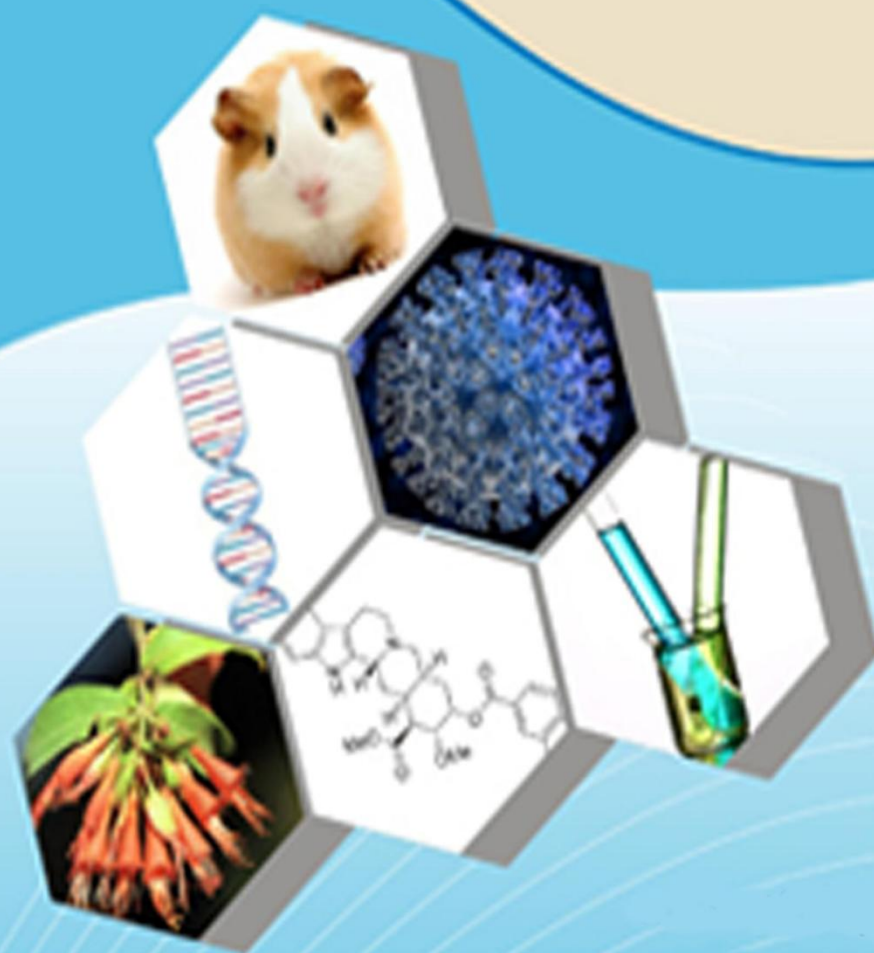




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## A Computed Tomography-based Morphometric Analysis of Lumbar Vertebrae with Respect to Gender

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### Background:

Morphometric analysis of the lumbar vertebrae is crucial for spinal surgery planning, implant development, forensic identification, and anthropological studies. Vertebral dimensions can differ according to sex, age, ethnicity, and biomechanical factors, making it essential to understand these variations for optimal clinical and research outcomes.

### Objectives:

This study aimed to investigate sex-based differences in lumbar vertebral morphometry (L1–L5) among adults in the Indian population using computed tomography (CT), thereby generating anatomical reference data specific to region and sex.

### Materials and Methods:

A cross-sectional CT-based study was performed on 1,000 adults (473 males, 527 females) aged 18–50 years, with equal representation from North and South India. High-resolution (1 mm) images from 64-slice multidetector CT scans were assessed using PACS software. Various vertebral parameters—including pedicle dimensions, vertebral body heights, vertebral widths and depths, spinal canal measurements, angular measurements, and posterior element parameters—were recorded for vertebrae L1–L5. Statistical analyses were conducted with SPSS v20, employing independent t-tests to compare morphometric differences between sexes.

### Results:

Males exhibited significantly greater values for most lumbar morphometric parameters across L1–L5, including pedicle measurements, vertebral body heights, spinal canal dimensions, and posterior elements ( $P < 0.001$ ). Sexual dimorphism was most consistent at L3 and most marked at the lower lumbar levels (L4–L5). No significant sex difference was observed in pedicle width at L5, whereas the interlaminar angle at L5 was significantly greater in females. Anteroposterior canal diameter displayed minimal or inconsistent sex differences, with occasional higher values in females at the upper lumbar levels.

### Conclusion:

This study demonstrates distinct, vertebral level-dependent sexual dimorphism in lumbar vertebral morphology within the Indian population. The results underscore the importance of



incorporating both gender and vertebral level considerations in spinal instrumentation, surgical planning, forensic evaluation, and anthropological research.

**Keywords:**

Lumbar vertebrae, CT morphometry, Sexual dimorphism, Pedicle dimensions, Spinal canal, Indian population

**Introduction:**

Analyzing the structure of lumbar vertebrae is crucial for a range of medical and scientific purposes, such as spinal surgery planning, designing orthopedic implants, forensic investigations, and anthropological research. Research has shown that the size and shape of vertebrae are affected by factors like sex, age, ethnicity, and individual biomechanical demands.<sup>1,2</sup> As people age, both vertebral bodies and intervertebral discs experience degenerative changes—including decreased height, shape modifications, and loss of bone density—which have been thoroughly described in anatomical and imaging studies.<sup>3,4</sup> Although significant correlations were observed between age and various measurements across different vertebral levels, the lumbar vertebral bodies did not exhibit uniform geometric changes with aging. Instead, particular regions and aspects of vertebral morphology showed distinct, sex-specific patterns of change.<sup>5</sup>

This study aimed to assess the morphometric characteristics of lumbar vertebrae with respect to gender, thereby enriching anatomical databases and providing valuable insights into clinical variations of the vertebral column.

**Materials and Methods:**

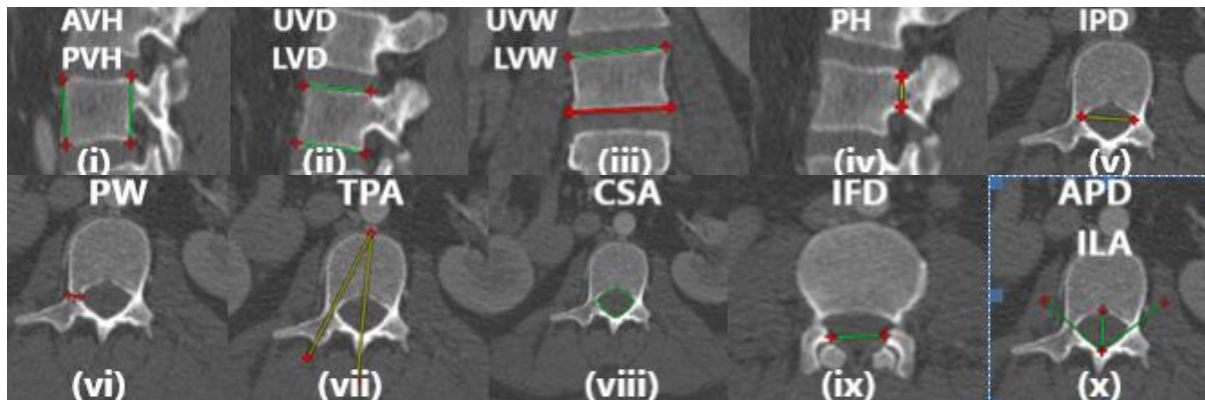
The study was conducted in the Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut. Study subjects were recruited from the Departments of Radiology at Chhatrapati Shivaji Subharti Hospital (Meerut), Sri Venkateshwara Medical College (Ariyur, Puducherry), and Virk Hospital (Karnal, Haryana). Ethical approval was obtained from the Institutional Ethics Committee and the Professor and Head, Department of Anatomy, Subharti Medical College. Demographic data (age, sex, and region) were recorded for all participants. All individuals with age <18 years or age >50 and subjects with history of spinal surgery, vertebrae fractures, deformities, osteoporosis, pre-existing spinal pathology and with congenital anomalies were excluded.

The digital imaging and communications in medicine (DICOM) Viewer, PACS 3.0.11.5 (INFINITT Healthcare Co, Ltd, South Korea), will be used to measure the thin-cut (1mm) abdominal CT Scan image by using 64-slice multidetector CT scan (Brilliance 190P 64-channel CT scanner, Philips). CT was taken from the level of diaphragm to pubic symphysis with area to be covered (field of view) from L1 to L5 vertebral level. The scan will be acquired with slice thickness of 3 mm and then 1 mm thick images were reconstructed in bone window setting from the source data. Then the images will be reformatted in axial, sagittal, and coronal planes and analyzed. In the presented study, different parameters of each vertebra from L1 to L5 level was 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), left and 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:

The data were entered into an Excel spreadsheet, then cleaned, validated, and analyzed using SPSS software (version 20). Categorical variables are presented as frequencies and percentages, while quantitative data are summarized as mean and standard deviation. The normality of numerical variables was assessed with the Kolmogorov-Smirnov test. Differences between regions and between genders for all parameters were evaluated using the two-sample t-test. Associations between parameters were examined using Pearson's correlation coefficient. A p-value less than 0.05 was considered statistically significant.

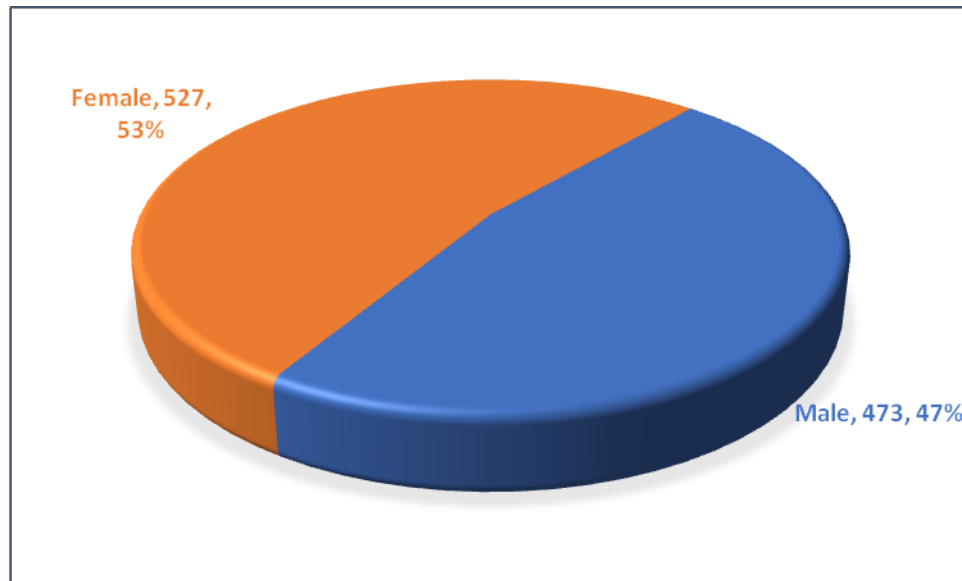
### Results

A total of 1,000 subjects comprising 500 North Indian and 500 South Indian individuals between the ages of 18 and 50 years were included in the present study. Demographic details such as age, gender, and regional distribution were recorded for all participants.

**Table 1: Gender distribution**

Gender	Frequency	Percent
Male	473	47.3
Female	527	52.7
Total	1000	100.0

The sample consists of slightly more females (52.7%) than males (47.3%). Overall, both genders are almost equally represented.

**Figure 1: Gender distribution****Table 2:** Comparative morphometric analysis at the level of L1 vertebra

L1	Gender		t	P-value
	Male	Female		
PW	0.78±0.12	0.68±0.12	12.756	<0.001
PH	1.38±0.30	1.25±0.21	8.138	<0.001
IPD	2.20±0.14	2.10±0.23	8.162	<0.001
TPA	22.55±3.04	21.54±3.49	4.850	<0.001
AVH	2.52±0.23	2.41±0.20	8.555	<0.001
PVH	2.79±0.20	2.61±0.22	13.195	<0.001
UVW	4.19±0.29	3.84±0.36	17.147	<0.001
LVW	4.54±0.35	4.13±0.36	18.152	<0.001
UVD	3.04±0.29	2.77±0.32	14.019	<0.001
LVD	3.15±0.24	2.84±0.29	18.142	<0.001
AP	1.66±0.17	1.66±0.15	.052	0.958
Area	2.48±0.49	2.43±0.38	1.854	0.064
IFD	1.72±0.24	1.57±0.20	10.938	<0.001
ILA	113.86±6.14	109.73±6.34	10.451	<0.001

\*P-value based on Two sample t-test, Statistically significant if  $P < 0.05$

At L1, males have significantly larger dimensions than females in most parameters ( $P < 0.001$ ), including pedicle width and height (0.78 vs 0.68; 1.38 vs 1.25), interpedicular distance (2.20 vs 2.10), vertebral heights—AVH (2.52 vs 2.41) and PVH (2.79 vs 2.61), (UVW 4.19 vs 3.84; LVW 4.54 vs 4.13; UVD 3.04 vs 2.77; LVD 3.15 vs 2.84), and posterior



elements— Interfacet distance( IFD) (1.72 vs 1.57) and interlaminar distance (ILA) (113.86° vs 109.73°). Transpedicular angle (TPA) is also higher in males (22.55° vs 21.54°). No significant gender difference is seen in AP diameter (1.66 vs 1.66; P = 0.958) and cross sectional area (2.48 vs 2.43; P = 0.064).

**Table 3: Comparative morphometric analysis at the level of L2 vertebra**

L2	Gender		t	P-value
	Male	Female		
PW	0.73±0.10	0.70±0.13	4.149	<0.001
PH	1.32±0.34	1.24±0.20	4.416	<0.001
IPD	2.20±0.19	2.13±0.21	5.326	<0.001
TPA	22.14±2.67	21.64±3.57	2.455	0.014
AVH	2.60±0.26	2.54±0.23	4.194	<0.001
PVH	2.73±0.36	2.69±0.23	2.040	0.042
UVW	4.38±0.34	4.06±0.38	13.907	<0.001
LVW	4.69±0.33	4.36±0.42	13.611	<0.001
UVD	3.18±0.27	2.98±0.36	9.594	<0.001
LVD	3.27±0.34	3.09±0.35	8.220	<0.001
AP	1.57±0.17	1.61±0.15	-4.451	<0.001
Area	2.38±0.49	2.39±0.38	-.514	0.607
IFD	1.71±0.24	1.60±0.21	7.221	<0.001
ILA	112.66±7.02	111.96±5.83	1.722	0.085

\*P-value based on Two sample t-test, Statistically significant if P<0.05

At L2, males show significantly larger dimensions than females in most parameters. Pedicle width and height are greater in males (PW: 0.73 vs 0.70; PH: 1.32 vs 1.24), as is interpedicular distance (2.20 vs 2.13). Vertebral heights are also higher in males—AVH (2.60 vs 2.54; P < 0.001) and PVH (2.73 vs 2.69; P = 0.042). vertebral width and height show marked male predominance (UVW 4.38 vs 4.06; LVW 4.69 vs 4.36; UVD 3.18 vs 2.98; LVD 3.27 vs 3.09; all P < 0.001). Trans pedicular angle TPA is slightly higher in males (22.14° vs 21.64°; P = 0.014), and interfacet distance IFD is greater (1.71 vs 1.60; P < 0.001). In contrast, AP diameter of canal is significantly larger in females (1.61 vs 1.57; P < 0.001), while vertebral canal area (2.38 vs 2.39; P = 0.607) and intralaminar angle ILA (112.66° vs 111.96°; P = 0.085) show no significant gender difference.

**Table 4: Comparative morphometric analysis at the level of L3 vertebra**

L3	Gender		t	P-value
	Male	Female		
PW	0.86±0.13	0.82±0.14	5.240	<0.001
PH	1.28±0.36	1.20±0.22	4.249	<0.001
IPD	2.37±0.27	2.27±0.24	6.691	<0.001
TPA	24.08±3.26	23.18±4.05	3.840	<0.001
AVH	2.65±0.29	2.57±0.27	4.480	<0.001
PVH	2.75±0.40	2.66±0.24	4.094	<0.001



UVW	4.62±0.35	4.34±0.36	2.198	<0.001
LVW	4.93±0.35	4.71±0.37	9.624	<0.001
UVD	3.29±0.29	3.13±0.33	8.086	<0.001
LVD	3.30±0.28	3.14±0.31	8.564	<0.001
AP	1.45±0.17	1.48±0.18	-2.020	0.044
Area	2.40±0.46	2.31±0.35	3.494	<0.001
IFD	1.73±0.24	1.54±0.21	2.759	<0.001
ILA	112.83±6.65	111.96±7.03	2.013	0.044

\*P-value based on Two sample t-test, Statistically significant if P<0.05

At L3, males demonstrate significantly larger dimensions than females in nearly all parameters ( $P < 0.001$ ). Pedicle dimensions are greater in males (PW: 0.86 vs 0.82; PH: 1.28 vs 1.20), with a wider interpedicular distance (2.37 vs 2.27). Transpedicular angle is more lateral in males (TPA: 24.08° vs 23.18). Vertebral body heights are higher in males—AVH (2.65 vs 2.57) and PVH (2.75 vs 2.66). Vertebral width and depths show marked male predominance (UVW 4.62 vs 4.34; LVW 4.93 vs 4.71; UVD 3.29 vs 3.13; LVD 3.30 vs 3.14). Posterior elements (interfacet distance) are also larger in males (IFD: 1.73 vs 1.54). Females show a slightly larger AP diameter (1.48 vs 1.45;  $P = 0.044$ ). Canal cross sectional area (2.40 vs 2.31) and ILA (112.83° vs 111.96°) are significantly higher in males ( $P < 0.05$ ).

**Table 5: Comparative morphometric analysis at the level of L4 vertebra**

L4	Gender		t	P-value
	Male	Female		
PW	1.06±0.17	1.01±0.16	5.377	<0.001
PH	1.25±0.32	1.10±0.22	8.721	<0.001
IPD	2.46±0.32	2.39±0.35	3.224	0.001
TPA	27.13±4.51	26.25±5.13	2.888	0.004
AVH	2.60±0.28	2.53±0.27	3.847	<0.001
PVH	2.67±0.26	2.51±0.22	10.141	<0.001
UVW	4.91±0.45	4.61±0.41	10.863	<0.001
LVW	5.06±0.39	4.84±0.41	8.672	<0.001
UVD	3.36±0.29	3.19±0.28	9.231	<0.001
LVD	3.36±0.29	3.24±0.28	6.876	<0.001
AP	1.53±0.27	1.49±0.22	3.099	0.002
Area	2.61±0.57	2.42±0.49	5.468	<0.001
IFD	1.89±0.30	1.62±0.27	15.069	<0.001
ILA	105.69±8.82	105.11±7.74	1.110	0.267

\*P-value based on Two sample t-test, Statistically significant if P<0.05

At L4, males show significantly larger values than females in almost all parameters. Pedicle dimensions are greater in males (PW: 1.06 vs 1.01; PH: 1.25 vs 1.10;  $P < 0.001$ ), with a wider interpedicular distance (2.46 vs 2.39;  $P = 0.001$ ). Transpedicular angle is more lateral in males (TPA: 27.13° vs 26.25°;  $P = 0.004$ ). Vertebral body heights are higher in males—AVH (2.60 vs 2.53) and PVH (2.67 vs 2.51;  $P < 0.001$ ). Vertebral width and height are markedly larger in males (UVW 4.91 vs 4.61; LVW 5.06 vs 4.84; UVD 3.36 vs 3.19; LVD 3.36 vs 3.24; all  $P < 0.001$ ). AP diameter (1.53 vs 1.49) and canal cross sectional area (2.61



vs 2.42) are also significantly greater in males. Interfacet distance (IFD) shows the largest gender difference (1.89 vs 1.62;  $P < 0.001$ ), while interlaminar angle (ILA) does not differ significantly between genders ( $105.69^\circ$  vs  $105.11^\circ$ ;  $P = 0.267$ ).

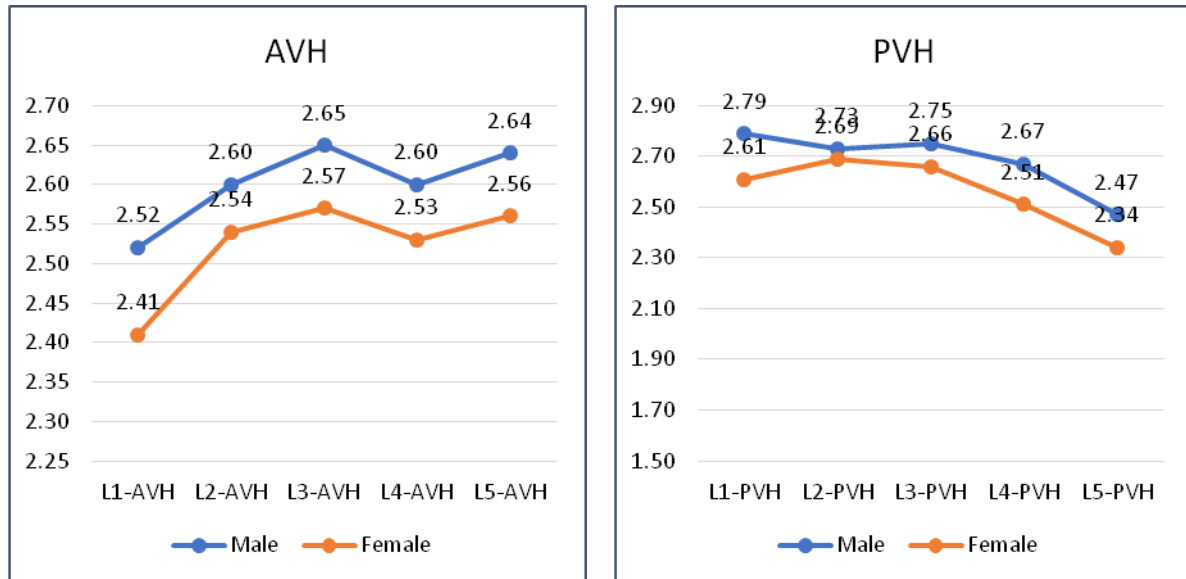
**Table 6: Comparative morphometric analysis at the level of L5 vertebra**

L5	Gender		t	P-value
	Male	Female		
PW	1.36±0.21	1.35±0.23	.302	0.763
PH	1.16±0.41	1.03±0.20	6.500	<0.001
IPD	2.97±0.56	2.89±0.43	2.528	0.012
TPA	34.43±5.87	33.35±6.87	2.664	0.008
AVH	2.64±0.26	2.56±0.26	4.848	<0.001
PVH	2.47±0.24	2.34±0.20	9.316	<0.001
UVW	5.02±0.41	4.82±0.38	8.192	<0.001
LVW	5.05±0.51	4.83±0.47	7.317	<0.001
UVD	3.33±0.35	3.22±0.33	4.831	<0.001
LVD	3.37±0.30	3.23±0.29	7.231	<0.001
AP	1.62±0.33	1.54±0.41	3.530	<0.001
Area	3.05±0.68	2.93±0.76	2.747	<0.001
IFD	2.17±0.32	2.00±0.34	7.792	<0.001
ILA	95.82±8.53	98.95±9.75	-5.370	<0.001

\*P-value based on Two sample t-test, Statistically significant if  $P < 0.05$

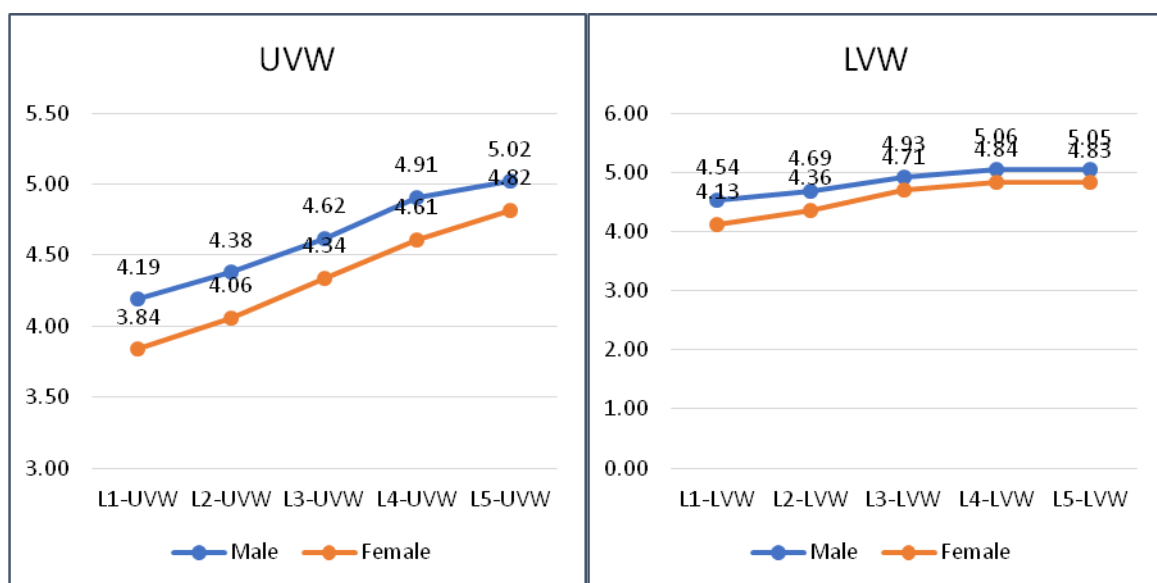
At L5, males show significantly larger dimensions than females in most parameters. Pedicle height is greater in males (1.16 vs 1.03;  $P < 0.001$ ), while pedicle width shows no gender difference (1.36 vs 1.35;  $P = 0.763$ ). Interpedicular distance (2.97 vs 2.89) and trans pedicle angle (TPA:  $34.43^\circ$  vs  $33.35^\circ$ ) are higher in males ( $P < 0.05$ ). Vertebral body heights—AVH (2.64 vs 2.56) and PVH (2.47 vs 2.34)—are significantly greater in males. Vertebral width and height are larger in males (UVW 5.02 vs 4.82; LVW 5.05 vs 4.83; UVD 3.33 vs 3.22; LVD 3.37 vs 3.23; all  $P < 0.001$ ). AP diameter, vertebral area, and interlaminar distance are also greater in males (AP 1.62 vs 1.54; Area 3.05 vs 2.93; IFD 2.17 vs 2.00;  $P < 0.001$ ). In contrast, interlaminar angle (ILA) is significantly higher in females ( $98.95^\circ$  vs  $95.82^\circ$ ;  $P < 0.001$ ).

**Figure 2&3: Anterior (AVH) and posterior vertebral height (PVH) variation:**



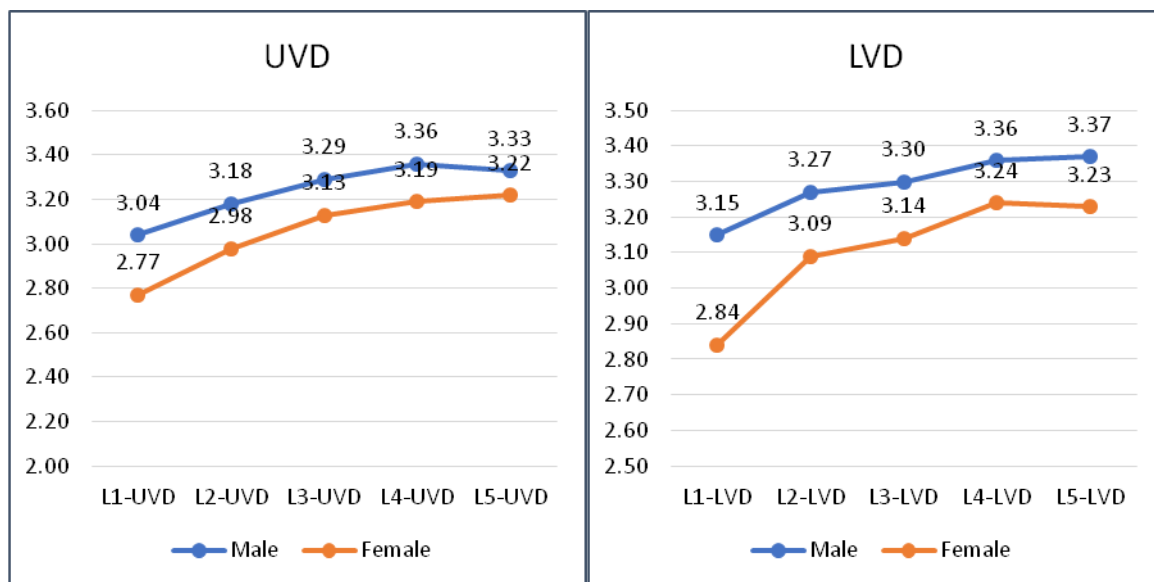
Males show consistently higher AVH (figure 1) and PVH (figure 2) than females from L1 to L5. AVH increases from L1 to a peak at L3, slightly decreases at L4, and rises again at L5 in both sexes. PVH is highest at upper lumbar levels (L1–L3) and progressively decreases toward L5. Overall, the graphs demonstrate clear sexual dimorphism and level-specific lumbar vertebral height patterns.

**Figure 4&5: Upper (UVW) and lower vertebral weight (UVW) variation:**



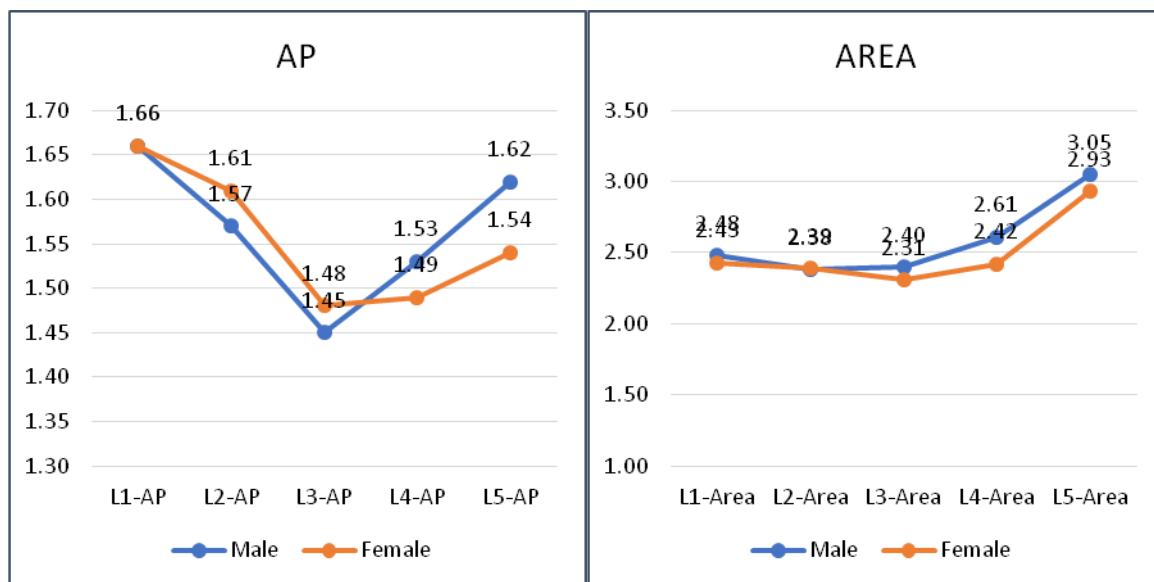
Both upper vertebral width (UVW) (figure 4) and lower vertebral width (LVW) (figure 5) increase progressively from L1 to L5 in males and females. At all levels, males have greater widths than females, demonstrating clear sexual dimorphism. The widening toward the lower lumbar levels reflects adaptation to increasing axial load and biomechanical demands, with the male–female difference remaining relatively consistent across levels.

**Figure 6&7: Upper (UVW) and lower vertebral weight (UVW) variation:**



Both upper vertebral depth (UVD) (figure 6) and lower vertebral depth (LVD) (figure 7) show a gradual increase from L1 to L5 in males and females. Males consistently demonstrate greater depths than females at all levels, indicating sexual dimorphism. The progressive increase toward the lower lumbar vertebrae reflects adaptation to increasing axial load, with only minor leveling toward L5.

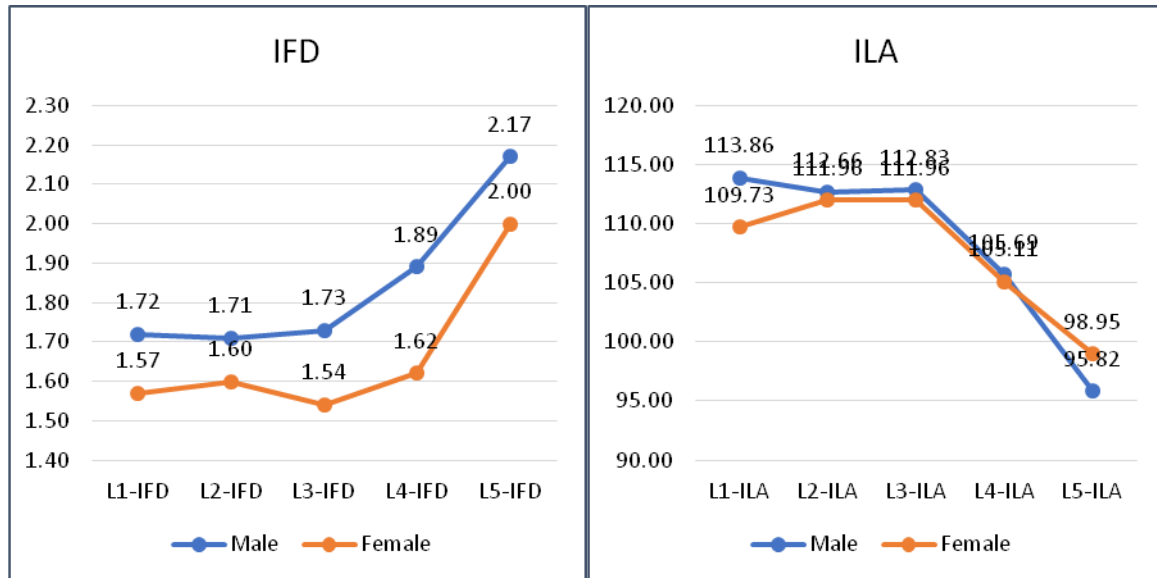
**Figure 10&11: Upper (UVW) and lower vertebral weight (UVW) variation:**





The anteroposterior (AP) diameter (figure 10) shows a U-shaped pattern in both sexes, decreasing from L1 to L3 and then increasing toward L5. Females are slightly higher at L1–L2, while males show greater values at L4–L5. The vertebral canal cross (figure 11) sectional area is relatively stable from L1 to L3 and then increases markedly at L4–L5, with males consistently having larger areas than females. Overall, these trends reflect level-specific canal remodeling with mild sexual dimorphism, more pronounced in canal area than in AP diameter.

**Figure 12&13: Upper (UVW) and lower vertebral weight (UVW) variation:**



Interfacet distance (IFD) (figure 12) shows a mild increase from L1 to L3 followed by a marked rise at L4–L5 in both sexes, with males consistently demonstrating larger values than females. In contrast, the interlaminar angle (ILA) (figure 13) is highest at upper lumbar levels (L1–L3) and progressively decreases toward L5 in both sexes. Males show slightly higher angles at L1–L3, while values converge and decline caudally. Together, these patterns reflect facet joint widening and angular reorientation in the lower lumbar spine to accommodate increased mobility and load.

### Discussion:

The current study included 1,000 people, 500 North Indian and 500 South Indian, aged 18–50. Age, gender, and regional distribution were recorded for all participants. After applying the inclusion and exclusion criteria, abdomen CT scans from Chhatrapati Shivaji Subharti Hospital, Meerut; Sri Venkateshwara Medical College, Puducherry; and Virk Hospital, Karnal, were used for the study. Across L1–L5, the present data demonstrate a consistent male predominance in most lumbar morphometric parameters, particularly pedicle dimensions, vertebral body heights, spinal canal dimensions, and posterior element measurements. This pattern reflects greater overall vertebral robustness in males, likely related to differences in body size, muscle mass, and axial loading. At L1 and L2, males show significantly larger pedicle width and height, interpedicular distance, vertebral heights (AVH, PVH), canal dimensions (UVW, LVW, UVD, LVD), and posterior elements (IFD, often ILA). AP diameter and vertebral area show minimal or no gender difference at these levels,



and at L2 the AP diameter is slightly larger in females. This suggests that sexual dimorphism at upper lumbar levels predominantly affects the posterior elements and canal size, rather than central vertebral body proportions. At L3, sexual dimorphism is most uniform, with males having larger values in almost all parameters, including pedicle size, vertebral heights, canal dimensions, vertebral area, and posterior elements. Only AP diameter is marginally greater in females. This level appears to represent a transition zone where both load-bearing and mobility demands accentuate gender differences. At L4 and L5, male predominance becomes more pronounced in canal dimensions, vertebral body heights, interpedicular distance, AP diameter, vertebral area, and interlaminar distance. Pedicle width equalizes at L5, while pedicle height remains significantly greater in males, highlighting level-specific adaptations. Notably, intralaminar angle (ILA) shows no gender difference at L4 and becomes larger in females at L5, likely reflecting differences in lumbosacral curvature and pelvic morphology.

These results are in line with previous studies highlighting the importance of gender-specific anatomical variations for anthropological and clinical applications.<sup>6</sup> These findings are in close agreement with reports by Shashikant Kiragi et al<sup>7</sup> and Alam et al<sup>8</sup>, who described larger pedicle dimensions, canal diameters, and vertebral heights in males, with diminishing gender differences in certain parameters at lower lumbar levels. Similarly, Soha A et al<sup>5</sup> reported male predominance in canal and pedicle measurements, while noting minimal or absent sex differences in AP diameter and vertebral area at selected levels, and occasional female predominance in angular parameters such as ILA at L5. Our results are consistent with extensive imaging research, including the NHANES-II radiographic dataset, which established normative vertebral morphometry and highlighted gender- and age-related differences in spinal measurements.<sup>9</sup> Investigations by Priya et al.<sup>10</sup> and others have demonstrated that advanced imaging techniques yield precise morphometric information, underscoring the clinical value of reliable anatomical reference data for surgical planning and implant.

### **Conclusion:**

This CT-based morphometric analysis of 1,000 adults from both North and South India reveals distinct, level-specific sexual dimorphism in the lumbar vertebrae (L1–L5). Across most parameters—including pedicle dimensions, vertebral body heights, spinal canal sizes, and posterior element measurements—males consistently displayed larger values than females, indicative of greater vertebral robustness and biomechanical adaptation. The degree of sexual dimorphism was least evident at the upper lumbar levels (L1–L2), most consistent at L3, and most pronounced at the lower levels (L4–L5). At L5, pedicle width was similar between sexes, while the interlaminar angle was greater in females, highlighting unique level-dependent anatomical differences. These results are consistent with prior Indian and international studies and underscore the need for gender- and level-specific lumbar morphometric data in spinal surgery planning, implant development, forensic identification, and anthropological investigations.

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