

Morphometric Analysis of L1–L5 Pedicles: Evaluation of Sexual Dimorphism and Bilateral Asymmetry

Análisis Morfométrico de los Pedículos L1-L5: Evaluación del Dimorfismo Sexual y la Asimetría Bilateral

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SUMMARY: To conduct a comprehensive morphometric analysis of lumbar pedicle dimensions (L1–L5) in a Turkish population using a linear mixed-effects model (LMM) to establish a reliable anatomical baseline and investigate the impact of sexual dimorphism and bilateral asymmetry. This retrospective study analyzed high-resolution computed tomography (CT) scans of 129 healthy adults (70 females, 59 males; mean age 47.38 ± 17.13 years). Pedicle diameter, length, and transverse angle were measured from L1 to L5. An LMM was employed to account for within-subject dependencies, treating sex and side as fixed effects and subject ID as a random effect. Significant sexual dimorphism was observed, with males generally exhibiting larger pedicle calibers. For L1 diameter, significant main effects were found for sex ($p = 0.028$) and side ($p = 0.001$), with left-side measurements being significantly higher in both sexes. Pedicle length demonstrated a consistent left-side dominance across most levels (L1–L5, $p < 0.05$). A significant sex $\times$ side interaction was observed in pedicle transverse angles, particularly at L4 ($p = 0.007$). In females, the left L4 pedicle angle tended to be greater than the right ($p = 0.070$), whereas in males, the right-side angle was significantly greater than the left ($p = 0.041$). Lumbar pedicle morphology in the Turkish population is governed by complex interactions between genetic sex and directional asymmetry. The distinct left-side dominance in length and the unique angular shifts at L4 diverge from findings in other ethnic cohorts. These population-specific nuances are critical for preoperative planning and the selection of optimal screw dimensions. Integrating these variations into surgical practice is essential to enhance the precision of transpedicular instrumentation and minimize neurovascular risks.

KEY WORDS: Bilateral asymmetry; Lumbar vertebrae; Pedicle morphometry; Sexual dimorphism.

INTRODUCTION

The lumbar region represents the most dynamic and mobile segment of the human vertebral column, a characteristic that inherently renders it highly susceptible to biomechanical instability. Spinal stability can be compromised by a diverse array of pathological factors, including high-energy trauma (e.g., motor vehicle accidents and extreme sports), mechanical strain, congenital defects, metastatic lesions, and age-related degenerative conditions (Chawla, 2013). As global life expectancy increases, the prevalence of spinal degenerative diseases is rising, further intensifying the demand for durable and reliable surgical interventions.

lumbar stability in cases involving trauma, infection, and degenerative disorders (Roy-Camille & Saillant, 1972). In contemporary spinal surgery, this methodology has evolved into routine clinical practice and is widely recognized as the “gold standard” for vertebral stabilization (Jutte & Castelein, 2002). Structurally, the vertebral pedicle functions as a critical anatomical “bridge” situated at the junction of the anterior, posterior, and lateral columns. This strategic positioning allows transpedicular instrumentation to provide rigid, multi-columnar fixation, facilitating superior load-sharing across the vertebral column.

Since its inception in 1963, transpedicular screw fixation has served as a foundational technique for restoring

Despite its widespread application, the complex anatomical architecture of the lumbar region poses

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formidable challenges for surgeons. Inaccurate screw trajectory or sizing represents a substantial clinical risk, potentially resulting in devastating neurovascular complications or mechanical hardware failure (Gurumurthy *et al.*, 2022). Furthermore, the safety margin for instrumentation is exceptionally narrow, as the pedicle's cortical boundaries must be respected to avoid neurological deficits. Extensive research has demonstrated that pedicle morphology exhibits significant variation influenced by age, sex, and ethnicity (Maaly & El-Rakhawy, 2010; Chawla, 2013; Gurumurthy *et al.*, 2022). Notably, literature consistently indicates marked sexual dimorphism, with males generally possessing larger pedicle dimensions than females (Gurumurthy *et al.*, 2022; Düzkalır *et al.*, 2015). However, data regarding bilateral asymmetry—the subtle differences between right and left pedicle dimensions within the same individual—remain inconsistent and require further investigation. Consequently, a comprehensive understanding of these morphometric nuances is essential for precise screw positioning and minimizing perioperative risks (Chadha *et al.*, 2003; Düzkalır *et al.*, 2015).

While direct intraoperative visualization is fundamental, radiographic data serve as the primary navigation tool for the surgical team (Maaly & El-Rakhawy, 2010). Plain radiographs frequently provide insufficient resolution regarding the internal dimensions and three-dimensional angulation of the pedicle; therefore, multi-slice computed tomography (CT) is regarded as the superior modality for characterizing these intricate features (Cheung *et al.*, 1994; Chawla, 2013). CT-based morphometry enables high-fidelity assessment that is critical for preoperative templating. Although general anatomical trends are documented in Western and East Asian cohorts, localized, population-specific data—particularly regarding bilateral asymmetry—are essential for optimizing surgical outcomes in specific ethnic groups.

Despite the clinical importance of vertebral symmetry, data regarding bilateral asymmetry remain notably inconsistent across different populations and methodologies. For instance, while Arockiaraj *et al.*, reported a high degree of symmetry in the lumbar pedicles of a Saudi cohort, indicating no significant differences between right and left dimensions, other researchers such as Maaly and El-Rakhawy identified a distinct left-side dominance in pedicle length within an Egyptian population. Furthermore, some studies suggest that while pedicle diameter remains symmetrical, length and angulation exhibit significant lateralization. This lack of consensus in the global literature underscores the necessity for population-specific investigations.

Research Gap and Significance: Although lumbar pedicle morphometry has been described in various populations, data specific to the Turkish population are limited, and bilateral asymmetry has not been systematically analyzed using robust statistical models. Understanding these population-specific anatomical characteristics is critical for enhancing the safety and efficacy of transpedicular screw fixation. By applying a linear mixed-effects model to account for within-subject variability, the present study aims to establish a reliable anatomical baseline, clarify patterns of bilateral asymmetry, and provide evidence-based guidance for optimal screw selection in the Turkish population.

This study aims to investigate the detailed morphometric characteristics of lumbar vertebral pedicles (L1–L5) within the Turkish population. By establishing a reliable anatomical baseline and utilizing a linear mixed-effects model to account for within-subject dependencies, we aim to facilitate the selection of optimal screw dimensions and enhance the safety and efficacy of transpedicular stabilization procedures.

MATERIAS AND METHOD

Study Design and Ethical Approval

This retrospective, cross-sectional morphometric study was conducted using computed tomography (CT) images of adult individuals who presented to the Adana Dr. Turgut Noyan Application and Research Center for various clinical indications between 1990 and 2023. The study protocol was reviewed and approved by the Bas, kent University Non-Interventional Clinical Research Ethics Committee (14.02.2024- project number: KA24/87). All procedures were performed in strict accordance with the ethical principles of the Declaration of Helsinki.

Participant Selection and Criteria

A total of 129 individuals (70 females, 59 males) were included in the final analysis. All subjects were assessed for the absence of structural spinal pathologies.

Inclusion Criteria: Healthy adult individuals (aged 20–84 years) with high-resolution CT scans of the lumbar spine.

Exclusion Criteria: Individuals with a documented history of vertebral column disease, prior spinal surgery, congenital spinal malformations, primary or metastatic spinal tumors, or any radiologically identified pathology (e.g., severe degenerative changes, fractures, or scoliosis) that could interfere with precise morphometric measurements.

Radiological Assessment and Morphometry

All CT images were archived in a Picture Archiving and Communication System (PACS). Morphometric evaluations were performed under the supervision of a senior radiologist with over 10 years of experience in musculoskeletal imaging. To ensure measurement reliability and minimize intra-observer variability, all linear and angular parameters were measured twice by the same investigator, and the mean values were recorded for final analysis.

All measurements were performed on LI-LV vertebral levels on right and left sides. Parameters were measured and evaluated according to gender.

Pedicle width (cm): It is measured at narrowest point on the axial section, perpendicular to the pedicle axis (Maaly2010) (Fig. 1).

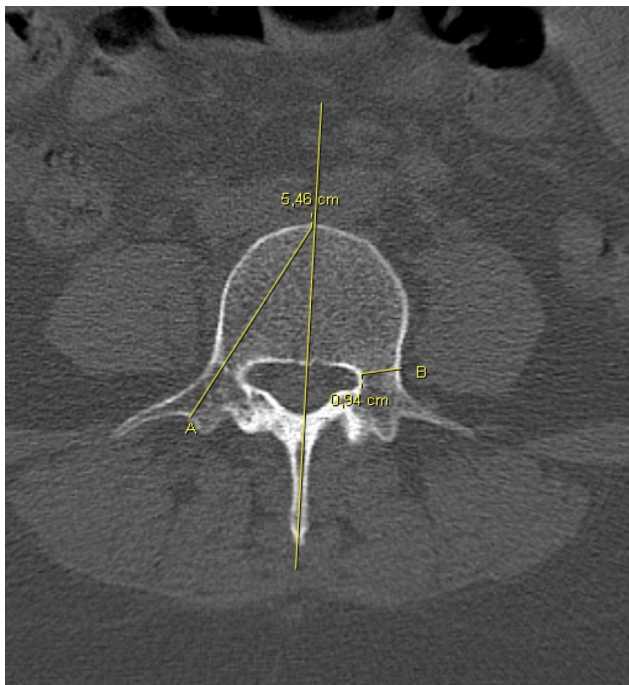


Fig. 1. Pediculus arcus vertebrae width (A), Pediculus corpus length (B).

Pedicle-corpus distance (cm): The length between the most posterior point of the pedicle and the anterior margin of the body of the vertebra is measured along the longitudinal axis (Düzkalır, 2015) (Fig. 1).

Pedicle transvers angle (°): The angle between the line between the most anterior point of the vertebral body and the most posterior point of the spinous process and the pedicle longitudinal axis is measured (Gurumurthy, 2022) (Fig. 2).

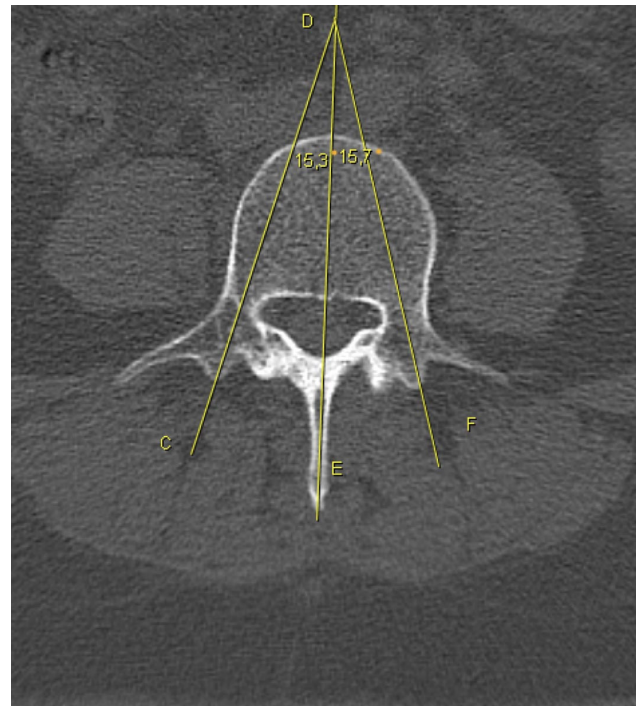


Fig. 2. Pediculus arcus vertebrae transverse diameter.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 30.0 (Armonk, NY: IBM Corp). Descriptive statistics are reported as mean $\pm$ standard deviation (SD) for normally distributed variables and as median (minimum–maximum) for variables with non-normal distribution. Data normality was rigorously assessed using the Shapiro-Wilk test and visual inspection of histograms.

For variables violating normality assumptions, the Mann-Whitney U test was utilized for comparisons between independent groups. To account for the correlated nature of the data, specifically the repeated measurements (right and left sides) obtained from the same individual, a linear mixed-effects model (LMM) was employed. In this model, Sex (male vs. female) and Side (right vs. left) were defined as fixed effects. Their interaction term (sex x side) was included to evaluate whether the effect of side varied between sexes. Subject ID was incorporated as a random effect to account for within-subject dependency.

For significant main effects or interactions, post-hoc pairwise comparisons were conducted with Bonferroni correction to control for Type I error inflation. Results are reported as Mean Differences (MD) with associated p-values. The level of statistical significance was set at $\alpha = 0.05$.

RESULTS

Demographic Data

The study cohort comprised 129 individuals, with females representing 54.26 % (n=70) of the population. The mean age of the participants was 47.38 ± 17.13 years (range: 20–84 years). Notably, the mean age of male participants was significantly higher than that of females ($p = 0.032$).

Pedicle Diameter

For the L1 level, analysis revealed significant main effects for both sex ($p = 0.028$) and side ($p = 0.001$). The sex $\times$ side interaction was not statistically significant ($p = 0.876$), indicating that the influence of sex remained consistent across both sides. Post-hoc analyses demonstrated that left-side measurements were significantly higher than right-side measurements in both females ($p = 0.013$, MD = -0.021) and males ($p = 0.038$, MD = -0.019).

As presented in **Table I**, regarding L2 diameter, no significant differences were observed between the right and left sides ($p = 0.373$), however, significant sex-based differences were observed ($p = 0.011$). Measurements were statistically comparable between sides for both females ($p = 0.347$, MD = -0.01) and males ($p = 0.729$, MD = -0.004). For the L3 level, neither main effects nor interaction effects reached statistical significance. At the L4 level, although left-side measurements were higher than right-side measurements in both sexes, this difference reached

significance only in females ($p = 0.010$, MD = -0.038) and was not significant in males ($p = 0.137$, MD = -0.024) (Fig. 3). Finally, L5 diameter measurements were similar between sides ($p = 0.503$), however, significant sex-based differences were observed ($p < 0.001$).

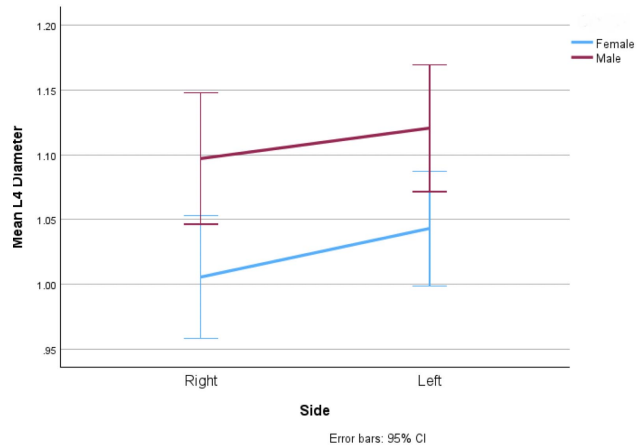


Fig. 3. Interaction between sex and side (right/left) in relation to L4 diameter.

Pedicle Length

At the L1 level, significant main effects were found for both sex and side ($p < 0.001$ for both). The sex $\times$ side interaction was non-significant ($p = 0.218$). Post-hoc analyses indicated that left-side measurements were significantly higher than right-side measurements in both females ($p < 0.001$, MD = -0.112) and males ($p = 0.027$, MD = -0.064).

Table I. Effects of Sex and Side on L1–L5 Morphometric Measurements (Linear Mixed-Effects Model).

Parameter	Female (Mean $\pm$ SD) R / L	Male (Mean $\pm$ SD) R / L	Sex p (MD)	Side p (MD)	Sex $\times$ Side p
L1 Diameter	0.57 $\pm$ 0.10 / 0.59 $\pm$ 0.10	0.61 $\pm$ 0.12 / 0.63 $\pm$ 0.12	0.028 (-0.041)	0.001 (-0.020)	0.876
L1 Length	5.24 $\pm$ 0.36 / 5.36 $\pm$ 0.38	5.56 $\pm$ 0.48 / 5.62 $\pm$ 0.51	<0.001 (-0.290)	<0.001 (-0.088)	0.218
L1 Angle	9.57 $\pm$ 1.34 / 9.69 $\pm$ 1.57	9.84 $\pm$ 1.32 / 10.09 $\pm$ 1.44	0.160 (-0.336)	0.029 (-0.183)	0.410
L2 Diameter	0.69 $\pm$ 0.12 / 0.70 $\pm$ 0.12	0.75 $\pm$ 0.15 / 0.75 $\pm$ 0.15	0.011 (-0.059)	0.373 (-0.007)	0.703
L2 Length	5.37 $\pm$ 0.28 / 5.42 $\pm$ 0.28	5.53 $\pm$ 0.38 / 5.61 $\pm$ 0.36	0.001 (-0.178)	<0.001 (-0.061)	0.533
L2 Angle	11.13 $\pm$ 1.79 / 11.58 $\pm$ 1.94	11.46 $\pm$ 1.54 / 11.65 $\pm$ 1.42	0.477 (-0.205)	<0.001 (-0.319)	0.139
L3 Diameter	0.83 $\pm$ 0.22 / 0.82 $\pm$ 0.16	0.87 $\pm$ 0.16 / 0.86 $\pm$ 0.14	0.150 (-0.041)	0.200 (0.014)	0.878
L3 Length	5.26 $\pm$ 0.39 / 5.35 $\pm$ 0.43	5.41 $\pm$ 0.37 / 5.52 $\pm$ 0.37	0.015 (-0.164)	<0.001 (-0.097)	0.588
L3 Angle	13.69 $\pm$ 1.59 / 13.95 $\pm$ 1.72	14.06 $\pm$ 1.60 / 13.87 $\pm$ 1.73	0.594 (-0.145)	0.753 (-0.036)	0.051
L4 Diameter	1.01 $\pm$ 0.20 / 1.04 $\pm$ 0.19	1.10 $\pm$ 0.19 / 1.12 $\pm$ 0.19	0.010 (-0.085)	0.005 (-0.031)	0.513
L4 Length	4.91 $\pm$ 0.45 / 5.03 $\pm$ 0.45	5.09 $\pm$ 0.55 / 5.23 $\pm$ 0.54	0.029 (-0.187)	<0.001 (-0.127)	0.630
L4 Angle	15.63 $\pm$ 1.48 / 15.86 $\pm$ 1.49	15.85 $\pm$ 1.74 / 15.56 $\pm$ 1.71	0.889 (0.037)	0.779 (0.027)	0.007
L5 Diameter	1.30 $\pm$ 0.21 / 1.30 $\pm$ 0.18	1.43 $\pm$ 0.22 / 1.40 $\pm$ 0.20	<0.001 (-0.114)	0.503 (0.009)	0.356
L5 Length	4.85 $\pm$ 0.42 / 4.98 $\pm$ 0.44	5.04 $\pm$ 0.46 / 5.12 $\pm$ 0.39	0.027 (-0.161)	<0.001 (-0.100)	0.380
L5 Angle	22.19 $\pm$ 2.50 / 22.25 $\pm$ 2.32	21.77 $\pm$ 2.37 / 21.70 $\pm$ 2.36	0.234 (0.483)	0.961 (0.006)	0.584

Values are presented as mean $\pm$ standard deviation (right / left). MD = estimated mean difference (Female - Male or Right - Left). p values were obtained from a linear mixed-effects model including fixed effects of sex, side, and their interaction. Significant results ($p < 0.05$) are shown in bold. Bonferroni correction was applied for pairwise comparisons.

For L2, L3, and L4 lengths, the effect of sex was consistent across both sides (interaction $p = 0.533$, 0.588 , and 0.630 , respectively). Left-side length measurements were significantly higher in both females ($p = 0.040$, MD = -0.050 ; $p < 0.001$, MD = -0.087 ; $p < 0.001$, MD = -0.117 , respectively) and males ($p = 0.007$, MD = -0.072 ; $p < 0.001$, MD = -0.107 ; $p < 0.001$, MD = -0.138 , respectively) (Fig. 4). Similarly, for L5 length, the interaction effect was non-significant ($p = 0.380$), and left-side measurements were significantly higher in both sexes (females: $p < 0.001$, MD = -0.121 ; males: $p = 0.023$, MD = -0.080)

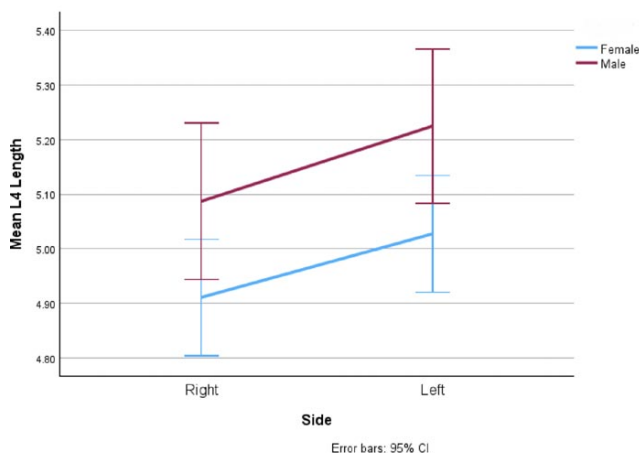


Fig. 4. Interaction between sex and side (right/left) for L4 length.

Transverse Angle

For the L1 angle, the main effect of sex was non-significant ($p = 0.160$), while the main effect of side was significant ($p = 0.029$). The sex $\times$ side interaction did not reach significance ($p = 0.410$). While side-based differences were not significant in females ($p = 0.308$, MD = -0.114), the left-side angle was significantly higher in males ($p = 0.041$, MD = -0.251).

Regarding the L2 angle, although both sexes exhibited higher values on the left side, this difference was significant only in females ($p < 0.001$, MD = -0.448). For the L3 angle, the interaction between sex and side did not reach statistical significance, although a marginal trend was observed ($p = 0.051$). In females, the left angle was higher than the right ($p = 0.093$, MD = -0.263), whereas in males, the right angle was higher than the left ($p = 0.263$, MD = 0.190).

Notably, the sex $\times$ side interaction for the L4 angle was statistically significant ($p = 0.007$). In females, the left angle was higher than the right ($p = 0.070$, MD = -0.235), while in males, the right angle was significantly

higher than the left ($p = 0.041$, MD = 0.289) (Fig. 5). For the L5 angle, side-based differences were not statistically significant for either females or males ($p = 0.712$, MD = -0.061 and $p = 0.686$, MD = 0.073 , respectively).

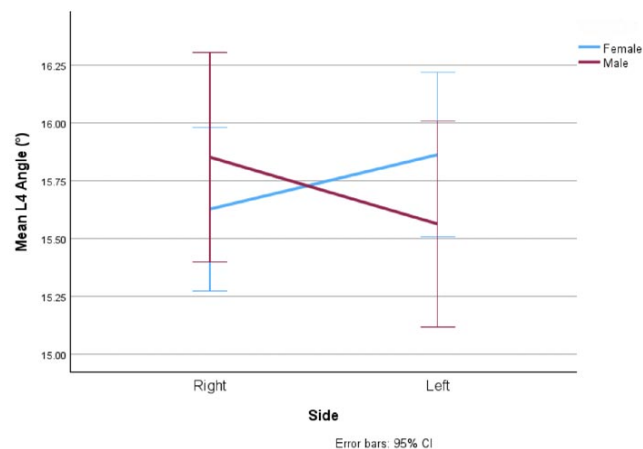


Fig. 5. Interaction between sex and side (right/left) with respect to the L4 angle.

DISCUSSION

The primary objective of this study was to provide a comprehensive morphometric analysis of the lumbar pedicle dimensions (diameter, length, and transverse angle) from L1 to L5. By utilizing a linear mixed-effects model, we accounted for within-subject dependencies, offering a statistically reliable perspective. Our findings reveal a distinct lateralization in pedicle morphology, characterized by significantly higher values in left-side measurements across most lumbar levels, particularly regarding pedicle length. While sexual dimorphism was evident in certain parameters, most notably in L1, L4 and L5 dimensions, the interaction between sex and side was particularly striking in pedicle angles. Specifically, at the L4 level, females exhibited higher left-side angles while males demonstrated higher right-side angles. While the interaction effect for the L3 transverse angle demonstrated a borderline trend, it did not meet the formal criteria for statistical significance. This finding should be interpreted with caution, potentially suggesting a transitional morphological pattern that warrants further investigation in larger cohorts. These results suggest that lumbar pedicle morphology is governed by complex interactions between genetic sex and biomechanical asymmetry, which may have profound implications for the precision and safety of transpedicular instrumentation.

Moreover, our findings regarding sexual dimorphism align with data reported in Mexican

populations, where males exhibited significantly greater pedicle width and length. Additionally, while the Mexican study emphasizes that age negatively impacts pedicle height and angle, our data further clarifies the role of lateralization, revealing a distinct left-side dominance in pedicle length. Interestingly, both studies underscore the necessity of population-specific morphometric data. Furthermore, our use of a linear mixed-effects model provides a more nuanced understanding of the interaction between sex and side, particularly the unique angular shifts observed at the L4 segment. Consequently, integrating these anatomical variations into preoperative planning is critical for enhancing surgical precision across different ethnic groups (Moncada-Habib *et al.*, 2025)

Considering the findings from previous literature, our results demonstrate both significant parallels and noteworthy divergences. Consistent with studies on Saudi and spinal stenosis populations, our data confirms a substantial sexual dimorphism where males generally exhibit larger pedicle dimensions (Arockiaraj *et al.*, 2025; Abbas *et al.*, 2020). However, a critical point of discrepancy arises in symmetry; while Arockiaraj *et al.*, reported no significant differences between sides, our study identified a clear lateralization (Arockiaraj *et al.*, 2025;). Moreover, while Abbas *et al.* (2020), concluded that dimensions are independent of age, our findings suggest that specific parameters, particularly the L4 transverse angle, involve a complex sex-side interaction not consistently observed in more homogenous cohorts. These discrepancies underscore that while the transition from narrow L1 to wider L5 pedicles follows a universal trend, the degree of bilateral asymmetry is highly influenced by ethnic variations.

Additionally, in comparison with international datasets, our results contribute to the growing evidence of lumbar diversity. Consistent with large-scale American and Turkish studies, our data reaffirms that male subjects possess significantly larger pedicle calibers (Yu *et al.*, 2015; Bozdog & Karaman, 2021). Notably, Bozdog & Karaman (2021) utilized L1 morphometry for sex estimation with 72.6 % accuracy, echoing our findings of significant sex-based differences at the L1 level. Nevertheless, our study offers a unique perspective on bilateral asymmetry. While Yu *et al.* (2015) suggests that race and age do not influence dimensions significantly; our findings reveal a left-side dominance that necessitates careful consideration during surgery. Furthermore, while we observed the standard cranio-caudal increase in pedicle width (peaking at L5), we emphasize that the transverse angle interaction with gender is a critical, population-specific variable for the Turkish population.

In addition to these findings, a comparative analysis reveals that the transverse pedicular angle progressively increases from L1 to L5, aligning with Eastern Indian data Priya *et al.* (2023). However, while Priya *et al.* (2023), reported the widest width at L3, our Turkish cohort demonstrated a linear increase toward L5, highlighting ethnic variations in growth patterns. Conversely, unlike symmetry models often assumed in avian morphometrics, our human subjects exhibit pronounced directional asymmetry (Güzel *et al.*, 2025). Moreover, while Ebraheim *et al.* (1997), focused on dried bone symmetry, our use of a linear mixed-effects model allows for a clinically focused detection of asymmetry in living subjects. Consequently, our results reinforce the conclusion that localized data is indispensable for the success of free-hand pedicle screw insertion. Our analysis reveals that while commercially available lumbar stabilization screws, typically ranging from 4.5 to 7.5 mm in diameter, align with the general dimensions of the Turkish population, their application requires careful consideration of the specific lateralization and sexual dimorphism identified in this study.

Notably, the distinct left-side dominance in pedicle length suggests that utilizing identical screw lengths bilaterally may significantly increase the risk of anterior cortical perforation on the shorter (right) side. This is a critical finding, as such perforations can lead to major vascular injury or visceral damage. Furthermore, the unique sex-side interaction observed at the L4 transverse angle emphasizes that a "one-size-fits-all" approach to screw trajectory is insufficient. Failing to account for this gender-specific lateralization could result in medial or lateral wall breaches, compromising the safety of the procedure. Therefore, for optimal lumbar stabilization in our population, we recommend that preoperative planning should not only rely on vertebral level but also strictly account for gender and inherent bilateral asymmetry to ensure precise screw trajectory and maximum pull-out strength. Integrating these population-specific variations into preoperative CT templating or robotic-assisted techniques is essential to minimize the risk of iatrogenic neurovascular complications.

However, this study has limitations. Firstly, it is a single-center retrospective design, which may limit generalizability. In this context, the integration of automated or AI-based measurements represents a promising future direction to enhance objective quantification and further reduce the inherent variability associated with manual morphometric assessments among centers. Secondly, we did not include anthropometric data such as BMI, which may influence caliber. Finally, as a CT-based study, these results do not fully capture intraoperative soft tissue complexities.

CONCLUSION

In conclusion, this study provides a comprehensive morphometric profile of lumbar pedicles in the Turkish population, highlighting the critical roles of sexual dimorphism and bilateral asymmetry. By employing a linear mixed-effects model, we demonstrated that pedicle dimensions are not only gender-dependent but also exhibit significant lateralization, particularly at the L4 level. Ultimately, integrating these population-specific variations into preoperative planning and robotic-assisted techniques can significantly enhance the safety of transpedicular instrumentation and minimize neurovascular complications.

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RESUMEN: El objetivo de este estudio fue realizar un análisis morfométrico exhaustivo de las dimensiones de los pedículos lumbares (L1-L5) en una población turca mediante un modelo lineal de efectos mixtos (MLM) para establecer una base anatómica fiable e investigar el impacto del dimorfismo sexual y la asimetría bilateral. Este estudio retrospectivo analizó tomografías computarizadas (TC) de alta resolución de 129 adultos sanos (70 mujeres, 59 hombres; edad media $47,38 \pm 17,13$ años). Se midieron el diámetro, la longitud y el ángulo transversal del pedículo desde L1 hasta L5. Se empleó un modelo lineal mixto (MLM) para tener en cuenta las dependencias intrasujeto, tratando el sexo y el lado como efectos fijos y la identificación del sujeto como un efecto aleatorio. Se observó un dimorfismo sexual significativo, con los hombres exhibiendo generalmente calibres de pedículo mayores. Para el diámetro de L1, se encontraron efectos principales significativos para el sexo ($p = 0,028$) y el lado ($p = 0,001$), siendo las mediciones del lado izquierdo significativamente mayores en ambos sexos. La longitud del pedículo demostró un predominio constante del lado izquierdo en la mayoría de los niveles (L1-L5, $p < 0,05$). Se observó una interacción significativa sexo $\times$ lado en los ángulos transversales del pedículo, particularmente en L4 ($p = 0,007$). En mujeres, el ángulo del pedículo L4 izquierdo tendía a ser mayor que el derecho ($p = 0,070$), mientras que en hombres, el ángulo del lado derecho era significativamente mayor que el izquierdo ($p = 0,041$). La morfología del pedículo lumbar en la población turca se rige por interacciones complejas entre el sexo genético y la asimetría direccional. El marcado predominio del lado izquierdo en longitud y los singulares cambios angulares en L4 difieren de los hallazgos en otras cohortes étnicas. Estos matices específicos de la población son cruciales para la planificación preoperatoria y la selección de las dimensiones óptimas de los tornillos. Integrar estas variaciones en la práctica quirúrgica es esencial para mejorar la precisión de la instrumentación transpedicular y minimizar los riesgos neurovasculares.

PALABRAS CLAVE: Asimetría bilateral; Vértebras lumbares; Morfometría del pedículo; Dimorfismo sexual.

REFERENCES

- Abbas, J.; Peled, N.; Hershkovitz, I. & Hamoud, K. Pedicle morphometry variations in individuals with degenerative lumbar spinal stenosis. *Biomed. Res. Int.*, 2020:7125914, 2020.
- Arockiaraj, J.; Alawaji, A. I.; Alkuhaimi, T. S.; Alshahrani, M. S.; Prithishkumar, I. J.; Wani, T. A.; Bauones, S.; Attia, W. I. & Almusrea, K. N. Morphometric analysis of lumbar pedicles in the Saudi Arabian population – A CT-based study on 1500 vertebrae. *J. Craniovertebr. Junction Spine*, 16(3):312-9, 2025.
- Bozdag, M. & Karaman, G. Virtual morphometry of the first lumbar vertebrae for estimation of sex using computed tomography data in the Turkish population. *Cureus*, 13(7):e16597, 2021.
- Castro Reyes, C. D.; Morales Avalos, R.; Vélchez Cavazos, F.; De la Garza Castro, O.; Salinas Zertuche, A.; Aguirre, P. O. M.; Cámara Rodríguez, L.; Vidal Torres, O.; Elizondo Omaña, R. E. & Guzmán López, S. Morphometry of pedicle and vertebral body in a Mexican population by CT and fluoroscopy. *Int. J. Morphol.*, 27(4):1299-303, 2009.
- Chawla, A. Morphometric analysis of the lumbar vertebrae. *J. Anat. Soc. India*, 62(1):45-52, 2013.
- Cheung, K. M. C.; Ruan, D.; Chan, F. L. & Fang, D. Computed tomographic osteometry of Asian lumbar pedicles. *Spine (Phila Pa 1976)*, 19(13):1495-8, 1994.
- Düzkalır, Z.; Özdoğan, S.; Gül, A.; Gergin, S.; Senol, Ö. & Düzkalır, A. H. Sexual dimorphism in lumbar pedicles: CT evaluation. *Turk. Neurosurg.*, 25(4):521-8, 2015.
- Ebraheim, N. A.; Xu, R.; Ahmad, M. & Yeasting, R. A. Projection of the thoracic pedicle and its morphometric analysis. *Spine (Phila Pa 1976)*, 22(3):233-8, 1997.
- Gurumurthy, H.; Sujana Theja, J. S.; Prakash, M.; Nandish, K. K. C.; Girish, K. & Sastry, P. Morphometric analysis of lumbar pedicle in our population based on computed tomography. *Int. J. Health Sci.*, 6(S1): 7283-94, 2022.
- Güzel, B. C.; Ünal, B.; Eroglu, M.; Isbilir, F. & Szara, T. Exploring sexual dimorphism and asymmetry in quail (*Coturnix coturnix*) feet using geometric morphometrics. *Vet. Sci.*, 12(9):871, 2025.
- Jutte, P. C. & Castelein, R. M. Surgical management of lumbar instability. *Eur. Spine J.*, 11(6):527-34, 2002.
- Maaly, M. & El Rakhawy, M. CT based morphometric analysis of lumbar vertebrae. *Egypt. J. Radiol. Nucl. Med.*, 41(3):321-8, 2010.
- Moncada-Habib, T.; Jiménez-Molina, T.; Muñuzuri-Camacho, M. A.; Pulido Bayona, P. A.; Toache, K. S.; Álvaro Heredia, J.; López-Valencia, G. & Alvaro-Heredia, J. A. Lumbar pedicle morphometry in the Mexican population: Defining anatomical references for safer spine surgery. *Cureus*, 17(9):e91799, 2025.
- Priya, A.; Narayan, R. K.; Ghosh, S. K. & Sarangi, P. K. Analysing lumbar pedicle morphometry observed via traditional and recent modalities. *J. Orthop.*, 43:17-24, 2023.
- Roy-Camille, R. & Saillant, G. Surgery of the cervical spine. 2. Dislocation. Fracture of the articular processes. *Nouv. Presse Med.*, 1(37):2484-5, 1972.
- Yu, C. C.; Yuh, R. T.; Bajwa, N. S.; Toy, J. O.; Ahn, U. M. & Ahn, N. U. Pedicle morphometry of lumbar vertebrae: Male, taller, and heavier specimens have bigger pedicles. *Spine (Phila. Pa. 1976)*, 40(21):1639-46, 2015.

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