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Morphometric Analysis of Lumbar Vertebral Pedicles According to Age and Gender

Morfometrická analýza pediklů bederních obratlů podle věku a pohlaví

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ABSTRACT

Purpose of the study
A thorough understanding of pedicle morphometrics is crucial for selecting suitable pedicle screws and their optimal trajectory in spinal stabilization. This study aims to provide a detailed morphometric analysis of lumbar pedicles in a Turkish population from the Aegean region, considering gender and age based on CT scans.

Material and methods
This retrospective study analyzed CT scans of 500 lumbar vertebrae from 100 healthy individuals (50 females, 50 males) residing in the Aegean region of Turkey.

Results
Our study found that pedicule axial length (PAL), pedicle width (PW), pedicle height (PH), and foramen vertebra transverse diameter (FTD) parameters were significantly higher in males than in females ($p < 0.05$). In both genders, from L1 to L5, there was an increase in PW (left and right), FTD, pedicle transverse angle (PTA) (left and right), and a decrease in pedicle length (PL) (left and right) and foramen vertebra sagittal diameter (FSD). PTA right values were significantly lower than PTA left values at L1 and L2 levels in females and at L2 and L3 levels in males ($p < 0.05$). However, there were no statistically significant differences between the left and right mean measurements for the remaining parameters in both genders ($p > 0.05$).

Discussion
Recent studies indicate significant racial and gender variations in pedicle morphometry, making gender a crucial factor in screw size selection. Our study found notable gender-based differences in PAL, PH, PW, PTA, and PSA. Prior research showed no significant asymmetry in left and right pedicle dimensions. Consistent with these findings, our study observed symmetrical left-right pedicle measurements in both genders, with the exception of PTA.

Conclusions
Gender and race differences had a significant impact on the characteristics of pedicle morphometry. This study demonstrates significant gender-based differences in lumbar vertebral morphometric parameters, independent of age. The presented morphometric data provide valuable reference information for the local population and contribute to the expanding body of knowledge in the field.

Key words: lumbar spine, pedicle morphology, pedicle screw, spinal surgery, computed tomography.

INTRODUCTION

Surgical interventions to place internal fixators in the vertebrae have become increasingly common in recent decades due to causes such as vertebral fractures leading to spinal instability, spinal deformities, degenerative changes in the vertebrae, infections, and neoplasms (10). Posterior transpedicular screw-rod fixation is the widely accepted gold standard for spinal stabilization. Accurate knowledge of detailed vertebral pedicle anatomy is crucial for safe and effective spinal surgery, as they are adjacent to vital neural and vascular tissues. Furthermore, understanding the morphometric characteristics of the pedicles is vital for selecting pedicle screws of appropriate length and width, as well as for determining the ideal entry point and angle for screw insertion (22). Although vertebrae possess fundamental similarities, they exhibit variations

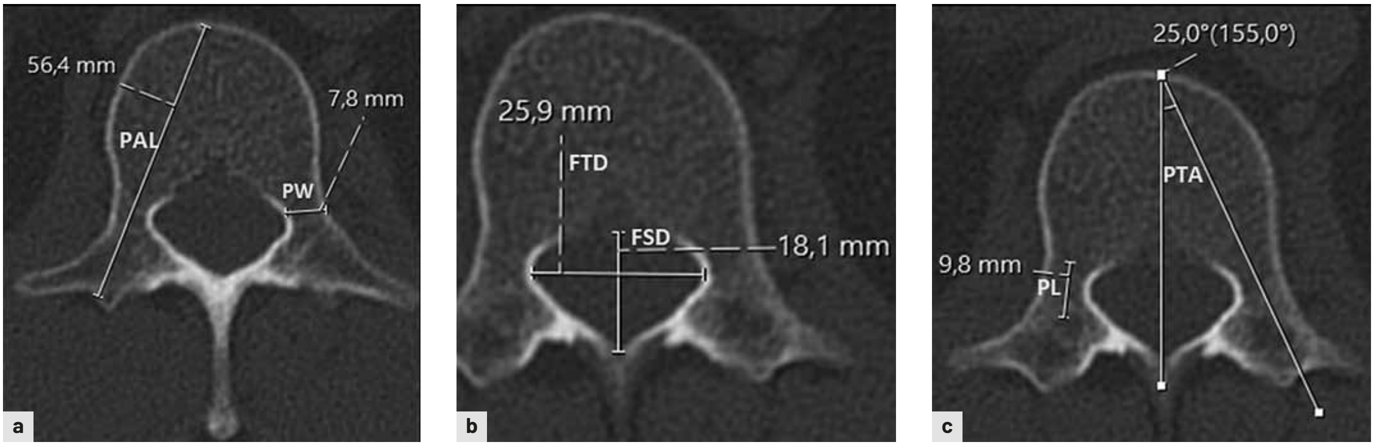

Fig. 1. **Axial plane measurements of vertebra pedicules (a). Pedicule axial length (PAL) and Pedicle width (PW), (b). Foramen vertebra transverse diameter (FTD), Foramen vertebra sagittal diameter (FSD), (c). Pedicle length (PL), Pedicle transverse angle (PTA).**

in dimensions and morphometric properties across different spinal column regions, which are correlated with their distinct functional requirements (26). Furthermore, variations in the morphometric structure of vertebrae may be observed based on factors such as race, gender, and age. Numerous studies on the morphology of lumbar vertebrae have revealed variations among different races (4, 29). Therefore, racial and gender-specific data on pedicle morphometry are required for achieving optimal and uncomplicated spinal surgical procedures.

In literature, there are many studies comparing pedicle morphometry between males and females (6, 16, 18–20, 28). However, it is known that there are morphological differences between genders in the skeletal system. Therefore, the goal of this study is to conduct a thorough morphometric analysis of lumbar vertebral pedicles, considering gender and age differences in a population from the Aegean region of Turkey. In this study, computed tomography (CT) imaging is employed, a method widely recognized for its efficacy in evaluating pedicle morphometry, specifically for the measurement of lumbar pedicles.

MATERIAL AND METHODS

Approval for this study was obtained from the Aydin Adnan Menderes University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (protocol no: 2023/90; date: 11. 05. 2023). This retrospective study included CT scans of the lumbar vertebrae from 100 adult cases (aged 18-65 years) collected between January 2020 and April 2023. Morphometric analyses were conducted on 500 lumbar vertebrae from 100 healthy cases (50 females and 50 males) included in the study. Cases with a history of previous vertebral surgeries, scoliosis, congenital vertebral anomalies, fractures, tumors, severe degenerative vertebral diseases, and low-quality CT images were excluded from this study. Measurements were conducted using CT, which is considered the most reliable and optimal radiological imaging method for evaluating pedicle morphometric features (8, 30). CT scan images were acquired using a Toshiba Aquilion Prime 160 Slice CT scanner with Cardiac Options, with a slice thickness of 2 mm.

Morphometric parameters

Morphometric measurements of each vertebra were conducted by a specialist radiologist on axial and sagittal CT scans, with parameters measured separately for the left and right sides. All morphometric measurements were adopted from Zindrick et al. and Olsewski et al. (21, 30).

Axial plane measurements

The axial measurements were performed at the level of the mid-pedicles isthmus, which was determined from the sagittal view. The widest interpedicular distance of the foramen vertebra was measured as the foramen vertebra transverse diameter (FTD) (Fig. 1b). The antero-posterior diameter of the foramen vertebra along the median line was measured as the foramen vertebra sagittal diameter (FSD) (Fig. 1b). The pedicle length (PL) was measured as the distance between the posterior edge of the corpus vertebra and the basis of processus (proc.) transversus (Fig. 1c). The pedicle width (PW) was the medial-lateral diameter of the pedicle isthmus in the transverse plane (Fig. 1a). The pedicule axial length (PAL) was obtained as the midpoint of the basis of proc. transversus and the distance of the axis passing through the center of the pedicle to the anterior periosteum of the corpus vertebra (Fig. 1a). The pedicle transverse angle (PTA) was measured as the angle between the midsagittal axis and the PAL (Fig. 1c).

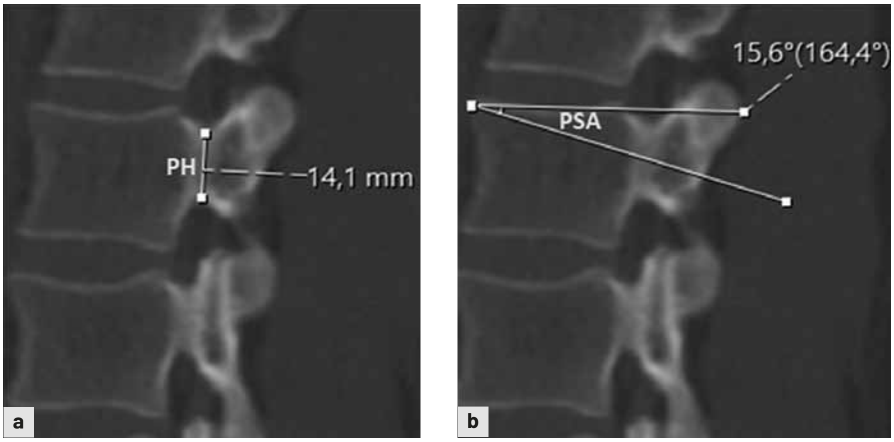

Fig. 2. **Sagittal plane measurements of vertebra pedicules (a). Pedicle height (PH), (b). Pedicul sagittal angle (PSA).**

Sagittal plane measurements

The narrowest part of the pedicle in the cranio-caudal direction was defined as pedicle height (PH) (Fig. 2a). The angle between the axis parallel to the superior endplate of the corpus vertebra and the axis passing through the midpoint of the pedicle height was obtained as the pedicle sagittal angle (PSA) (Fig. 2b).

Statistical analysis

Due to the difference in morphometric structure between males and females, statistical analysis of the measurement results was performed on a gender basis. The statistical analyses were performed as mean ± standard deviation (SD), median, and range for descriptive analyses. The Shapiro Wilk test was used to evaluate the normality of the data. The Student's t-test was used for the analyzing of normally distributed data. Non-parametric Mann-Whitney U test was used to compare gender differences in the parameters. Statistics were considered significant for values below 0.05 ($p < 0.05$).

RESULTS

In the study, morphometric measurements of the pedicles of 500 vertebrae from 100 healthy cases (50 females, 50 males) aged 18 to 65 years were performed. The mean age of the females was 45.00 ± 12.76 years, the mean age of the males was 41.50 ± 13.08 years. All parameters were measured separately at each level (left-right) to determine asymmetry, and statistical analysis of the data was performed according to gender (Table 1). For the mean PTA, asymmetry was found at the L1 and L2 levels in females and at the L2 and L3 levels in males. The mean PTA right was significantly lower at L1 and L2 levels in females and at L2 and L3 levels in males ($p < 0.05$). However, across all lumbar levels, there were no statistically significant differences between the left and right mean measurements for the remaining parameters in both genders when comparing the left and right sides. In both males and females from L1 to L5, the mean measurements for PW left, PW right, FTD, PTA left, and PTA right increased, while the mean measurements for PL left, PL right, and FSD decreased (Table 1).

Significant differences were found between genders for several pedicle measurements (Table 2). Specifically, mean values for PAL (left and right) and PH were significantly lower in females than in males at all vertebral levels. Similarly, mean PW values (left and right) were also significantly lower in females than in males at all levels except L5. Additionally, females demonstrated significantly lower values than males for PTA at L3 (left) and L1 (right), PSA at L3 and L5, and FTD at L3, L4, and L5 ($p < 0.05$).

In our study, all cases were also divided into age groups (18–35, 36–50, 51–65), and statistical analysis of the measurements was performed according to these age groups (Table 3). Significant age-related differences were observed in several pedicle measurements. The mean values for PSA at the L1, L2, and L3 levels and PH at the L3 level were significantly lower in the 51–65 age group compared to the 18–35 age group. Conversely, the mean values for FTD at the L4 level, PAL left at the L4 level, and PAL right at the L5 level were significantly higher in the 51–65 age group ($p < 0.05$). A statistically significant decrease was observed exclusively in PSA measurements at the L1 level between the 18–35 and 36-50 age groups ($p < 0.05$).

DISCUSSION

The transpedicular screw fixation technique has been widely applied by surgeons in recent years to provide fusion in the treatment of instabilities in the spine (2). Applying the pedicle

Table 1. **Lumbar vertebral pedicle measurements (right and left) by gender. Data were presented as (Minimum–Maximum) Mean±standard deviation (SD).**

MEASURAMENTS (MM)	L1 (MIN–MAX) MEAN ± SD	L2 (MIN–MAX) MEAN ± SD	L3 (MIN–MAX) MEAN ± SD	L4 (MIN–MAX) MEAN ± SD	L5 (MIN–MAX) MEAN ± SD
PAL left (female)	(45.1–58.0) 52.72 ± 2.94	(45.1–59.1) 53.76 ± 3.05	(45.0–60.2) 52.62 ± 3.38	(45.7–64.5) 51.74 ± 3.73	(45.2–70.8) 53.31 ± 4.12
PAL right (female)	(46.9–61.4) 53.44 ± 3.63	(47.4–61.0) 53.74 ± 3.00	(44.1–60.2) 53.00 ± 3.31	(45.2–61.6) 52.07 ± 3.93	(43.8–71.6) 52.46 ± 4.24
PAL mean (female)	53.08 ± 3.28	53.75 ± 3.02	52.81 ± 3.34	51.90 ± 3.83	52.88 ± 4.18
PAL left (male)	(47.4–64.1) 56.51 ± 3.49	(49.9–64.4) 57.16 ± 3.08	(43.8–63.2) 56.16 ± 3.47	(44.7–64.5) 55.12 ± 3.92	(49.2–70.8) 57.02 ± 4.31
PAL right (male)	(49.8–66.5) 57.29 ± 3.18	(50.4–64.0) 57.17 ± 3.12	(47.2–62.4) 56.47 ± 3.26	(49.1–64.7) 55.21 ± 3.49	(49.9–71.6) 56.18 ± 4.12
PAL mean (male)	56.9 ± 3.33	57.16 ± 3.10	56.31 ± 3.36	55.16 ± 3.70	56.6 ± 4.21
PL left (female)	(5.1–12.2) 8.81 ± 1.68	(5.0–11.2) 8.20 ± 1.49	(5.1–11.0) 7.30 ± 1.22	(4.3–8.4) 6.18 ± 0.96	(3.9–8.3) 5.08 ± 0.78
PL right (female)	(4.3–13.6) 9.02 ± 1.78	(5.1–10.9) 8.48 ± 1.46	(4.7–11.1) 7.31 ± 1.24	(4.3–8.5) 6.18 ± 0.91	(4.0–7.6) 4.99 ± 0.71
PL mean (female)	8.91 ± 2.57	8.34 ± 1.47	7.30 ± 1.23	6.18 ± 0.93	5.03 ± 0.74
PL left (male)	(4.5–12.1) 8.40 ± 1.50	(4.5–11.5) 7.97 ± 1.22	(5.3–11.0) 7.12 ± 1.08	(4.3–7.9) 6.24 ± 0.88	(4.5–6.6) 5.21 ± 0.66
PL right (male)	(4.2–11.6) 8.61 ± 1.52	(5.4–12.2) 8.06 ± 1.24	(4.8–11.1) 7.26 ± 1.95	(4.0–8.1) 6.06 ± 0.36	(4.2–6.5) 5.08 ± 0.64
PL mean (male)	8.50 ± 1.51	8.01 ± 1.23	7.19 ± 1.51	6.15 ± 0.62	5.14 ± 0.65
PW left (female)	(2.8–7.4) 5.13 ± 1.08	(3.5–8.5) 5.69 ± 1.32	(5.1–11.4) 7.30 ± 1.47	(6.5–11.7) 9.30 ± 1.48	(8.5–17.6) 13.35 ± 1.83
PW right (female)	(2.7–7.8) 5.09 ± 1.23	(3.2–8.7) 5.66 ± 1.21	(5.6–11.3) 7.61 ± 1.67	(6.1–13.4) 9.59 ± 1.61	(9.0–17.0) 13.47 ± 1.94
PW mean (female)	5.11 ± 1.15	5.67 ± 1.26	7.45 ± 1.57	9.44 ± 1.54	13.41 ± 1.88
PW left (male)	(2.9–11.5) 6.60 ± 1.77	(4.1–10.0) 6.96 ± 1.55	(4.8–12.2) 8.83 ± 1.68	(6.6–15.3) 10.48 ± 1.74	(9.7–18.2) 14.00 ± 2.35
PW right (male)	(2.6–10.8) 6.81 ± 1.71	(3.6–10.0) 7.17 ± 1.70	(5.6–12.6) 8.91 ± 1.77	(7.8–14.7) 11.02 ± 1.66	(10.4–18.3) 14.05 ± 1.94
PW mean (male)	6.70 ± 1.74	7.06 ± 1.62	8.87 ± 1.72	10.75 ± 1.70	14.02 ± 2.14
PH (female)	(7.8–16.2) 12.59 ± 1.40	(7.9–14.7) 11.96 ± 1.43	(7.9–18.7) 15.50 ± 2.28	(8.1–15.8) 10.62 ± 1.68	(4.9–12.5) 8.94 ± 1.73
PH (male)	(7.9–17.5) 14.24 ± 1.59	(8.9–16.6) 13.26 ± 1.59	(8.3–21.2) 17.89 ± 2.11	(7.9–14.7) 11.54 ± 1.43	(7.4–19.9) 10.26 ± 2.09
FSD (female)	(13.5–21.1) 17.58 ± 1.61	(13.0–24.4) 17.20 ± 1.86	(12.6–24.8) 16.00 ± 2.20	(12.4–23.1) 16.16 ± 2.46	(12.3–24.1) 16.68 ± 2.58
FSD (male)	(12.0–21.6) 17.31 ± 2.12	(13.6–20.3) 16.99 ± 1.75	(12.9–21.3) 16.03 ± 2.21	(12.6–22.2) 16.20 ± 2.74	(12.3–22.4) 17.06 ± 2.75
FTD (female)	(18.6–27.5) 22.76 ± 1.85	(18.6–27.9) 23.17 ± 1.88	(19.0–29.8) 23.70 ± 2.20	(18.8–29.8) 24.59 ± 2.38	(23.0–38.1) 27.95 ± 3.17
FTD (male)	(20.1–28.0) 23.62 ± 1.97	(19.2–28.7) 23.87 ± 2.02	(20.2–28.0) 24.67 ± 2.33	(20.5–30.2) 26.08 ± 2.62	(21.6–37.0) 29.72 ± 3.69
PTA (0) left (female)	(11.1–26.4) 22.71 ± 2.34	(20.1–26.1) 23.09 ± 1.41	(21.6–28.1) 25.26 ± 1.70	(24.0–33.1) 27.96 ± 1.91	(27.7–38.6) 33.49 ± 2.96
PTA right (female)	(8.6–25.3) 21.81 ± 2.36*	(17.3–25.0) 22.33 ± 1.44*	(20.7–29.9) 24.64 ± 1.89	(22.3–34.2) 27.59 ± 2.08	(27.0–39.6) 32.91 ± 3.17
PTA mean (female)	22.26 ± 2.35	22.71 ±1 .42	24.95 ± 1.79	27.72 ± 2.08	33.2 ± 3.06
PTA left (male)	(19.6–28.1) 23.33 ± 1.89	(20.4–26.6) 23.59 ± 1.51	(22.6–29.6) 26.17 ± 1.77	(25.4–36.7) 28.77 ± 2.57	(28.3–42.6) 33.75 ± 3.24
PTA right (male)	(18.3–27.2) 22.86 ± 2.04	(19.3–26.7) 22.85 ± 1.59*	(21.7–29.1) 25.27 ± 1.85*	(24.8–32.8) 27.89 ± 2.00	(27.4–38.4) 32.20 ± 3.11
PTA mean (male)	23.09 ± 1.96	23.22 ± 1.55	25.72 ± 1.81	28.33 ± 2.28	32.97 ± 3.17

MEASURAMENTS (MM)	L1 (MIN-MAX) MEAN ± SD	L2 (MIN-MAX) MEAN ± SD	L3 (MIN-MAX) MEAN ± SD	L4 (MIN-MAX) MEAN ± SD	L5 (MIN-MAX) MEAN ± SD
PSA (female)	(11.9–21.7) 15.43 ± 1.99	(11.4–20.2) 15.45 ± 2.05	(11.0–14.3) 11.49 ± 1.45	(9.2–19.5) 14.87 ± 2.18	(7.9–20.1) 13.02 ± 3.08
PSA (male)	(10.4–19.1) 15.18 ± 2.13	(10.9–18.8) 15.08 ± 1.82	(11.3–20.3) 12.75±1.66	(9.7–21.0) 14.48 ± 2.54	(7.7–20.4) 15.36 ± 2.06

Pedicule axial length (PAL), Pedicle length (PL), Pedicle width (PW), Pedicle height (PH), Foramen vertebra sagittal diameter (FSD), Foramen vertebra transverse diameter (FTD), Pedicle transverse angle (PTA), Pedicul sagittal angle (PSA). *Statistically significant asymmetry in pedicle measurements (p<0.05).

Table 2. **Comparison of the lumbar vertebral pedicle measurements between males and females. Data were presented as Mean ± standard deviation (SD)**

MEASURAMENTS (MM)	L1 MEAN ± SD	L2 MEAN ± SD	L3 MEAN ± SD	L4 MEAN ± SD	L5 MEAN ± SD
PAL left (female)	52.72 ± 2.94*	53.76 ± 3.05*	52.62 ± 3.38*	51.74 ± 3.73*	53.31 ± 4.12*
PAL left (male)	56.51 ± 3.49	57.16 ± 3.08	56.16 ± 3.47	55.12 ± 3.92	57.02 ± 4.31
PAL left (All)	54.62 ± 3.73	55.39 ± 3.46	54.39 ± 3.84	53.43 ± 4.17	55.23 ± 4.62
PAL right (female)	53.44 ± 3.63*	53.74 ± 3.00*	53.00 ± 3.31*	52.07 ± 3.93*	52.46 ± 4.24*
PAL right (male)	57.29 ± 3.18	57.17 ± 3.12	56.47 ± 3.26	55.21 ± 3.49	56.18 ± 4.12
PAL right (All)	55.36 ± 3.91	55.45 ± 3.50	54.73 ± 3.70	53.64 ± 4.02	54.32 ± 4.57
PL left (female)	8.81 ± 1.68	8.20 ± 1.49	7.30 ± 1.22	6.18 ± 0.96	5.08 ± 0.78
PL left (male)	8.40 ± 1.50	7.97 ± 1.22	7.12 ± 1.08	6.24 ± 0.88	5.21 ± 0.66
PL left (All)	8.60 ± 1.60	8.09 ± 1.36	7.21 ± 1.52	6.21 ± 0.92	5.14 ± 0.72
PL right (female)	9.02 ± 1.78	8.48 ± 1.46	7.31 ± 1.24	6.18 ± 0.91	4.99 ± 0.71
PL right (male)	8.61 ± 1.52	8.06 ± 1.24	7.26 ± 1.95	6.06 ± 0.36	5.08 ± 0.64
PL right (All)	8.81 ± 1.66	8.27 ± 1.36	7.28 ± 1.21	6.12 ± 0.87	5.03 ± 0.68
PW left (female)	5.13 ± 1.08*	5.69 ± 1.32*	7.30 ± 1.47*	9.30 ± 1.48*	13.35 ± 1.83
PW left (male)	6.60 ± 1.77	6.96 ± 1.55	8.83 ± 1.68	10.48 ± 1.74	14.00 ± 2.35
PW left (All)	5.86 ± 1.63	6.32 ± 1.57	8.07 ± 1.75	9.89 ± 1.71	13.68 ± 2.12
PW right (female)	5.09 ± 1.23*	5.66 ± 1.21*	7.61 ± 1.67*	9.59 ± 1.61*	13.47 ± 1.94
PW right (male)	6.81 ± 1.71	7.17 ± 1.70	8.91 ± 1.77	11.02 ± 1.66	14.05 ± 1.94
PW right (All)	5.95 ± 1.71	6.42 ± 1.65	8.26 ± 1.83	10.30 ± 1.78	13.76 ± 1.95
PH (female)	12.59 ± 1.40*	11.96 ± 1.43*	15.50 ± 2.28*	10.62 ± 1.68*	8.94 ± 1.73*
PH (male)	14.24 ± 1.59	13.26 ± 1.59	17.89 ± 2.11	11.54 ± 1.43	10.26 ± 2.09
PH (All)	13.4 ± 1.70	12.61 ± 1.64	16.66 ± 2.34	11.08 ± 1.62	9.60 ± 2.02
FSD (female)	17.58 ± 1.61	17.20 ± 1.86	16.00 ± 2.20	16.16 ± 2.46	16.68 ± 2.58
FSD (male)	17.31 ± 2.12	16.99 ± 1.75	16.03 ± 2.21	16.20 ± 2.74	17.06 ± 2.75
FSD (All)	17.44 ± 1.88	17.09 ± 1.80	16.02 ± 2.20	16.18 ± 2.59	16.87 ± 2.66
FTD (female)	22.76 ± 1.85	23.17 ± 1.88	23.70 ± 2.20*	24.59 ± 2.38*	27.95 ± 3.17*
FTD (male)	23.62 ± 1.97	23.87 ± 2.02	24.67 ± 2.33	26.08 ± 2.62	29.72 ± 3.69
FTD (All)	23.19 ± 1.95	23.52 ± 1.97	24.19 ± 2.31	25.33 ± 2.60	28.84 ± 3.53
PTA left (female)	22.71 ± 2.34	23.09 ± 1.41	25.26 ± 1.70*	27.96 ± 1.91	33.49 ± 2.96
PTA left (male)	23.33 ± 1.89	23.59 ± 1.51	26.17 ± 1.77	28.77 ± 2.57	33.75 ± 3.24
PTA left (All)	23.02 ± 2.14	23.34 ± 1.48	25.71 ± 1.79	28.36 ± 2.29	33.62 ± 3.09
PTA right (female)	21.81 ± 2.36*	22.33 ± 1.44	24.64 ± 1.89	27.59 ± 2.08	32.91 ± 3.17
PTA right (male)	22.86 ± 2.04	22.85 ± 1.59	25.27 ± 1.85	27.89 ± 2.00	32.20 ± 3.11
PTA right (All)	22.34 ± 2.62	22.59 ± 1.53	24.73 ± 2.97	27.47 ± 2.04	32.55 ± 3.14
PSA (female)	15.43 ± 1.99	15.45 ± 2.05	11.49 ± 1.45*	14.87 ± 2.18	13.02 ± 3.08*
PSA (male)	15.18 ± 2.13	15.08 ± 1.82	12.75 ± 1.66	14.48 ± 2.54	15.36 ± 2.06
PSA (All)	15.31 ± 2.05	15.26 ± 1.94	12.12 ± 1.68	14.68 ± 2.36	14.19 ± 2.16

*Statistically significant difference between genders (p < 0.05).

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Table 3. **Comparison of measurements according to age groups. Data were presented as (Minimum–Maximum) Mean ± standard deviation (SD)**

18–35 AGE (N = 26) (MIN–MAX) MEAN ± SD	PAL LEFT (MM)	PAL RIGHT (MM)	PL LEFT (MM)	PL RIGHT (MM)	PW LEFT (MM)	PW RIGHT (MM)
L1	(47.4–62.9) 54.40 ± 3.69	(47.7–62.1) 55.07 ± 4.00	(7.1–12.1) 8.87 ± 1.30	(7.2–10.7) 9.08 ± 1.19	(2.5–9.5) 5.85 ± 1.78	(2.6–8.5) 5.74 ± 1.85
L2	(48.8–62.9) 55.10 ± 3.38	(47.4–63.5) 54.89 ± 3.94	(6.3–10.7) 8.36 ± 0.98	(5.8–10.9) 8.55 ± 1.12	(3.7–9.4) 5.83 ± 1.51	(3.2–9.7) 6.10 ± 1.72
L3	(43.8–61.7) 53.45 ± 4.47	(44.1–66.0) 53.65 ± 4.55	(4.8–10.2) 7.35 ± 1.13	(4.8–10.3) 7.40 ± 1.30	(4.8–11.5) 7.16 ± 1.58	(4.1–12.6) 7.25 ± 2.19
L4	(44.7–60.4) 52.07 ± 3.76	(45.4–61.4) 52.25 ± 3.43	(4.4–8.4) 6.28 ± 1.17	(4.0–8.5) 6.11 ± 1.12	(7.3–12.5) 9.74 ± 1.66	(7.5–13.7) 10.09 ± 1.72
L5	(45.2–61.1) 53.57 ± 4.02	(43.8–60.4) 52.55 ± 3.71	(3.6–7.0) 5.10 ± 0.74	(3.8–6.5) 5.05 ± 0.74	(9.7–18.0) 13.40 ± 1.94	(11.1–18.3) 13.48 ± 1.68
36–50 AGE (N = 38) (MIN–MAX) MEAN ± SD						
L1	(47.6–61.1) 54.57 ± 3.52	(47.8–62.3) 55.47 ± 3.51	(5.1–11.6) 8.49 ± 1.62	(4.3–11.6) 8.78 ± 1.68	(3.1–9.8) 6.22 ± 1.53	(2.9–9.6) 6.04 ± 1.73
L2	(49.1–61.1) 55.39 ± 2.78	(50.8–61.7) 55.59 ± 2.83	(5.0–11.5) 8.05 ± 1.44	(5.4–12.2) 8.19 ± 1.50	(3.5–9.8) 6.43 ± 1.54	(3.7–10.0) 6.57 ± 1.64
L3	(48.2–61.7) 54.53 ± 3.45	(48.9–60.9) 54.89 ± 2.98	(5.1–10.6) 6.90 ± 1.15	(5.4–10.2) 6.90 ± 1.12	(5.0–12.2) 7.16 ± 1.40	(6.2–12.1) 7.57 ± 1.42
L4	(45.7–64.5) 53.19 ± 3.85	(45.3–64.7) 53.58 ± 3.97	(4.4–7.5) 6.12 ± 0.81	(4.7–8.5) 6.08 ± 0.77	(6.5–15.3) 10.05 ± 1.71	(6.1–14.0) 10.47 ± 1.90
L5	(45.4–63.9) 54.71 ± 4.54	(46.6–62.7) 54.20 ± 4.23	(3.9–8.3) 5.00 ± 0.77	(4.0–7.6) 5.05 ± 0.66	(8.5–18.7) 13.67 ± 2.16	(9.0–18.3) 13.71 ± 2.11
51–65 AGE (N = 36) (MIN–MAX) MEAN ± SD						
L1	(45.1–64.1) 54.83 ± 4.05	(46.9–66.5) 54.47 ± 4.31	(5.3–12.2) 8.52 ± 1.78	(4.2–13.6) 8.66 ± 1.92	(3.4–10.3) 5.89 ± 1.57	(3.3–10.8) 5.99 ± 1.63
L2	(45.1–64.4) 55.60 ± 4.18	(49.9–64.4) 55.71 ± 3.85	(5.3–10.8) 7.92 ± 1.50	(5.4–10.8) 8.14 ± 1.37	(3.7–10.0) 6.57 ± 1.60	(3.6–9.7) 6.48 ± 1.63
L3	(43.8–63.2) 54.92 ± 3.73	(46.6–62.1) 55.35 ± 3.65	(5.1–11.0) 7.10 ± 1.17	(4.7–11.1) 7.10 ± 1.24	(5.1–12.2) 7.50 ± 1.52	(4.8–11.3) 7.85 ± 1.60
L4	(47.1–64.5) 54.66 ± 4.53*	(46.5–62.9) 54.70 ± 4.26	(4.3–8.0) 6.25 ± 0.83	(4.8–8.5) 6.17 ± 0.78	(6.6–14.1) 9.83 ± 1.79	(6.9–14.3) 10.28 ± 1.72
L5	(49.2–70.8) 56.99 ± 4.64	(45.1–71.6) 55.73 ± 5.08*	(4.0–6.6) 5.20 ± 0.66	(3.8–6.5) 5.00 ± 0.66	(10.1–18.6) 13.88 ± 2.24	(10.8–17.2) 13.76 ± 1.95

*Statistically significant difference between the 18–35 age group and the 35–50 and 50–65 age groups ($p < 0.05$).

	PH (MM)	FSD (MM)	FTD (MM)	PTA LEFT (°)	PTA RIGHT (°)	PSA (°)
	(11.2–16.8) 13.63 ± 1.39	(12.0–19.9) 17.10 ± 1.79	(18.6–27.3) 22.98 ± 2.02	(11.1–27.2) 22.45 ± 2.71	(8.6–26.6) 22.00 ± 3.23	(11.9–19.6) 16.57 ± 2.11
	(10.6–14.5) 13.02 ± 0.94	(13.8–24.4) 17.10 ± 2.19	(20.0–28.7) 23.02 ± 1.83	(20.1–25.5) 23.18 ± 1.69	(19.3–25.5) 22.37 ± 1.36	(11.3–20.2) 16.05 ± 2.04
	(11.3–15.1) 16.30 ± 1.95	(12.5–24.8) 16.05 ± 2.49	(19.8–28.5) 23.22 ± 2.30	(22.6–29.6) 25.72 ± 2.01	(21.1–28.7) 24.92 ± 2.13	(10.7–21.0) 12.75 ± 1.21
	(8.5–15.8) 11.58 ± 1.47	(12.2–21.9) 16.60 ± 3.04	(18.8–30.2) 24.49 ± 2.46	(25.0–34.2) 27.85 ± 2.44	(24.8–32.8) 27.40 ± 2.31	(12.7–19.5) 15.66 ± 1.94
	(6.4–19.9) 10.60 ± 2.55	(11.8–21.7) 27.81 ± 2.91	(24.2–33.8) 27.81 ± 2.91	(25.7–41.2) 33.40 ± 3.41	(28.0–39.6) 32.20 ± 3.30	(9.6–18.7) 12.60 ± 2.68
	(10.4–16.9) 13.58 ± 1.48	(13.4–21.6) 17.56 ± 2.01	(20.4–27.5) 22.89 ± 1.76	(19.0–28.1) 23.10 ± 2.03	(18.3–27.2) 22.30 ± 1.98	(11.6–21.7) 15.05 ± 1.82*
	(9.2–16.7) 12.79 ± 1.71	(14.3–20.3) 16.95 ± 1.67	(19.2–28.2) 23.53 ± 2.07	(20.5–26.6) 23.35 ± 1.48	(17.3–26.7) 22.47 ± 1.78	(11.4–19.0) 16.95 ± 2.78
	(10.9–15.3) 15.88 ± 2.03	(12.4–20.1) 15.60 ± 2.10	(19.0–30.0) 24.18 ± 2.25	(23.2–30.0) 25.98 ± 1.90	(20.7–29.9) 25.21 ± 2.07	(9.8–20.3) 12.15 ± 1.54
	(8.4–14.7) 11.13 ± 1.75	(11.9–23.0) 16.58 ± 2.36	(19.8–30.6) 25.42 ± 2.58	(24.0–38.3) 28.60 ± 2.50	(25.0–34.2) 28.22 ± 2.42	(11.0–21.2) 14.88 ± 2.47
	(5.6–13.0) 9.70 ± 1.68	(12.3–22.3) 28.64 ± 3.67	(23.0–37.0) 28.64 ± 3.67	(27.7–40.1) 34.15 ± 2.77	(27.0–39.6) 32.86 ± 3.00	(7.9–20.4) 12.20 ± 3.21
	(7.8–17.5) 13.09 ± 2.09	(13.5–20.8) 17.57 ± 1.82	(19.4–28.0) 23.66 ± 2.05	(19.6–26.4) 23.45 ± 1.63	(19.7–25.2) 22.70 ± 1.53	(10.4–19.0) 1 4.66 ± 1.89*
	(7.9–16.5) 12.13 ± 1.87	(14.1–20.2) 16.95 ± 1.66	(18.6–27.8) 23.88 ± 1.94	(21.3–26.1) 23.44 ± 1.33	(20.3–26.7) 22.87 ± 1.35	(11.3–18.6) 16.95 ± 2.78*
	(11.3–16.2) 14.55 ± 2.27*	(12.3–21.3) 16.00 ± 2.10	(19.5–29.8) 24.89 ± 2.18*	(22.5–28.3) 25.43 ± 1.47	(20.8–28.8) 24.71 ± 1.48	(8.9–18.9) 11.55 ± 1.96*
	(7.9–13.3) 10.66 ± 1.50	(12.4–23.1) 15.45 ± 2.40	(20.5–31.7) 25.85 ± 2.65	(22.6–32.2) 28.15 ± 1.86	(23.9–31.3) 27.48 ± 1.49	(8.7–18.9) 13.77 ± 2.24
	(5.8–11.6) 8.80 ± 1.74	(12.2–22.3) 29.78 ± 3.64	(21.6–38.1) 29.78 ± 3.64	(28.2–42.6) 33.23 ± 3.17	(26.8–38.4) 32.49 ± 3.23	(7.7–19.1) 12.10 ± 2.88

screw technique without complications and developing pedicle screws with spinal implants requires detailed knowledge of vertebrae and pedicle anatomy.

In the literature, there are many studies showing that the morphometry of the lumbar spine shows significant differences between races and genders (3, 5, 9, 11, 17, 19, 20, 27). This study aimed to provide comprehensive and validated data on lumbar pedicle morphometry for the Aegean region of Turkey and compare it with the existing literature. Our study provides detailed information about the pedicle morphometry of all lumbar vertebrae according to gender and age groups, containing important data for clinical applications.

It is very crucial to determine the optimum diameter and length of the pedicle screw for the successful application of the transpedicular screw fixation technique. PW, PAL, PL and PH measurements help to determine the optimum dimensions of the screw. PAL knowledge prevents damage to vital structures located in front of the corpus vertebrae. PTA and PSA are crucial pedicle morphometric parameters in determining the direction of screw placement. Detailed knowledge of PL, PW, PH, PTA and PSA is very important for screw fixation surgery to prevent damage to the medulla spinalis, nerve roots and spinal nerves.

Recent studies have revealed that pedicle morphometry parameters show significant differences according to race and gender (3, 5, 9, 11, 19, 20, 24, 27). For this reason, gender is an important factor to consider when selecting screw size.

The present study provided that PW increased from L1 to L5, while PAL and PH decreased from L1 to L5 in both males and females. In our study, significant differences were found between genders for PAL and PH at all levels, for PW at L1, L2, L3, L4 levels (except L5), for PSA at L3, L5 levels, for PTA left at L3 level, for PTA right at L1 level, for PSA at L3, L5 levels, and for FTD at L3, L4, L5 levels (Table 2).

These morphometric differences between males and females have important clinical implications. The longer PAL and greater PH values observed in males at all lumbar levels suggest that male vertebrae can accommodate longer and thicker pedicle screws, allowing for potentially stronger fixation and reduced risk of implant loosening. In contrast, the generally shorter PAL and PH measurements in females, especially in upper lumbar levels, necessitate more precise screw size selection to avoid cortical breach or nerve injury. Additionally, the narrower PW in females at most levels underscores the need for careful screw diameter choice to prevent pedicle wall violation. Variations in PSA and PTA angles between genders, particularly at levels L1 and L–L5, further indicate that screw trajectory may require adjustment based on gender to optimize fixation safety and efficacy.

In previous studies, there was no statistically significant difference between pedicul left-right measurements (14, 24, 25). In our study, only PTA was asymmetrical at the L1, L2 levels in females and at the L2, L3 levels in males, but the other measurements were symmetrical. Similar to the results of our study, another study in which pedicle morphometric measurements were performed determined asymmetry only between PTA left-right measurements at all levels of the lumbar vertebrae (20). The observed symmetry in pedicle morphometric features can be leveraged to improve the precision and safety of surgical procedures. This highlights the need for careful side-specific assessment of the PTA to ensure safe screw placement.

In our study, in males, the longest PAL mean was 57.16 ± 3.10 and the shortest PAL mean was 55.16 ± 3.70. In famale, the longest PAL mean was 53.75 ± 3.02 and the shortest PAL mean was 51.90 ± 3.83. In both genders, the highest value of PAL mean at L2 level and the lowest value of PAL mean were at L4 level. In a study of 240 Turkish peoples, it was found that the PAL decreased gradually from L1 to L5, the longest PAL was 56.27 mm and the shortest was 52.92 mm in males and the longest PAL was 50.71 mm and the shortest was 48.16 mm in females (13). The mean PAL values of these two studies conducted on the Turkish population are quite close to each other for both genders. In the study conducted on the Jordanian people, similar to our study, the longest PAL mean value was found at the L2 level in both males (56.8 mm ± 0.43) and females (53.9 ± 0.42 mm) and the shortest PAL value was found at the L4 level in both males (52.5 ± 0.35 mm) and females (49.9 ± 0.46 mm) (3). Grivas et al. (11) for the Greek population, the longest PAL was on average 55.31 ± 4.52 mm in males and 48.7 ± 4.17 mm in females at the L4 level, while the shortest PAL was approximately 51 mm in males and approximately 46 mm in females at the L5 level in both genders. Morita et al. (20) obtained for the Japanese population the longest PAL was mean 56.5 ± 4.6 mm at the L3 level in males and mean 51.1 ± 3.6 mm at the L4 level in females, while the shortest PAL was 54.6 ± 4.1 mm in males and 49.1 ± 3.9 mm in females at the L1 level in both genders. Lin et al. (16) conducted a study on Caucasian and Taiwanese individuals and found that the longest PAL mean was at the L2 level (48.1 ± 3.6 mm) and the shortest PAL mean was at the L5 level (44.1 ± 4.3 mm) as a result of the analysis obtained regardless of gender. In the study conducted on the Nigerian population, the longest PAL mean was found at L2 level (47.33 ± 2.31 mm) and the shortest PAL mean was found at L5 level (47.65 ± 2.02 mm) in males, while the longest PAL mean was found at L3 level (45.66 ± 1.92 mm) and the shortest PAL mean was found at L1 level (44.29 ± 1.44 mm) in females (7). In our study in the Turkish population, PAL mean values were found to be higher in both genders compared to Greek, Japanese, Nigerian, Taiwanese, and Caucasian populations.

In our study, the highest PL mean value was found as 8.50 ± 1.51 mm and the lowest PL mean value as 5.14 ± 0.65 mm in males, and the highest PL mean value was found as 8.91 ± 2.57 mm and the lowest PL mean value as 5.03 ± 0.74 mm in females, and there was no significant difference by vertebral side (Table 1) or genders (Table 2). In study conducted by Tall et al. (29) on the African population, found that the highest PL mean value was 9.4 mm and the lowest PL mean value was 6.5 mm in males, while the highest PL mean value was 9.6 mm and the lowest PL mean value was 6.4 mm in females. This cross-sectional study was conducted on Persian ethnic group (18–45 years), the highest PL mean value was found as 12.43 ± 1.95 mm and the lowest PL mean value as 6.61 ± 1.20 mm in males, and the highest PL mean value was found as 10.80 ± 1.74 mm and the lowest PL mean value as 6.29 ± 1.01 mm in females (19). The PL values of the Turkish population are more similar to those of the African population. In our study, the mean value of PL decreases gradually from L1 to L5, as in these studies. This may be caused by enlargement of the corpuses of the lumbar vertebrae from L1 to L5.

In the Persian ethnic group (18–45 years), the highest PW mean value was found as 16.14 ± 1.94 mm and the lowest PW mean value as 7.88 ± 1.73 mm in males, and the highest PW mean value was found as 13.68 ± 2.03 mm and the lowest PW mean value as 6.18 ± 1.48 mm in females (19). Tall et al. (29) found the highest mean PW value as 15.5 mm and the lowest mean PW value as 7.3 mm in males of African race, while the highest mean PW value was 14.7 mm and the lowest mean PW value was 6.5 mm in females of African race. In the study's Morita et al. (20), the highest PW mean value was obtained as 16.4 ± 2.6 mm and the lowest PW mean value as 8.4±1.8 mm in males of Japanese race, and the highest PW mean value was obtained as 14.1 ± 2.1 mm and the lowest PW mean value as 6.5 ± 1.6 mm in females of Japanese race. Lin et al. (16) determined that the longest mean PW of Caucasian and Taiwanese subjects was 12.6 ± 2.1 mm, and the shortest mean PW was 5.7 ± 1.2 mm. The highest mean PW of the Jordanian race was 15.1 ± 0.31 mm in males and 13.9 ± 0.24 mm in females, and the lowest mean PW was 7.5 ± 0.16 mm in males and 6.1 ± 0.18 mm in females (3). In a CT study on the Indian race, the mean widest PW value was 13.57 ± 1.13, and the narrowest was 6.64 ± 0.52 in males, and the mean widest PW value was 12.69 ± 1.14, and the narrowest was 6.38 ± 0.65 in females (12). In a CT study on the Nigerian race, the mean widest PW value was 13.11 ± 1.74, and the narrowest was 7.23 ± 1.50 in males, while the mean widest PW value was 12.78 ± 1.21, and the narrowest was 6.38 ± 0.74 in females (7). Results of all these studies show that L5 has the widest pedicle and L1 has the narrowest pedicle in all races and both genders, and that PW increases gradually from L1 to L5. The mean PW values of the Persian ethnic group, Japanese race, African race, and Jordanian race were higher in both genders compared to the results of our study. The highest PW mean values in both genders of our study are higher than the highest PW mean values in both genders of the Nigerian race. The mean PW values of the Indian race were very close to each other between genders, with the highest being 13.83 ± 2.9 mm and the lowest being 6.7 ± 1.08 mm (26). In a similar CT study on Indian race, the highest PW mean values obtained at L5 level in both genders were almost the same with our results, but the lowest PW mean values obtained at L1 level were considerably higher than our results (27).

The study was carried to by Morita et al. (20) on Japanese race, the highest PH mean value was obtained as 16.7 ± 1.6 mm and the lowest PH mean value as 13.3 ± 1.8 mm in males, and the highest PH mean value was obtained as 14.8 ± 1.3 mm and the lowest PW mean value as 12.1 ± 1.6 mm in females. Badmus et al. (7) found that the PH value of the African race is very similar across each other at all levels in males and females, with an average of 10.75 ± 1.48 mm in males and 9.07 ± 1.37 mm in females. Singh et al. (26) reported mean PH values of 14.44 ± 1.85 mm (highest) and 13.44±1.75 mm (lowest) for males and 13.77 ± 1.64 mm (highest) and 12.53 ± 1.83 mm (lowest) for females in the Indian race.

In most of studies, the highest PH was consistently observed at the L1 level, while the lowest PH was consistently observed at the L5 level for both males and females (3, 7, 11, 20, 26). Our findings showed that both genders exhibited the highest mean PH at the L3 level, contrary to previous research, but the lowest mean PH at the L5 level, consistent with previous studies.

Our study found that mean PTA values were very close in both genders, ranging from 23.09° ± 1.96 to 32.97 ± 3.17° in males and 22.26 ± 2.35° to 33.2 ± 3.06° in females. These values were higher than those reported in previous studies (3, 11, 12, 17, 20, 26, 28, 29). Only the PTA values of the Indian population closely resembled ours (27). Across all studies, PTA values increased from L1 to L5. The mean PSA values were highly comparable between males and females except at the L3 and L5 levels. The overall mean ranged from 12.12 ± 1.68° to 15.31 ± 2.05°. In contrast to our findings, Tall et al. (29) reported lower mean PSA values, which consistently decreased from L1 to L5 in both genders.

Consistent with previous literature, our study found that mean FTD values were higher in males compared to females. Additionally, a gradual increase in FTD was observed from L1 to L5 in both genders (1, 6, 26). Our findings suggest that the mean PTA values for both males and females were distinct from those reported in other studies, yet were more closely aligned with the mean PTD values reported for Turkish and African populations (24, 29).

Our findings demonstrate that mean FSD values were highly similar between genders across all levels. Confirming our findings, Azu et al. (6) and Abbas et al. (1) also determined that the FSD mean values of both genders were very close.

In a study of an Indian population aged 18-30 years, Choubey et al. (9) found a gradual decrease in mean PL values from L1 to L5, with the highest mean PL at L1 (7.72 ± 1.48 mm) and the lowest at L5 (6.57 ± 1.55 mm). Our study, conducted on a population aged 18-35 years, also revealed a similar decreasing trend in mean PL values, with the highest and lowest values observed at L1 (8.97 ± 1.48 mm) and L5 (5.07 ± 0.74 mm), respectively (Table 3).

Koken et al. (15) provided a comparable age-based classification and reported similar mean PW values at the L1 level. Consistent with our findings, they observed no significant age-related differences in PW mean values.

The present study revealed both consistencies and discrepancies with previous literature regarding age-related changes in lumbar pedicle morphology. In contrast to the findings of Gülec et al. (13), who reported a significant age-related decrease in PW at the L4 and L5 levels, our results demonstrated only a minimal decrease across age groups, with no statistically significant differences observed. Furthermore, while Gülec et al. (13) identified a statistically significant decrease in PAL with advancing age at all lumbar vertebral levels, our study found a significant age-related increase specifically at the L4–L5 level. Regarding PH, Gülec et al. (13) reported significant reductions at all lumbar levels; however, our data showed a statistically significant decrease only at the L3 level. Lastly, although Gülec et al. (13) observed significant age-related declines in PTA at the L2 and L5 levels, we did not detect any significant differences in PTA (left and right) values across age groups at any lumbar level. A plausible explanation for the discrepancies between our findings and those reported in the literature could be differences in the demographic characteristics of the study populations. Variations in sex distribution, average body height and weight, as well as geographic background, are well-established factors known to significantly influence vertebral and pedicle morphology.

The age-related differences in pedicle morphometrics were observed between the 18–35 and 51–65 age groups in this study. The mean PAL, PH, PSA decreased with age, while FTD increased. These changes may reflect age-related anatomical remodeling due to degenerative processes such as osteoporosis. As a result, elderly patients may require shorter, thinner screws and modified angulation during transpedicular fixation to ensure safety and stability. These findings emphasize the importance of tailoring implant selection and screw trajectory to both the gender and age of the patient, rather than relying solely on standard implant sizes.

The limitations of our study include that it provides information on the pedicle morphometry of a specific population residing in a localized region, and that the measurements were performed by a single specialist radiologist. However, the present study provides a comprehensive analysis of all measurements pertinent to pedicle morphometry.

CONCLUSIONS

In conclusion, this retrospective study analyzed detailed morphometric properties of 500 lumbar vertebrae from 100 Turkish individuals, highlighting significant gender- and ethnicity-related differences in pedicle morphology, with minimal age-related variation. These findings underscore the importance of individualized preoperative assessment for optimal screw selection and safe transpedicular fixation, tailored to patient-specific anatomical variations. Our data contribute valuable insights toward developing a region-specific pedicle morphometry database to guide surgical planning and reduce intraoperative risks. Further research with larger and more diverse populations is warranted to better understand these morphometric differences and improve clinical outcomes. ■

Ethics approval: *This study was performed in line with the principles of the Declaration of Helsinki and the study was approved by Ethics Committee University of Aydin Adnan Menderes Faculty of Medicine.*

Data availability: *The data that support the findings of this study are available from the corresponding author upon reasonable request.*

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