

# Demographic Analysis of Lumbar Pedicle Diameters in a Diverse Population

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**Study Design:** Retrospective chart review.

**Purpose:** We sought to determine the differences in pedicle diameter (PD) in the lumbar spine between various races: 'Asian,' 'Black,' 'White,' and 'Other.' These data could aid in perioperative planning during instrumented spinal fusion.

**Overview of Literature:** Recent literature underscores the importance of understanding diverse pedicle isthmus morphology to perform successful transpedicular procedures. These studies suggest that more detailed and reliable measurements of pedicles should be undertaken. However, none of the current literature comprehensively compares average PDs between diverse racial populations with a standardized study design.

**Methods:** Coronal cuts of 5,060 lumbar spine pedicles were inspected to obtain their transverse outer cortical PD as measured through the isthmus at L1–L5. Data were collected and categorized on the basis of patient-reported race. We examined average PD and PD range at each level for each race. To determine the significance, we used a mixed analysis of variance and a post hoc analysis.

**Results:** The Asian cohort consistently had a significantly smaller PD at L1–L5 than Blacks or Whites ( $p < 0.001$ ), as did the 'Other' group compared with Blacks ( $p < 0.001$ ) and Whites ( $p = 0.032$ ). At L1–L2, the 'Other' group showed the least variability in PD. At L3–L5, the Asian population showed the smallest range, and the Black population had the largest variability in PD except at L5. There was a significant difference in PD between the various races.

**Conclusions:** The Asian population consistently has significantly smaller pedicles in the lumbar spine than the Black or White populations. This information could prove useful for surgical planning. We suggest using preoperative computed tomography for pedicle screw templating as a safe method for pedicle screw instrumentation with the highest pullout strength given the wide range of PD in the Black population and the variability of PD between races.

**Keywords:** Pedicle screws; Spine; Orthopedics; Osteology; Demography

## Introduction

A thorough understanding of bone anatomy is of the ut-

most importance when performing instrumented spinal fusion. A slight deviation in screw trajectory can result in devastating patient outcomes. Knowledge of subtle

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anatomic variability can help a surgeon perform these procedures more safely and precisely. General orthopedic surgery instruction promotes templating with exact measurements prior to implant insertion. However, the exact diameter of the vertebral pedicle is rarely ascertained prior to screw insertion. This shortcoming is primarily due to the difficulty of obtaining this measurement in situ. In this study, we discuss the inherent variability related to patient demographics in pedicle morphology and the potential benefits of understanding and predicting pedicle variation.

An estimation technique is commonly used when selecting pedicle screw size intraoperatively, which involves an evaluation of perioperative fluoroscopic images and an approximation by the surgeon of pedicle diameter (PD). Alternatively, some surgeons will preferentially use a particular screw size for all patients. The clinical concern for improper PD estimation, and thus pedicle screw size estimation, holds considerable weight, given improper screw size selection could theoretically lead to screw failure, requiring risky and costly revision surgery. The estimated cost of care based on instrument failure and pseudoarthrosis alone in spinal surgery is \$66,838 and \$76,695, respectively, whereas the average cost of revision surgery ranges from \$26,592 to \$86,673 [1]. These costly outcomes related to screw placement obviate the value of precise pedicle measurement, screw selection, and instrumentation to prevent later complications.

Recent literature underscores the importance of understanding diverse pedicle isthmus morphology for successful transpedicular procedures. Li et al. [2] have proposed that the most important variable for considering pedicle screw size is endosteal width. Banta et al. [3] have suggested that the effective PD is the cancellous diameter of the pedicle, reasoning that it is the maximal diameter available for pedicle screw insertion. They have demonstrated that the difference between the historically reported outer cortical diameter and the effective cancellous diameter was considerable; therefore, a safe screw selection might not be consistently achieved using traditional methods [3].

Misenhimer et al. [4] had progressively loaded cadaveric pedicles and found that plastic deformity of the pedicles preceded fracture when the screw threads were larger than the endosteal diameter or were within 80% of the outer cortical diameter [4]. Therefore, approximately 80% of the measured cortical diameter is the maximum safe width into which a pedicle screw can be inserted.

Other studies have used computed tomography (CT) scans to analyze PD variation. Kaptanoglu et al. [5] have discovered the linear regression coefficient of 0.68 relative to the outer PD on CT, and Bernard et al. [6] have determined that although a safe pedicle screw diameter of 7.0 mm can be inserted into L5 and S1, CT evaluations should be performed for levels above L5 [6].

There is a considerable body of literature regarding variability among certain populations with respect to PD, particularly concerning the finding of smaller PDs in the Asian population [7,8]. To our knowledge, however, there has not been an extensive review of PD among different races using a standardized method. Christodoulou et al. [9] have investigated PD in the Greek population, and Singel et al. [10] have evaluated PD in the Suarashtra region, yet these studies had purely been focused on the findings in a single population. Yusof et al. [8] have examined the cervical PD in the Malaysian population as an Asian model, finding that transpedicular screw fixation should not be pursued within this group secondary to smaller PDs than average. Tse et al. [7] have reported the efficacy of using pedicle screws versus lateral mass screws in the Asian population and have found that lateral mass screws for the Southern Chinese population were safer; however, the final means of fixation should be confirmed preoperatively with a CT scan. These studies are inconclusive, but they suggest that the variation in PD as it relates to race makes the estimation of pedicle screw size difficult, which could therefore merit a better understanding of PD as it relates to this demographic.

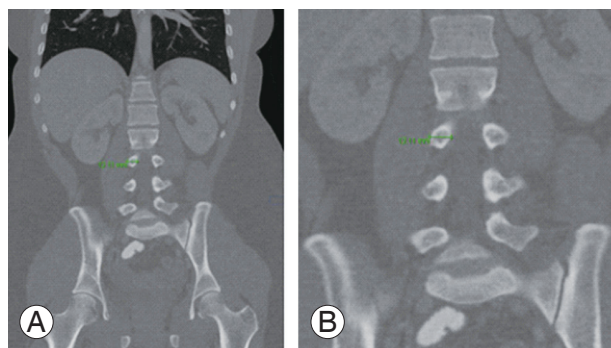
Overall, the current literature suggests that improper pedicle screw selection could lead to significant morbidity and cost. The literature also suggests that there can be a significant degree of difference in the average PD of each individual racial group. Therefore, a more precise understanding of this PD–race relationship could aid in pedicle screw selection, thereby reducing cost and mortality. We hypothesized that there would be a significant difference between the average lumbar spine PD of individual races. The purpose of this study was to determine the differences in PD in the lumbar spine between various races: ‘Asian,’ ‘Black,’ ‘White,’ and ‘Other.’ Such information might prove to be valuable for perioperative planning of instrumented spinal fusion, potentially reducing the morbidity and cost associated with improper screw size selection.

## Materials and Methods

Approval from our health system's Institutional Review Board (Northwell Health IRB approval no., Study 17-0367) was obtained to investigate the hypothesis that there is a significant difference between the average lumbar spine PD of individual races. It was determined that due to the low risk and retrospective nature of the study, informed consent would not be needed. A retrospective review of all CT scans of the abdomen and pelvis that were performed over a 2-week period (between July 1, 2016 and July 14, 2016) at seven hospitals within a single health system was analyzed for the purpose of this study. Using abdominal and pelvic studies rather than lumbar spine scans allowed us to screen a large and diverse population of patients who presented with chief complaints not related to back pain and, therefore, without any vertebral pathology that could potentially alter the geometry of a pedicle. Further exclusion criteria were established to exclude patients with other vertebral factors that could alter pedicle geometry.

Coronal cuts of the lumbar spine were examined to obtain the transverse outer cortical PD as measured through the isthmus at lumbar segments one through five on the left and the right spine. Despite the irregular shape of the pedicle, we used a standardized measurement similar to previously reported techniques to consistently obtain the middle-most slice of the pedicle isthmus with CT, ensuring a better comparison between patients [11]. Axial reference images were set to correlate parallel to the end plates of the corresponding vertebrae. The coronal plane was set 90° relative to the axial plane to ensure consistent measurement parameters, notwithstanding anatomic variations inherent in subtle deformity or positional discrepancies. Bone window CT images were selected for all measurements to allow for a sharp contrast between cortices and soft tissue. The standard General Electric picture archiving and communication systems (PACS; General Electric Medical Systems, Milwaukee, WI, USA) measuring tool was used for all measurements (Fig. 1).

Excluded from the study were patients with prior lumbar laminectomy or fusion (with or without instrumentation); patients whose scans did not allow full visualization of all five lumbar segments; patients with scoliosis involving lumbar vertebrae and a Cobb angle measurement greater than 20°; patients with spondylolysis; and patients with spondylolisthesis having greater than 25% slippage.



**Fig. 1.** Measurement technique. (A, B) Demonstration of the measurement technique of a right L3 isthmic transverse outer cortical pedicle diameter using the General Electric picture archiving and communication systems measuring tool (General Electric Medical Systems, Milwaukee, WI, USA).

Following the exclusion criteria, 506 patients were included in the study, allowing us to evaluate 5,060 lumbar pedicles in total.

Data were collected and categorized on the basis of patient-reported racial information. This information is routinely entered at the time of patient registration in accordance with the health system's protocol. These data are automatically linked to all imaging uploaded to the PACS. Within this health system's PACS, race is categorized as 'Asian,' 'Black,' or 'Other.' These four categories were used as the basis of this demographic study.

The data analysis was performed using IBM SPSS Statistics ver. 23.0 (IBM Corp., Armonk, NY, USA) and compared the average PD at each level for each self-reported racial group. Sex, average age, and age range were recorded for each self-reported racial group and were evaluated with a mixed analysis of variance (ANOVA) to identify any significant differences between groups ( $p=0.05$ ). A mixed ANOVA with Dunn–Bonferroni correction was used to compare the differences in average PD of each racial group ( $p=0.05$ ). The analysis was performed by a Senior Research Statistics Analyst to determine the significance of the study findings.

## Results

Of the 506 patients who met the inclusion criteria, 213 (42.01%) were male and 293 (57.91%) were female. The demographic breakdown yielded 198 Black (39.13%), 122 White (24.11%), 99 Asian (19.57%), and 87 'Other' patients (17.19%) (Table 1). The average age of the total study population was 58 years, with a range of 16 to

**Table 1.** Study population demographics

Race	No. of patients	Male	Female	Average age (yr)	Age range (yr)
Black	198	62	136	56	16 to 98
White	122	54	68	66	22 to 97
Asian	99	54	45	55	16 to 91
Other	87	43	44	51	17 to 94
Total	506	213	293	58	16 to 98

Study population demographics including gender and age separated by ethnicity.

**Table 2.** Mixed ANOVA test of between-subject effects

Source	Type III sum of squares	Degrees of freedom	Mean square	F-statistic	Significance level <sup>a)</sup> (<0.05)
Intercept	18,087.91	1	18,087.91	2146.11	0.000
Age	4.04	1	4.04	0.48	0.489
Gender	1,769.41	1	1,769.41	209.94	0.000
Race	338.47	3	112.82	12.39	0.000
Error	4,214.12	500	8.428	-	-

Mixed ANOVA analysis showing the differences between races and genders were unlikely related to chance.

ANOVA, analysis of variance.

<sup>a)</sup>Significant values (<0.05).

98 years (Table 1).

The average transverse isthmic outer cortical PD at L1 was found to be largest in the Black group and smallest in the Asian group (7.73 and 5.98, respectively). At L2, the average PD was also largest in the Black group and smallest in the Asian group (7.90 and 7.32, respectively). Lumbar pedicles three through five were found to be largest in the White group and smallest in the Asian population (9.42, 11.32, and 14.73; and 8.79, 10.55, and 14.05, respectively).

The data were analyzed using a mixed ANOVA with one repeated factor (L1–L5) and one between factor (race). Because there were differences in age and sex between the races (Table 1), these variables were used as covariates in the analyses. Tests of between-subjects effects demonstrated that the differences between races observed in our study were unlikely to be related to chance (Table 2).

The races were found to be significantly different ( $p < 0.001$ ) in PD. Post hoc analyzes using Dunn–Bonferroni correction showed that Asians had significantly smaller PDs than Blacks and Whites ( $p < 0.001$ ), as did ‘Others’ compared with Blacks ( $p < 0.001$ ) and Whites ( $p = 0.032$ ). An examination of the estimated marginal means indicates that Whites had larger diameters at L5 but Blacks had larger pedicles at L1. Asians consistently had the

**Table 3.** Mixed ANOVA pairwise comparisons

Race (A)	Race (B)	Mean difference (A-B)	Lower bound CI	Upper bound CI
Asian	Black	-0.922	-1.352	-0.492
	Other	-0.223	-0.729	0.284
	White	-0.750	-1.226	-0.274
Black	Asian	0.922	0.492	1.352
	Other	0.699	0.251	1.148
	White	0.172	-0.234	0.577
Other	Black	-0.699	-1.148	-0.251
	Asian	0.223	-0.284	0.729
	White	0.527	-1.026	-0.028
White	Black	-0.172	-0.577	0.234
	Asian	0.750	0.274	1.226
	Other	0.527	0.028	1.026

Mixed ANOVA with Dunn–Bonferroni correction showing ‘Asians’ having significantly smaller pedicle diameters than ‘Blacks’ and ‘Whites,’ and ‘Others’ had significantly smaller pedicle diameters than ‘Blacks’ and ‘Whites.’

ANOVA, analysis of variance; CI, confidence interval.

smallest diameter, and ‘Others’ were in between (Table 3). Due to our large sample size, an analysis of estimated marginal means depicts narrow confidence intervals and

**Table 4.** Pedicle diameter average, SD, and range

Pedicle	Race	Average±SD (mm)	Range (mm)	Smallest–largest (mm)
L1	Asian	5.98±1.49	8.11	3.8–11.91
	Black	7.73±1.68	9.52	3.36–12.88
	Other	6.89±1.76	7.75	3.11–10.86
	White	7.36±1.67	8.23	3.84–12.07
L2	Asian	7.32±1.52	8.38	4.24–12.62
	Black	7.90±1.63	9.79	4.34–12.62
	Other	7.42±1.43	6.86	4.53–11.38
	White	7.84±1.66	7.83	4.69–12.52
L3	Asian	8.79±1.65	7.54	5.2–12.74
	Black	9.31±1.73	11.38	4.92–16.3
	Other	8.94±1.70	9.21	5.11–14.32
	White	9.42±1.82	9.11	5.76–14.87
L4	Asian	10.55±1.64	7.61	7.05–14.66
	Black	11.05±1.80	15.37	5.71–21.08
	Other	10.87±1.94	9.95	6.96–16.91
	White	11.32±1.88	9.75	6.93–16.68
L5	Asian	14.05±1.65	10.44	8.15–18.59
	Black	14.31±2.08	11.23	9.4–20.63
	Other	14.20±2.54	11.39	8.75–20.14
	White	14.73±1.96	10.81	9.99–20.8

Average pedicle diameter with SD and range of pedicle diameters for each race at each vertebral level. SD, standard deviation.

thus validates that our results are highly representative of these different races.

We evaluated the ranges to examine the variability and outliers within races. The range of pedicle size was also inspected at each level for each group studied (Table 4). The data obtained highlighted the significant variability between individuals. The lowest range at any level was 6.86 mm (found in the ‘Other’ group at L2). The largest range was found in the Black population at L4 (15.37 mm). At L1 through L4, the widest range was observed in the Black patient population. At L5, the ‘Other’ group range was greatest and slightly larger than the Black group.

The race with the least amount of variability in pedicle size was split between the ‘Other’ and Asian groups. At L1 and L2, the ‘Other’ group showed the smallest range (7.75 and 6.85, respectively), whereas the L3 through L5 Asian population showed the least deviation in PD (7.54, 7.61, and 10.44, respectively.)

## Discussion

The importance of preventing screw failure in spinal surgery cases cannot be overstated. It has been demonstrated that larger pedicle screws have greater pullout strength; therefore, an understanding of the maximum safe pedicle screw diameter can greatly aid in reducing failure and other complications [5].

Undoubtedly, preoperative analyses of exact PD are of immense importance. It was therefore the goal of this investigation to supplement preoperative and intraoperative methods of pedicle assessment. The data obtained in this anatomic study might allow surgeons to more safely gauge appropriate screw size, given this additional demographic information.

This multicenter study demonstrated that the Asian population consistently had significantly smaller pedicles in the lumbar spine than the Black or White populations. This supports the data published by Tse et al. [7] in a previous vertebral study. The ‘Other’ group in our study, which was largely made up of patients of Hispanic origin, also had a smaller PD than the Black or White populations. Although we cannot directly draw conclusions regarding the Hispanic population because it was not specifically defined, this opens the door to future research focusing on this population. Further efforts should be made to include a Hispanic distinction on self-reported race surveys, which could enable more in-depth research on this population.

Additionally, we suggest that a significant finding of this study was the range of PD across the entire study population, as well as within each of the four study groups individually. This wide range provides further evidence that it might be unsafe to select the same-sized screw for all patients. Further, it should be noted by surgeons that the Black population had the largest overall PD range, suggesting that particular attention is warranted when selecting pedicle screw size for this group.

An important consideration in this study is the heterogeneity of potential regions among those who identified as Asian. We report that the average L1 and L2 for our Asian population is 5.98 and 7.32 mm, respectively. However, previous literature reports a narrower gap between the PDs of L1 and L2. Specifically, one study focusing on a Korean population has reported that the PDs of L1 and L2 were similar (7.1 and 7.8 mm, respectively), as did another focusing on an Indian population (7.2 and 7.6 mm,



respectively) [12,13]. We suggest that the broader gap in our population is more representative of a heterogeneous population of patients identifying as Asian, which can be found in increasingly diverse areas in America. This could represent a strength in our study, in that these data are potentially more representative than previous studies that examined more homogenous Asian populations from one region only. Further, we suggest that these data provide a more realistic look at the populations a surgeon might encounter in America. Further, it might be appropriate for a future prospective study to be planned in which patients receiving abdominal and pelvic CTs unrelated to back issues are asked to report their race to a more specific degree.

On the basis of these results, we support previous research recommending the use of preoperative CT for pedicle screw templating as the safest method of inserting pedicle screws with the strongest pullout strength (largest safe diameter). However, we also recognize the potential of increased radiation exposure due to preoperative CT scans, as well as the increased costs incurred [14,15]. We suggest that the value of further preoperative pedicle analysis outweighs the minimally increased risk of radiation exposure and the cost of imaging. Surgical outcomes might be improved simply by recognition and understanding of our reported data. The combination of our data regarding average PD as it relates to race and the already commonplace use of intraoperative fluoroscopy could aid surgeons in estimation and selection of correct pedicle screw size, thereby potentially improving operative outcomes. Further research is needed to assess whether inclusion of our data in preoperative planning leads to improved surgical outcomes.

Although navigation-assisted surgery is gaining popularity because of its precision and reliability, it is still expensive and has not been globally adopted. One of the main conclusions to be drawn from this study is the importance of preoperative planning and intraoperative adjustments in instrumented spinal surgery. Although one can attain a better sense from this research of PD based on the race of the patient, there is still considerable variability.

Our study is significantly strengthened by the inclusion of information from a large number of hospitals over a large geographic area, which happens to be located in a very culturally diverse region of the country. Therefore, our population was not selective with respect to one pop-

ulation over another, which served as a drawback in previous studies focusing on a single racial population. Other strengths of the study include that the data were obtained by a single observer and were confirmed by a more senior physician, therefore enhancing reliability with respect to inter-observer variability.

Limitations of the study include not standardizing the position of the patient on the CT scanner. Simpson et al. [16] have described inaccuracies even by CT when evaluating on only one plane, further emphasizing the need for careful preoperative evaluation of PD. Notwithstanding, our sample size was sufficiently large, thereby ensuring a strong representation of true values. There was also variability in the size of the CT scan cuts used at different hospitals, which could mislead us as to the true midpoint of the pedicle isthmus. However, based on the retrospective nature of this study, this aspect was not possible to control. Other variables that could contribute to pedicle size differences include body mass index, age, and sex, which leave room for future prospective studies designed to control for these factors.

## Conclusions

Although the Asian population has previously been known to have small-diameter pedicles, particularly in the cervical spine, differences among several races have not been evaluated in a single study. This study demonstrates that there are significant inter-race differences that should be taken into consideration when performing instrumented lumbar spinal fusion. Accounting for these differences could aid surgeons in more precise and therefore safer surgical procedures.

## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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