4.35±0.36	4.21±0.33	4.43±0.42	26.979	<0.001
L1-UVD	2.83±0.46	2.97±0.32	2.74±0.27	2.97±0.33	34.275	<0.001
L1-LVD	2.92±0.23	3.05±0.34	2.86±0.28	3.05±0.29	28.852	<0.001
L1-AP	1.71±0.27	1.67±0.18	1.62±0.12	1.68±0.14	9.325	<0.001
L1-Area	2.41±0.27	2.49±0.48	2.29±0.38	2.56±0.43	24.494	<0.001
L1-IFD	1.53±0.10	1.67±0.25	1.65±0.19	1.64±0.25	5.092	0.002
L1-ILA	114.76±7.06	114.38±5.54	110.12±5.78	110.82±6.99	27.294	<0.001

*P-value based on ANOVA, Statistically significant if P<0.05

Most L1 variables differed significantly across age groups ($p < 0.001$). PW decreased from 0.73±0.13 in ≤20 years to 0.68±0.14 in >40 years (F=27.50). PH also showed major variation (F=93.19), confirming strong age-related structural changes.

Table 3: Comparison of vertebral parameters between age groups at the level of L2

L2	Age (in years				F	P-value
	<=20	21-30	31-40	>40		
L2-PW	0.77±0.22	0.73±0.10	0.71±0.09	0.70±0.12	9.914	<0.001
L2-PH	1.26±0.17	1.44±0.35	1.19±0.19	1.25±0.26	42.425	<0.001
L2-IPD	2.03±0.24	2.11±0.22	2.15±0.16	2.23±0.19	31.654	<0.001
L2-TPA	21.72±1.00	22.63±1.37	22.30±3.30	21.15±3.84	13.854	<0.001

L2-AVH	2.56±0.21	2.72±0.17	2.41±0.25	2.59±0.22	93.512	<0.001
L2-PVH	2.80±0.31	2.81±0.44	2.57±0.21	2.74±0.21	37.660	<0.001
L2-UVW	4.06±0.42	4.15±0.41	4.12±0.37	4.32±0.37	21.124	<0.001
L2-LVW	4.36±0.62	4.43±0.49	4.44±0.36	4.64±0.33	21.330	<0.001
L2-UVD	3.00±0.35	3.14±0.35	2.96±0.32	3.13±0.31	20.249	<0.001
L2-LVD	3.30±0.37	3.29±0.39	2.98±0.27	3.23±0.33	48.804	<0.001
L2-AP	1.55±0.10	1.54±0.20	1.59±0.15	1.62±0.14	13.581	<0.001
L2-Area	2.12±0.45	2.45±0.47	2.20±0.42	2.51±0.36	43.400	<0.001
L2-IFD	1.61±0.33	1.68±0.26	1.60±0.18	1.68±0.21	8.714	<0.001
L2-ILA	109.02±10.01	112.00±5.87	114.75±5.53	111.14±6.18	25.511	<0.001

*P-value based on ANOVA, Statistically significant if P<0.05

Almost all L2 variables varied significantly by age (p < 0.001). PW and PH showed strong age effects, with younger groups often having higher values. IPD increased steadily with age.

Table 4: Comparison of vertebral parameters between age groups at the level of L3

L3	Age (in years				F	P-value
	<=20	21-30	31-40	>40		
L3-PW	0.76±0.13	0.87±0.15	0.79±0.11	0.87±0.14	29.775	<0.001
L3-PH	1.11±0.33	1.38±0.40	1.13±0.24	1.25±0.22	36.992	<0.001
L3-IPD	2.24±0.38	2.23±0.28	2.32±0.21	2.38±0.25	19.172	<0.001
L3-TPA	22.69±3.29	23.69±2.07	24.46±3.42	23.06±4.52	9.508	<0.001
L3-AVH	2.75±0.19	2.80±0.24	2.44±0.31	2.59±0.22	94.070	<0.001
L3-PVH	2.88±0.20	2.77±0.50	2.56±0.22	2.74±0.23	31.759	<0.001
L3-UVW	4.30±0.57	4.39±0.35	4.47±0.32	4.55±0.40	13.388	<0.001
L3-LVW	4.62±0.56	4.73±0.36	4.72±0.34	4.95±0.33	36.836	<0.001
L3-UVD	3.16±0.23	3.23±0.36	3.06±0.25	3.29±0.32	33.879	<0.001
L3-LVD	3.13±0.36	3.19±0.35	3.16±0.26	3.29±0.29	14.050	<0.001
L3-AP	1.30±0.13	1.38±0.15	1.49±0.15	1.52±0.17	65.005	<0.001
L3-Area	2.09±0.32	2.21±0.38	2.30±0.39	2.51±0.40	41.424	<0.001
L3-IFD	1.66±0.10	1.64±0.28	1.60±0.22	1.64±0.24	2.381	0.068
L3-ILA	118.48±6.83	115.66±6.44	110.83±5.07	110.75±7.10	52.641	<0.001

*P-value based on ANOVA, Statistically significant if P<0.05

Most L3 measurements differed significantly across age groups (p < 0.001). TPA and AVH observed to be highly significant. Only IFD was nonsignificant (p=0.068).

Table 5: Comparison of vertebral parameters between age groups at the level of L4

L4	Age (in years				F	P-value
	<=20	21-30	31-40	>40		

L4-PW	1.05±0.17	1.04±0.13	0.98±0.15	1.06±0.18	12.795	<0.001
L4-PH	1.23±0.21	1.34±0.36	1.09±0.21	1.11±0.24	47.560	<0.001
L4-IPD	2.37±0.59	2.34±0.39	2.46±0.27	2.46±0.29	7.180	<0.001
L4-TPA	26.58±3.71	27.04±2.32	27.35±3.90	25.97±6.39	5.304	0.001
L4-AVH	2.64±0.28	2.74±0.24	2.34±0.21	2.62±0.23	155.976	<0.001
L4-PVH	2.71±0.27	2.73±0.26	2.45±0.21	2.58±0.22	69.359	<0.001
L4-UVW	4.48±0.70	4.65±0.41	4.71±0.43	4.88±0.42	24.841	<0.001
L4-LVW	4.74±0.47	4.87±0.41	4.83±0.41	5.10±0.36	38.091	<0.001
L4-UVD	3.23±0.32	3.27±0.34	3.18±0.24	3.33±0.30	16.167	<0.001
L4-LVD	3.21±0.20	3.35±0.30	3.17±0.24	3.36±0.30	33.206	<0.001
L4-AP	1.39±0.12	1.40±0.17	1.53±0.20	1.58±0.29	36.176	<0.001
L4-Area	2.12±0.42	2.33±0.51	2.52±0.44	2.65±0.58	31.107	<0.001
L4-IFD	1.53±0.23	1.81±0.30	1.70±0.28	1.77±0.34	15.585	<0.001
L4-ILA	109.98±6.84	109.25±8.88	104.57±8.89	103.10±6.40	38.393	<0.001

*P-value based on ANOVA, Statistically significant if P<0.05

Significant age differences were found for nearly all L4 variables, including AVH and PVH. Width measures also varied by age. These results indicate major age-linked morphological changes at L4.

Table 6: Comparison of vertebral parameters between age groups at the level of L5

L5	Age (in years)				F	P-value
	<=20	21-30	31-40	>40		
L5-PW	1.17±0.12	1.35±0.20	1.35±0.23	1.39±0.22	18.439	<0.001
L5-PH	1.03±0.14	1.28±0.53	1.00±0.20	1.06±0.20	39.631	<0.001
L5-IPD	3.06±0.68	2.81±0.59	2.92±0.41	2.98±0.44	7.483	<0.001
L5-TPA	34.92±5.74	34.70±3.14	34.35±4.94	32.88±8.46	5.665	0.001
L5-AVH	2.68±0.34	2.81±0.20	2.45±0.21	2.58±0.24	109.178	<0.001
L5-PVH	2.56±0.17	2.49±0.29	2.29±0.21	2.40±0.17	48.216	<0.001
L5-UVW	4.79±0.58	4.80±0.38	4.88±0.33	5.03±0.42	19.853	<0.001
L5-LVW	4.73±0.45	4.85±0.35	4.77±0.37	5.13±0.58	42.570	<0.001
L5-UVD	3.19±0.26	3.29±0.30	3.18±0.36	3.34±0.34	14.489	<0.001
L5-LVD	3.20±0.25	3.27±0.27	3.21±0.31	3.39±0.30	25.195	<0.001
L5-AP	1.40±0.11	1.41±0.14	1.71±0.53	1.60±0.30	35.848	<0.001
L5-Area	2.89±0.57	2.73±0.56	3.00±0.81	3.14±0.72	17.547	<0.001
L5-IFD	1.95±0.34	2.03±0.33	2.03±0.32	2.16±0.35	13.881	<0.001
L5-ILA	102.35±7.45	97.45±6.98	97.39±13.52	96.88±6.46	5.753	0.001

*P-value based on ANOVA, Statistically significant if P<0.05

L5 parameters showed widespread age-related differences (p < 0.001). PW and AVH were notably influenced. Older groups generally showed larger disc dimensions, indicating substantial age-associated structural variation.

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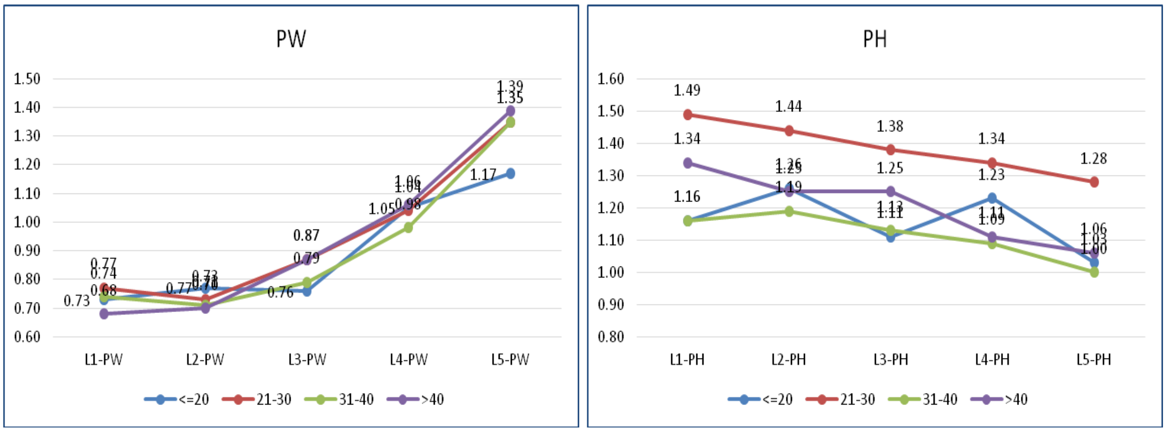
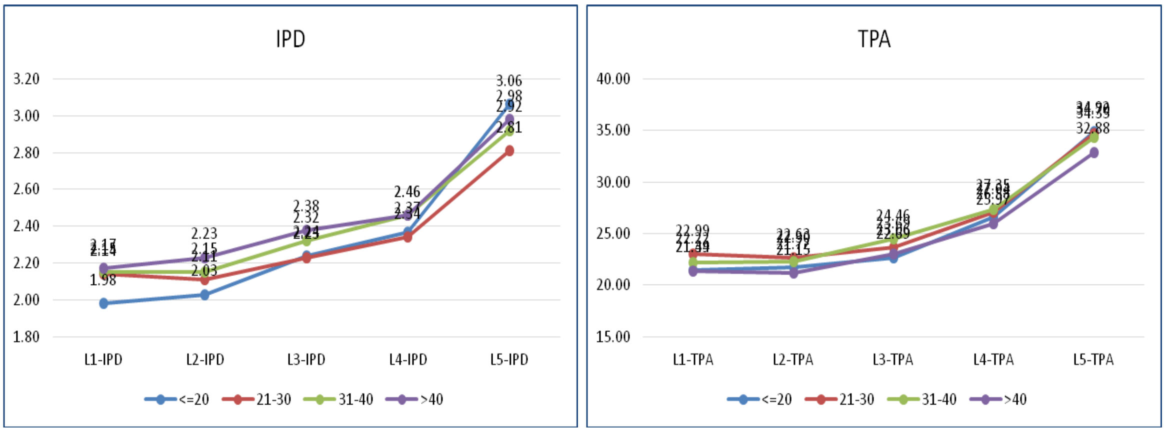
Figure 1,2: Variation in pedical dimensions in different age groups



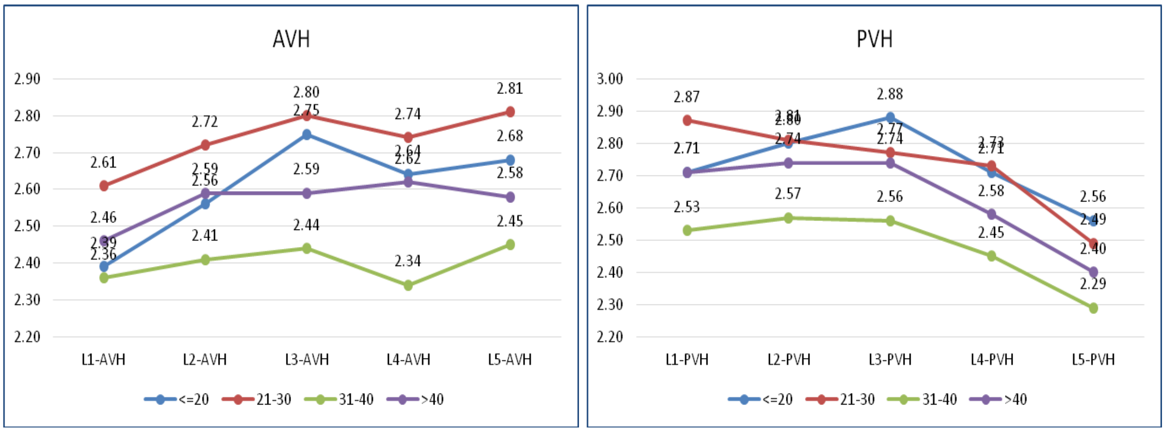
Pedicle width (PW)(figure 1) shows a progressive increase from L1 to L5 across all age groups, reflecting normal caudal enlargement, with higher values generally observed in older age groups, particularly at L5. In contrast, pedicle height (PH) (figure 2) demonstrates a gradual decrease from L1 to L5 in all age categories. Younger individuals tend to show slightly lower PW and relatively higher PH, while older age groups exhibit wider but shorter pedicles.

Figure 3,4: Variation in IPD and TPA in different age groups



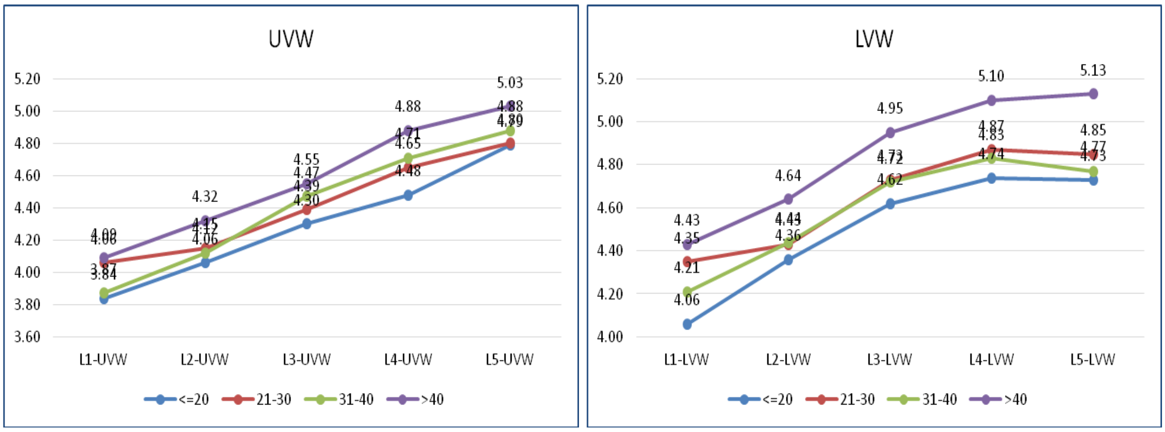
Interpedicular distance (IPD) (figure 3) increases progressively from L1 to L5 across all age groups, with a more marked rise at L5, reflecting normal caudal widening of the spinal canal. Older age groups generally show slightly higher IPD values, particularly at the lower lumbar levels. Transpedicular angle (TPA) (figure 4)also increases from L1 to L5 in all age categories, indicating a gradual lateralization of the pedicles in the caudal direction.

Figure 5,6: Variation in AVH and PVH in different age groups



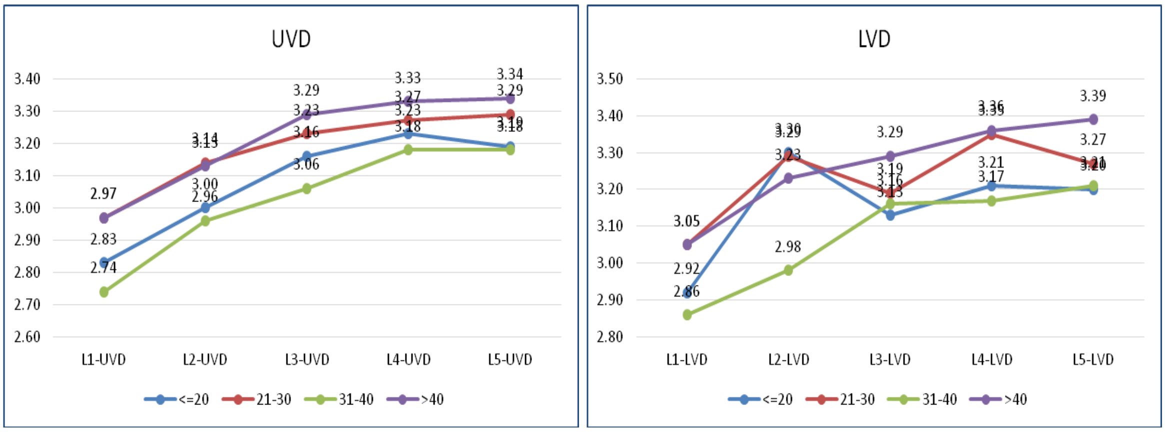
Anterior (AVH) (figure 5) and posterior vertebral height (PVH) (figure 6) show mild age-related variation across L1–L5. AVH generally increases from L1 to L3 in all age groups, followed by slight fluctuations at lower levels, with higher values typically observed in older age groups. PVH shows a gradual decline from L1 to L5 across all ages, more pronounced in older individuals.

Figure 7,8: Variation in UVW and LVW in different age groups



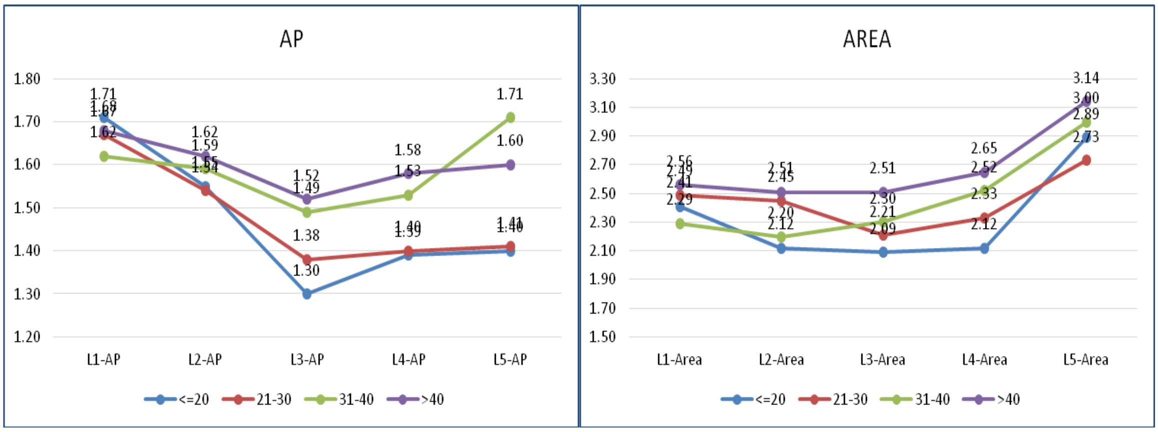
Upper (UVW)(figure 7) and lower vertebral width (LVW)(figure 8) increase progressively from L1 to L5 across all age groups, reflecting normal caudal widening of the lumbar vertebrae. Older age groups generally demonstrate greater widths, with the >40-year group showing the highest values, particularly at L4–L5.

Figure 8,9: Variation in UVD and LVD in different age groups



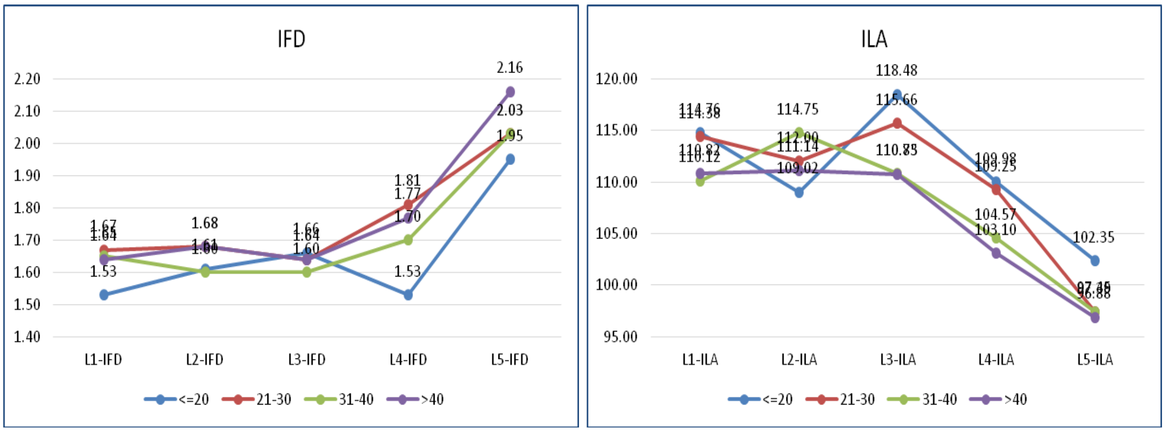
In **both UVD and LVD(figure (9,10)**, scores generally **increase from L1 to L5**, showing progressive improvement across levels.**Older age groups (+40)** consistently record the **highest values**, while **≤20** and **31–40** tend to start lower and improve more gradually. The gap between age groups **narrows at higher levels**, suggesting convergence in performance over time.

Figure 10,11: Variation in AP and AREA in different age groups



The **AP diameter (figure 10)** decreases from **L1 to L3** and then increases toward **L5** across all age groups, with younger individuals showing smaller values and older groups maintaining relatively larger dimensions. The **vertebral canal area(figure 11)** increases progressively from **L1 to L5** in all ages, with the largest areas seen in older age groups, especially at **L5**. Overall, both parameters demonstrate **caudal enlargement of lumbar vertebrae** and **age-related increase in vertebral dimensions**.

Figure 12,13: Variation in AP and AREA in different age groups



The **interfacet distance (IFD) (figure 12)** shows a gradual increase from **L1 to L5** across all age groups, with a marked rise at **L5**, particularly in older individuals, indicating caudal widening of the lumbar spine. In contrast, the **intra laminar angle (ILA) (figure 13)** demonstrates a general **decreasing trend from L1 to L5**, with higher values at upper lumbar levels and a pronounced reduction at **L4–L5**. Together, these patterns reflect **progressive caudal structural adaptation**, with increasing transverse dimensions and decreasing laminar angulation, more evident with advancing age.

Discussion:

The present study demonstrates significant age-related morphometric variations across all lumbar vertebral levels (L1–L5), with a clear cephalocaudal increase in the magnitude of change. Most parameters reached peak values in young adults (21–30 years) and showed variable remodeling in older age groups, reflecting adaptation to increasing biomechanical demands from L1 to L5.

At L1, most vertebral body and disc parameters varied significantly with age ($p < 0.001$). Pedicle width increased from 0.73 ± 0.13 cm in individuals ≤20 years to 0.77 ± 0.12 cm at 21–30 years, followed by a decline to 0.68 ± 0.14 cm in those >40 years. Posterior vertebral height showed a similar pattern (2.71 ± 0.26 cm to 2.87 ± 0.19 cm, then decreasing to 2.71 ± 0.20 cm). Intervertebral disc height also showed significant age-related variation (0.60–0.73 cm; $p < 0.001$**),** indicating early disc remodeling.

From L2 to L4, age-related changes became more pronounced. Vertebral widths and areas increased by approximately 5–10%**,** while vertebral heights declined by 8–15% with advancing age. Interpedicular distance and transverse pedicle angle increased significantly ($p < 0.001$), suggesting compensatory widening with increasing axial load.

The L5 vertebra showed the greatest degree of age-related remodeling. Transverse vertebral diameter was 15–20% larger than those at upper lumbar levels, while vertebral heights showed the greatest relative reduction with age.

In summary, lumbar vertebral morphometry is strongly influenced by both age and vertebral level. Upper lumbar levels show relatively modest changes, whereas lower levels—particularly L4 and L5—exhibit substantial remodeling characterized by reduced height, increased transverse dimensions. These findings provide valuable age- and level-specific reference data for radiological evaluation, implant design, and surgical planning.

The present findings are consistent with previous lumbar morphometric studies, all of whom reported level- and age-related variations in lumbar vertebral dimensions. Similar to Singh et al[11], this study demonstrates a progressive increase in pedicle width, interpedicular distance, and vertebral width from L1 to L5, reflecting increasing caudal load. Pedicle width increased from approximately 0.7–0.9 cm at L1 to 1.2–1.4 cm at L5, comparable to reported Indian population data.

Age-related reductions in vertebral body height observed in the present study align with findings by Masharawi et al[12], Bagri et al[13] ,who attributed these changes to degenerative remodeling. Vertebral height peaked in younger adults and declined after 40 years, particularly at L4–L5. The increase in vertebral area and canal dimensions toward the lower lumbar levels corresponds with CT-based observations by Zhou et al[14]**.**

Collectively, these similarities confirm that lumbar vertebral morphology is strongly influenced by age, spinal level, and biomechanical demand, and validate the present age-stratified data for clinical and surgical applications.

Conclusion:

The present CT-based study establishes comprehensive, age-specific morphometric reference values for lumbar vertebrae from L1 to L5 in an Indian population. Significant age-related changes were observed across most vertebral, pedicular, canal, and disc parameters, with a clear cephalocaudal gradient in the magnitude of variation. Upper lumbar vertebrae showed relatively modest remodeling, whereas lower levels—particularly L4 and L5—demonstrated pronounced structural adaptation characterized by increased transverse dimensions and reduced vertebral heights with advancing age. These changes likely reflect biomechanical compensation for increasing axial load and spinal stability requirements. The findings are consistent with previously reported biomechanical and morphometric studies and underscore the importance of population- and age-specific data. The normative values generated by this study may aid in accurate radiological assessment, optimize implant design, and improve surgical planning for lumbar spine disorders.

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