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Anatomic Study of the Relationship of Height and Weight to Lumbar Pedicle Diameter

Lentz JDO[1*], Albano JDO[2], Stockton RDO[2], Ganz MBS[3], Grewal KDO[3] and Katsigiorgis GDO[3] and Masterson NOMS

[1]Johns Hopkins University, USA

[2]Texas Back Institute, USA

[3]Northwell Health, USA

***Corresponding author:**

J Lentz DO,
Johns Hopkins University, USA, Tel: 9738652604,
E-mail: nrmasterson51@gmail.com;
albanojl@gmail.com

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1. Abstract

Safely performing instrumented spinal fusion requires an intimate knowledge of anatomy and anatomic variations. Pedicle screw position and size have implications on intraoperative and postoperative complications. We sought to determine the effect of height and weight based on previous studies showing significant correlations of height and weight on pedicle diameter. We retrospectively reviewed CT scans of the abdomen and pelvis in 270 patients performed over a two-week period at seven hospitals within a single health system centered in a diverse area of the country. Coronal cuts of the lumbar spine were assessed to obtain transverse outer cortical Pedicle Diameter (PD) as measured through the isthmus at lumbar vertebrae one through five on left and right pedicles. Both height and weight were found to significantly correlate with PD; however, explanation of variation based on these variables was relatively weak. Height explained roughly 10% of the variance in pedicle diameter and weight explained only 3-4%. BMI explained almost 0% of the variation. Height versus PD scatter plots for each lumbar level showed small Pearson coefficient values ranging from 0.070 (L5) to 0.113 (L1). Our findings suggest that height and weight do not correlate strongly enough with PD to meaningfully supplement pedicle screw size selection although they may have value in safely planning appropriate fixation constructs. By noting that taller and heavier patients cannot necessarily tolerate substantially larger pedicle screw diameters than their counterparts, adding supplemental fixation by increasing screw density, adding additional rods, or placing supporting hooks should all be considered when construct stress is increased.

2. Introduction

An intimate knowledge of vertebral anatomy and anatomic variations is essential for surgeons performing instrumented spinal fusion of the lumbar spine. The majority of current constructs rely heavily on pedicle screw fixation given the superior pullout strength when compared with hooks and sublaminar titanium cables. [1] Thus, particular attention must be paid to pedicle anatomy including variation in size and orientation. Variations in screw trajectory can have devastating consequences for the patient's safety, yet often, the exact Pedicle Diameter (PD) is not measured prior to operative intervention.

The importance of pedicle screw accuracy is best appreciated when analyzing the potential associated peri-operative complications. Iatrogenic neurologic, meningeal, bony, and/or vascular injuries can all occur secondary to misguided or improperly sized pedicle screws. Incidence of pedicle screw misplacement has been reported at 5.2% and 6.5% by two separate studies. [2, 3] retrospectively reviewed imaging of 915 spinal fusions involving 4,790 pedicle screws (76.3% lumbosacral procedures). They found 2.4% of patients had complications attributed to the use of pedicle screws. These included nerve root irritation in 1.0% of the procedures, pedicle fracture in 0.2%, and dural tear in 0.4% of procedures.4 In a survey analysis of 617 spinal fusion surgeries where pedicle screws were utilized, showed an incidence of pedicle fracture in

2.3%, CSF leak in 1.9%, 2.3% nerve root injury, and vascular injury in 0.16% of patients [2].

In terms of post-operative complications, there have been reported 0.81% screw loosening, 0.49% screw cutout, and 0.16% screw backout.2 A study of 105 patients that underwent lumbar or lumbosacral fusions showed eventual screw breakage in 12.5% [3].

Biomechanical analysis of factors influencing pedicle screw anchor strength has shown the pedicle screw to be the weak point in pedicle screw-rod constructs and screw diameter to have the most profound effect on construct strength. [5, 6] Screws that provide >80% pedicle fill have demonstrated superior pull-out strength to those with <80% fill. [7] The surgical goal, therefore, is to insert the safest maximum pedicle screw size for each given patient in each given pedicle in order to increase the stability of the instrumentation construct without causing iatrogenic injury. This translates to decreased screw pullout, screw breakage, and pedicle fracture.

Current methods used to estimate screw size include peri-operative radiographic estimation, peri-operative CT scan, and various intraoperative navigation based methods. [8, 9] The peri-operative method involves using preoperative radiographs and/or fluoroscopic images to estimate appropriate screw size. This practice relies heavily on surgeon experience and knowledge of pedicle anatomy. Additionally, it is often difficult to assess the degree of magnification imparted on a given x-ray in the peri-operative flat plate or intraoperative fluoroscopic image. It has been demonstrated though, that scrutinizing preoperative pedicle screw assessment with CT or MRI, in experienced hands does not significantly affect accuracy of screw placement compared to other techniques.8 Furthermore, radiographic evaluation after screw placement, has been shown to be a safe and effective method of evaluating quality of screw size and trajectory. [10] CT scan has the benefit of allowing direct measurement of the pedicle width and assessing appropriate trajectory but it bears the burden of additional radiation exposure [11].

The goal of this study was to contribute to the available anatomic data on lumbar pedicles. Further understanding of anatomic variations in pedicle diameter will supplement all methods of pedicle screw size selection. We investigated the relationship of height and weight to PD in a culturally diverse population. Yu et al studied this correlation using digital caliper measurement of PD in cadavers. They found that taller and heavier subjects had significantly larger PD. [12] A CT based study on a Turkish population also demonstrated that transverse PD values proportionally increase with subject height [13]. We sought to determine the extent to which this has clinical significance.

3. Materials and Methods

Approval from our institution's Investigational Review Board was obtained. 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 CT scans of the abdomen and pelvis, that were performed over a two-week period at seven hospitals within a single health system, were analyzed for the purpose of this study. Using abdomen and pelvis studies rather than lumbar spine scans allowed for screening of a population of patients who presented with chief complaints not related to back pain, and therefore theoretically nonpathologic pedicles.

Coronal cuts of the lumbar spine were inspected to obtain transverse outer cortical pedicle diameter as measured through the isthmus at lumbar segments one through five on left and right pedicles. Despite the irregular shape of the pedicle, using a standardized measurement site allowed for better comparison between patients. CT "Bone Window" images were used for all measurements to allow for sharp contrast between cortices and soft tissue. The standard GE PACS measuring tool was used for all measurements (Figures 1).

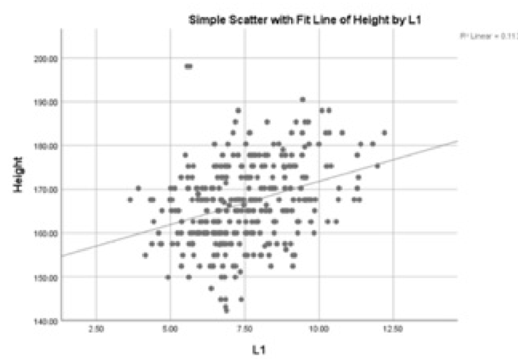

Figure 1: The relationship between patient height and the pedicle diameters of L1

Those 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, and patients with scoliosis in which all pedicles could not be evaluated in the same plane. Following the exclusion criteria, 270 patients and therefore 2,700 lumbar pedicles were evaluated.

Patient height, weight, and BMI as recorded on the visit that the CT scan was performed were recorded for all study patients as referenced in the hospitals' electronic health record. For the purpose of this study, the average left and right PD at a given level were used. All scans were reviewed initially by a single data analyst to ensure consistent measurements and verified by a senior contributor for validity. Further statistical analysis was carried out by a Senior Research Statistics Analyst to determine the significance of the study findings.

4. Results

The mean height, weight, and BMI for our population were found to be 166.78 cm, 77.25 kg and 27.78 kg/m2, respectively. Mean height, weight and BMI were reported with standard deviations, minimum and maximum values (Table 1). The mean diameter of the pedicles for the entire population at each vertebral level were; L1- 7.34 mm, L2- 7.68 mm, L3- 9.18 mm, L4- 10.99 mm, and L5- 14.36 mm. The pedicle diameter means at each level were reported along with standard deviations, minimum and maximum values (Table 2).

Table 1

	Mean	Standard Deviation	Min	Max
Height (cm)	166.78	9.44	142.24	198.1
Weight (kg)	77.25	20.67	38.6	170.8
BMI	27.78	6.76	15.56	61.24

Table 2

	Mean	Standard Deviation	Min	Max
L1	7.34	1.65	3.12	12.5
L2	7.68	1.57	4.28	13.88
L3	9.18	1.72	5.2	15.92
L4	10.99	1.79	5.78	17.26
L5	14.36	2.11	8.88	20.5

A Pearson product-moment correlation coefficient was computed to assess the relationship between PD and each variable (height, weight and BMI). We used a significance level of 0.01 (2-tailed) and found significant positive correlation between height and PD as well as weight and PD at all spinal levels L1-L5. However, we did not find a significant correlation between BMI and PD at any spinal level (Table 3). We then utilized the Pearson coefficient of determination to describe to what extent variance was due to height at each level. We found that at spinal levels L1-L4 there is a moderate (>9.0%) explanation for variance in pedicle diameter due to height (at L1, L2, L3 and L4; R2 =.113, R2 =.099, R2 =.093, R2 =.102, respectively; (Figures 2-4). At the fifth lumbar spinal level the explanation of PD variance due to height was found to be small (9.0%-1.0%) with R2 =.070 at L5 (Figure 5). When analyzing the effect of weight on PD using Pearson coefficient of determination, only small explanations of variance were found representing 3-4% of the PD variance at all lumbar spinal levels. Interestingly, BMI explained almost 0% of the variation in PD.

Table 3

		L1	L2	L3	L4	L5
Height	Pearson correlation	0.336*	0.314*	0.305*	0.32*	0.264*
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001
Weight	Pearson correlation	0.212*	0.182*	0.19*	0.187*	0.176*
	Sig. (2-tailed)	<.001	0.001	0.001	0.001	0.002
BMI	Pearson correlation	0.06	0.044	0.059	0.051	0.068
	Sig. (2-tailed)	0.294	0.44	0.298	0.371	0.233

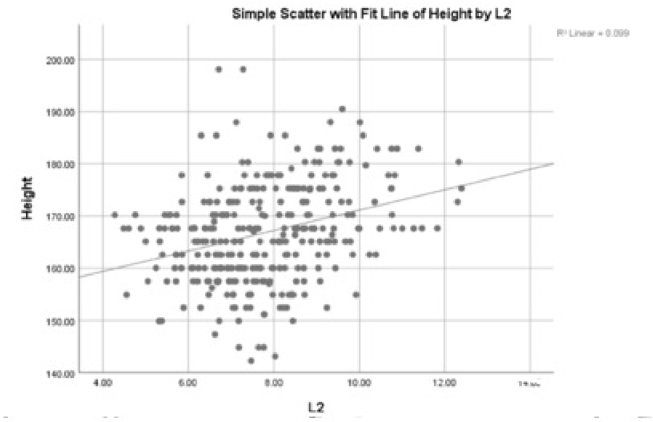

Figure 2: The relationship between patient height and the pedicle diameters of L2

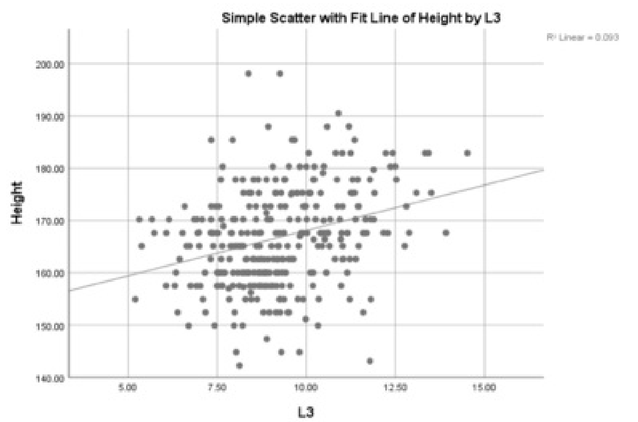

Figure 3: The relationship between patient height and the pedicle diameters of L3

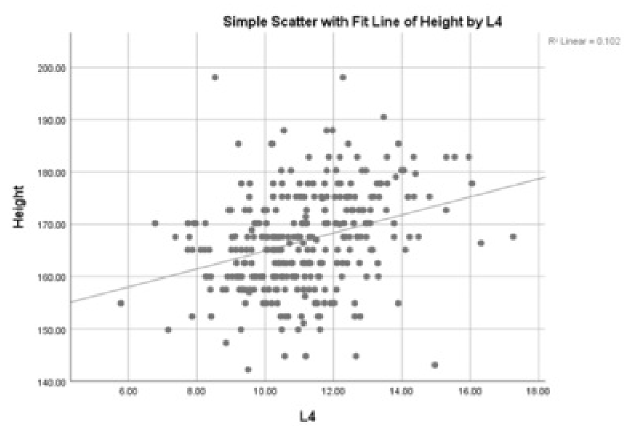

Figure 4: The relationship between patient height and the pedicle diameters of L4

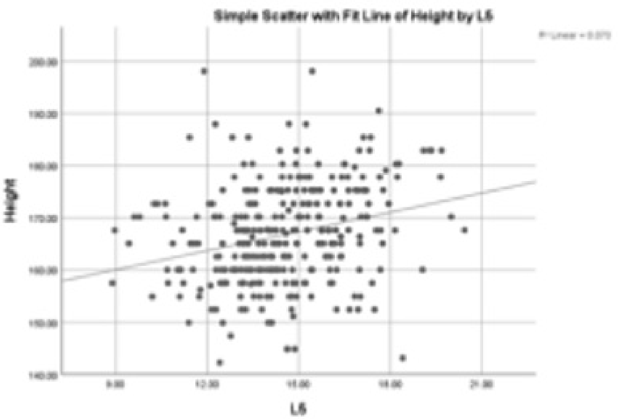

Figure 5: The relationship between patient height and the pedicle diameters of L5

5. Discussion

As mentioned, there are devastating complications that can be minimized by appropriate pedicle screw trajectory and size selection. With significant inter-subject variability in lumbar spine pedicles, an understanding of anatomic relationships enhances a surgeon's ability to make appropriate selections.

We previously reported statistically significant differences in lumbar PD between different races and TPA between different races. [14, 15] In the present study, we examined how height and weight correlated with PD. These variables showed statistically significant positive correlation in our study, however, height explained only 10% of the variance in PD and weight explained only 3-4%. BMI explained almost 0% of the variation. Although prior studies have also shown significant correlation between height and weight with PD and height alone with PD, our analysis suggests that these data points have relatively weak association [12, 13].

Height and weight are easily obtained, non-invasive measurements. While these values should have little role in selecting appropriate screw size, they are important to consider when planning fixation constructs. Contrary to the previous studies mentioned, which look at the correlation between PD and height, our study demonstrates that lumbar pedicles in taller and heavier patients may accommodate similar sized pedicle screws to those in shorter and lighter patients. With that in mind, the stress on the fixation construct is increased with heavier patients due to increased load, and also with taller patients due to the increased lever arm. Thus, by noting that taller and heavier patients cannot necessarily tolerate substantially larger pedicle screw diameters than their counterparts, adding supplemental fixation by increasing screw density, adding additional rods, or placing supporting hooks should all be considered when construct stress is increased [16, 17, 18].

A major strength of our study was the large, diverse population pulled from multiple hospitals within a large health system in one of the most culturally diverse regions of the world. As mentioned, we previously reported that there are significant variations between different races, so capturing a population that encomapsses those variations lends to the validity of our data.14 Our data was also obtained by a single observer, which allowed for more standardized measurements. Confirmation by a more senior physician, served to enhance the reliability with respect to inter-observer variability.

One limitation of this study was that we used CT scans of the abdomen and pelvis rather than the lumbar spine. The benefit of this was data on a population of patients that presented with chief complaints unrelated to back pain so avoid anomalous pedicle morphology. However, it is possible that processes that cause back pain, such as degenerative disc disease, can cause changes in pedicle morphology that would be missed by our study design. Another limitation is the methodology used to measure PD. Multiple studies have evaluated different techniques of pedicle measurement. Some suggest using the vertical diameter as it is the narrowest diameter of the pedicle, and others suggest using both coronal and transverse reconstructions to avoid overestimation that occurs from the effect of pedicle angle on the imaging sequence. [19, 20] While we acknowledge that there are other measurement techniques that may be more advantageous for peri-operative assessment, our measurement technique allowed for consistency and satisfied the goals of our study to assess for correlation. Additionally, due to the retrospective nature of the study, patient position in the CT scanner and the plane through which the pedicle was evaluated was not standardized, which has been shown to cause some inaccuracy. [20] Notwithstanding, our sample size was sufficiently large, thereby ensuring a strong representation of true values.

Further anatomic studies in the lumbar spine will serve to supplement our understanding of vertebral anatomic variations and may contribute to safer lumbar spine surgery. It is paramount to study each patient's case when planning pedicle screw size and construct type.

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