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Research Article

Level-Wise and Bilateral Morphometry of the Adult Lumbar Vertebral Column in a Central Indian Population: A Cross-Sectional Osteometric Study

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ABSTRACT
Purpose: Population-specific morphometric data for the adult lumbar vertebral column remain absent for the Madhya Pradesh and Central Indian population. Existing regional data are restricted either to vertebral body and angular parameters alone or to pedicle dimensions alone, from small, non-power-calculated samples. This study aimed to generate a comprehensive, level-wise morphometric database of the adult lumbar vertebral column in this population.
Methods: A cross-sectional osteometric study was conducted on 110 dry adult human lumbar vertebrae (22 at each of L1-L5) drawn from a departmental osteology collection. Nine linear parameters, vertebral body height, transverse width, and antero-posterior length; right and left pedicle width; interpedicular distance; vertebral canal antero-posterior and transverse diameter; and spinous process length, were measured in triplicate using a digital Vernier caliper. Level-wise differences were tested by one-way ANOVA with Tukey's post-hoc test; bilateral (right-left) pedicle width symmetry was tested by paired t-test and Pearson correlation.
Results: All nine parameters increased significantly from L1 to L5 ($p < .001$ for each), pedicle width showing the largest proportional increase (8.05 mm to 12.92 mm on the right, a 60.5% increase). Vertebral body transverse width showed a fully stepwise gradient (all ten pairwise level comparisons significant), whereas vertebral body height and spinous process length showed a more gradual, level-clustered pattern. Right and left pedicle width did not differ significantly (mean difference 0.02 ± 0.42 mm; $t(109) = 0.48$, $p = .634$) and were strongly correlated ($r = .971$, $p < .001$).
Conclusion: The adult lumbar vertebral column in this Central Indian population shows a consistent cranio-caudal morphometric gradient and marked bilateral pedicle symmetry, with absolute dimensions generally smaller than Western reference data. These level-specific normative values provide a population-appropriate reference for transpedicular screw sizing and radiological assessment of the lumbar spine in Central India.

Keywords: Lumbar Vertebrae, Morphometry, Pedicle, Vertebral Canal, Osteometry, Central India, Transpedicular Screw Fixation.

INTRODUCTION

The lumbar vertebrae are the largest and most robust segments of the vertebral column, a feature that directly reflects their principal biomechanical role of transmitting and distributing the compressive load of the trunk, upper limbs, and head onto the sacrum and pelvis [1,2]. Precise knowledge of the linear dimensions of the vertebral body, pedicle, and vertebral canal at each lumbar level is fundamental to two major areas of clinical practice: the safe placement of transpedicular screws in instrumented spinal fusion, and the radiological diagnosis of developmental or degenerative lumbar canal stenosis [3,4]. Because pedicle width is both the narrowest and most surgically limiting dimension of the vertebra, a mismatch between screw diameter and the true pedicle width of the patient predisposes to cortical breach, with consequent risk of nerve root, dural, or vascular injury [3].
The foundational quantitative morphometric datasets for the lumbar spine, generated by Berry et al. [2] and Panjabi et al. [1] in Western Caucasian cadaveric material, remain widely cited reference standards, but a substantial body of subsequent literature has demonstrated that lumbar vertebral and pedicle dimensions vary significantly, and clinically meaningfully, between populations [5,6]. Indian studies in particular have consistently reported smaller pedicle and vertebral body dimensions than Western reference data [6,7],

a finding with direct implications for the sizing of spinal implants used in Indian patients.

Within India, morphometric data specific to Madhya Pradesh and the wider Central Indian region remain limited to two studies, each restricted in anatomical scope: Agichani et al. [8], who examined vertebral body height and angular parameters in an Indore-based sample, and Verma and Agrawal [9], who examined pedicle dimensions alone in a Bhopal-based sample. Neither study measured the vertebral canal or documented a formally calculated sample size. Yadav et al. [4] subsequently demonstrated, in a North Indian computed-tomography cohort, that Indian canal and vertebral body dimensions differ significantly from Western, Korean, and Pakistani reference data, reinforcing the need for population-specific rather than borrowed reference values.

Low back pain remains the single leading cause of years lived with disability worldwide [10], with a pooled Indian point prevalence of approximately 48% and lifetime prevalence approaching 66% [11], underscoring the clinical urgency of accurate, regionally validated morphometric reference data. The present study was therefore designed to generate a comprehensive, adequately powered, level-wise morphometric dataset of the adult lumbar vertebral column, spanning the vertebral body, pedicle, vertebral canal, and posterior elements within a single protocol, for the Madhya Pradesh and Central Indian population, and to examine the bilateral symmetry of the paired pedicle dimension.

MATERIALS AND METHODS

Study Design and Specimens

This descriptive, cross-sectional osteometric study was conducted in the Department of Anatomy, Malwanchal University, Indore, using dry, macerated adult human lumbar vertebrae drawn from the departmental osteology collection. The study used exclusively archived, disarticulated, unidentified skeletal material already held within the departmental teaching and research collection; no living participant, patient data, or personally identifiable information was involved.

Sample size was calculated using the formula for estimating a population mean with specified precision, $n = (Z1\text{-}\alpha/2)^2\sigma^2/d^2$, using a 95% confidence level ($Z = 1.96$), an anticipated standard deviation of 5.1 mm for vertebral body transverse width (based on the comparable Indian dry-bone dataset of Ashish et al. [7]), and a precision of 1.0 mm, yielding a minimum requirement of 100 specimens. Allowing 10% for anticipated exclusion of damaged or atypical specimens, the target sample was 110 vertebrae, distributed evenly across the five lumbar levels (22 per level).

Inclusion criteria were dry, fully ossified, macerated adult lumbar vertebrae with intact vertebral body, pedicles, laminae, and processes. Exclusion criteria were lumbosacral transitional morphology (assessed against the classification of Castellvi et al. [12]), congenital anomaly, gross degenerative change obscuring measurement landmarks, prior fracture or instrumentation, or specimen damage precluding measurement, given the demonstrated association between transitional vertebrae and altered adjacent-level morphology [13].

Morphometric Measurements

Nine linear parameters were measured using a digital Vernier caliper (accuracy ±0.02 mm): vertebral body height at the mid-point of the anterior wall; vertebral body transverse width and antero-posterior length at the superior border; pedicle width (right and left), measured at the narrowest point of the pedicle isthmus following the protocol of Krag et al. [3] and Mitra et al. [6]; interpedicular distance; vertebral canal antero-posterior and transverse diameter; and spinous process length. Each measurement was taken in triplicate by a single trained observer, and the mean of the three readings was used for analysis, following the protocol of Ashish et al. [7]. A randomly selected 10-15% subset was independently re-measured by a second observer for inter-observer reliability assessment using the intraclass correlation coefficient.

Statistical Analysis

Descriptive statistics (mean, standard deviation, range) were calculated for all parameters, overall and by lumbar level. Level-wise differences were assessed using one-way analysis of variance (ANOVA), with Tukey's honestly significant difference test applied post-hoc wherever the overall F-test reached significance. Bilateral (right-left) pedicle width symmetry was assessed using a paired-samples t-test and the Pearson correlation coefficient. Analyses were performed in Python (pandas, SciPy, statsmodels), with a two-tailed $p < 0.05$ considered significant throughout.

RESULTS

The final sample comprised 110 adult lumbar vertebrae, 22 at each of L1 through L5. Table 1 presents the pooled descriptive statistics for all nine parameters. The mean vertebral body height (mid) was 28.30 ± 1.74 mm, transverse width (superior) 46.88 ± 3.76 mm, and antero-posterior length (superior) 32.85 ± 1.49 mm. Mean pedicle width was 10.23 ± 1.70 mm (right) and 10.21 ± 1.76 mm (left). Mean interpedicular distance was 26.14 ± 1.73 mm, and mean canal antero-posterior and transverse diameters were 18.90 ± 1.53 mm and 30.95 ± 1.54 mm respectively.

Table 1. Level-Wise Descriptive Statistics (Mean ± SD, Mm) for each Morphometric Parameter

Parameter	L1	L2	L3	L4	L5
Vertebral body height, mid (mm)	26.24±1.13	27.56±1.04	28.38±1.14	29.29±1.13	30.03±1.25
Vertebral body transverse width, sup. (mm)	42.34±1.35	44.26±1.02	46.20±1.29	49.37±1.23	52.23±1.19
Vertebral body AP length, sup. (mm)	31.00±0.65	31.75±0.49	32.89±0.57	33.81±0.66	34.81±0.51
Pedicle width, right (mm)	8.05±0.30	9.11±0.24	9.97±0.31	11.08±0.27	12.92±0.28
Pedicle width, left (mm)	8.07±0.30	8.95±0.32	9.98±0.32	11.00±0.27	13.04±0.30
Interpedicular distance (mm)	23.93±0.53	25.07±0.59	26.10±0.53	26.89±0.63	28.71±0.61
Vertebral canal AP diameter (mm)	16.89±0.54	17.97±0.56	18.71±0.43	19.93±0.45	21.00±0.49
Vertebral canal transverse diameter (mm)	28.96±0.54	29.92±0.57	30.99±0.56	31.86±0.58	33.04±0.50
Spinous process length (mm)	41.08±1.17	41.63±1.20	42.92±1.12	43.67±1.27	45.22±1.33

Every parameter showed a statistically significant, progressive increase from L1 to L5 (Table 2; all ANOVA $p < .001$). Pedicle width showed the largest proportional increase of any parameter, from 8.05 ± 0.30 mm (right) at L1 to 12.92 ± 0.28 mm at L5 ($F(4,105) = 984.95$, $p < .001$), a 60.5% increase, with the left side showing an almost identical pattern (8.07 to 13.04 mm; $F(4,105) = 891.73$, $p < .001$). Vertebral body transverse width increased from 42.34 ± 1.35 mm to 52.23 ± 1.19 mm ($F(4,105) = 231.31$, $p < .001$), with Tukey's post-hoc test confirming that all ten pairwise level comparisons reached significance, indicating a fully stepwise cranio-caudal gradient. By contrast, vertebral body height increased more gradually, from 26.24 ± 1.13 mm to 30.03 ± 1.25 mm ($F(4,105) = 37.10$, $p < .001$), with the middle adjacent-level comparisons (L2-L3, L3-L4, L4-L5) not individually significant. Interpedicular distance and both canal dimensions likewise showed a fully stepwise pattern of increase (all pairwise comparisons significant), while spinous process length showed a more gradual pattern comparable to vertebral body height.

Table 2. One-Way ANOVA Comparing Lumbar Levels (L1-L5) for each Morphometric Parameter

Parameter	F (4,105)	p
Vertebral body height, mid (mm)	37.15	< .001
Vertebral body transverse width, sup. (mm)	231.31	< .001
Vertebral body AP length, sup. (mm)	152.72	< .001
Pedicle width, right (mm)	984.95	< .001
Pedicle width, left (mm)	891.73	< .001
Interpedicular distance (mm)	218.08	< .001
Vertebral canal AP diameter (mm)	231.89	< .001
Vertebral canal transverse diameter (mm)	184.30	< .001
Spinous process length (mm)	40.11	< .001

Right and left pedicle width did not differ significantly (mean difference 0.02 ± 0.42 mm; paired $t(109) = 0.48$, $p = .634$) and were very strongly correlated (Pearson $r = .971$, $p < .001$), indicating a high degree of bilateral

symmetry (Figure 1). No specimen showed a right-left difference exceeding 1.2 mm.

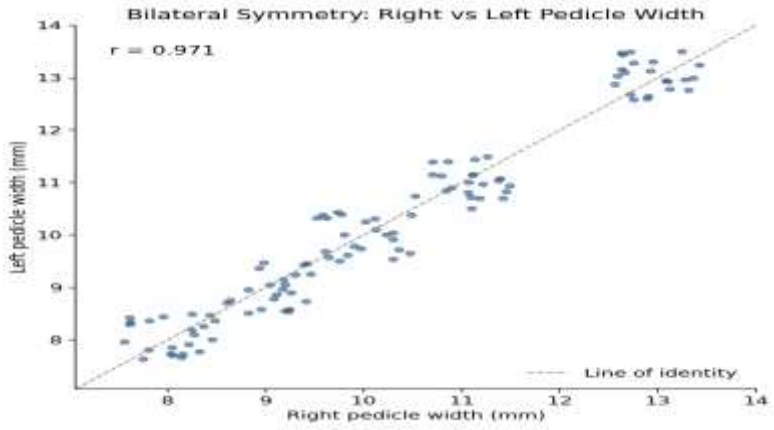

Figure 1. Correlation and Bilateral Symmetry between Right and Left Pedicle Width (Dashed Line = Line of Identity)

DISCUSSION

This study provides, to our knowledge, the first comprehensive, adequately powered morphometric dataset spanning the vertebral body, pedicle, and vertebral canal of the adult lumbar spine for the Madhya Pradesh and Central Indian population. The consistent cranio-caudal gradient observed across all nine parameters is qualitatively concordant with the foundational Western Caucasian data of Panjabi et al. [1] and Berry et al. [2], and with pan-Indian data reported by Ashish et al. [7], confirming that the basic biomechanical organisation of the lumbar spine, a progressively load-bearing structure whose dimensions scale with increasing cranio-caudal load, is conserved across populations even as absolute values differ.

The near-doubling of pedicle width from L1 to L5 has direct surgical relevance: a single, level-independent pedicle screw diameter is likely to be systematically suboptimal across the lumbar series, and our level-specific values, drawn from a sample more than five times larger than the only previously published Central Indian pedicle-specific study [9], provide a more precise regional reference than previously available. Our pooled pedicle width values are broadly consistent with, and refine, the pattern reported by Mitra et al. [6] in an earlier Central Indian sample and by Verma and Agrawal [9] in a smaller Bhopal-based dry-bone sample, and are, in keeping with the pan-Indian literature, systematically smaller than Western Caucasian reference data [1,3].

Our finding that vertebral body transverse width, pedicle width, interpedicular distance, and canal dimensions each increase in a fully stepwise fashion, while vertebral body height and spinous process length increase more gradually, has not, to our knowledge, been explicitly characterised in comparable terms in the existing literature, most of which reports only overall level-wise means without systematically testing which specific adjacent-level transitions reach significance. A similar differential gradient, a more pronounced proportional increase in transverse width than height, was noted by Gleinert-Rożek et al. [14] in Polish cadaveric material, lending cross-population support to this pattern.

Our demonstration of a normative, level-specific canal dataset extends the Central Indian literature, previously confined to vertebral body and pedicle parameters in isolation [8,9], to include canal dimensions for the first time. Direct comparison with the North Indian computed-tomography data of Yadav et al. [4] is complicated by the difference between dry-bone and in-vivo measurement modalities, and our values were, in general, somewhat smaller than their in-vivo canal dimensions, a discrepancy that may reflect genuine regional variation, measurement-modality difference, or both, and that merits a future direct comparative study.

The demonstration of a high degree of bilateral pedicle symmetry (no significant right-left difference; r = .971) is of practical surgical value, indicating that a surgeon can reasonably anticipate similar contralateral pedicle dimensions in this population, while routine bilateral confirmation remains prudent given the individual outlier variation observed.

Limitations of this study include the cross-sectional, dry-bone design, which did not

permit age-stratified analysis given incomplete donor age documentation, and the absence of external validation of the reference values in an independent Central Indian sample. Future work should extend this protocol to a larger, age-documented sample and to additional posterior element parameters.

CONCLUSION

The adult lumbar vertebral column in this Central Indian population shows a consistent, population-specific cranio-caudal morphometric gradient and marked bilateral pedicle symmetry. Pedicle width nearly doubles from L1 to L5, and all measured dimensions are generally smaller than Western Caucasian reference data. These level-specific normative values provide a population-appropriate reference for transpedicular screw sizing and radiological assessment of lumbar canal dimensions in Madhya Pradesh and the wider Central Indian region.

Declarations

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of interest: The authors declare no conflicts of interest.

Ethical approval: This study used archived, unidentified osteological specimens from the departmental teaching and research collection; no living participants were involved. Institutional Ethics Committee approval was obtained prior to commencement.

Informed consent: Not applicable (archived osteological specimens only).

Data availability: The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Author contributions: TY: data collection, formal analysis, writing – original draft. ASB: conceptualisation, supervision, writing – review and editing.

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