An Anatomical Study of the Mid-Lateral Pars Relative to the Pedicle Footprint in the Lower Lumbar Spine

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Study Design. An anatomic study that describes the relationship of the pedicle center to the mid-lateral pars (MLP) in the lower lumbar spine as a guide to pedicle screw placement.

Objective. Describe morphometric data of the lower lumbar pedicles, the unique coronal pedicle footprints of L4 and L5, and their impact on the relationship of the pedicle center to the MLP.

Summary of Background Data. Traditional medial-lateral starting points for lumbar pedicle screws use the facet as an anatomic reference for all lumbar levels. The facet is often a difficult landmark to use secondary to degenerative changes and the desire to minimize damage to the facet capsule in the most cephalad level. These techniques can also result in pedicle violation particularly in the lower lumbar spine. Use of the nonarthritic MLP is proposed in this study as an alternative anatomic reference point for the pedicle center.

Methods. Seventy-two pedicles (L3–S1) from embalmed cadaveric spines were used. Linear and angular dimensions of the pedicle were measured, including the degree of coronal pedicle tilt of L4 and L5. The center of the pedicle relative to the MLP and relative to the midline of the base of the transverse process was measured. The axial superior facet angle and angle of pedicle screw insertion were also measured.

Results. The minimum pedicle width was 10.9 and 12.4 mm and the coronal pedicle tilt was 36° and 55° for L4 and L5, respectively. A classification of 2 types of L5 pedicles relevant to pedicle center location was developed. In the medial-lateral direction, the pedicle center is 2.9 mm lateral to the MLP at L3 and L4. At L5, it is 1.5 and 4.5 mm lateral to the MLP for a type I and type II pedicle, respectively. In the superior-inferior direction, the pedicle center is 1 mm superior to the midline of the transverse process base for all lower lumbar levels. Significant differences between a type I and II L5 pedicle were a larger pedicle width and distance of the pedicle center to the MLP for a type II pedicle. The difference between the axial pedicle screw insertion angle and anatomic superior facet angles was 8° from L4–S1.

Conclusion. The MLP is a reliable anatomic reference point for the center of the pedicle in the lower lumbar spine. Consideration needs to be taken when inserting pedicle screws at L4 and L5 because of the degree of their coronal tilts and unique pedicle footprints. It is important to distinguish a type I from type II L5 pedicle as a type II pedicle is wider, has a more lateral pedicle center relative to the MLP, and has the potential for lateral screw placement while still remaining within the pedicle.

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In last 2 decades, pedicle screw fixation has become widespread and is now the mainstay of segmental fixation in the lumbosacral spine.1 Pedicle wall violation after screw placement ranges from 6.5%2 to 13%3 with the medial cortex being most commonly breached.3 Pihlajamaki et al found that approximately 10% of patients with pedicle screw fixation for lumbar degenerative disease had a misplaced screw and all but 1 patient underwent a revision operation.4 Although these complications seldom result in neurologic compromise, pedicle wall violation has the potential to decrease biomechanical construct strength and may complicate the management of postoperative neurologic deficits.2,5

The cranial-caudal relationship of the starting point for a pedicle screw is often referenced off the midline of the transverse process6 and the corresponding insertion angles in the axial and sagittal plane in the lumbar spine are well documented.7 In regards to the medial-lateral starting point, several authors, including Magerl and Roy-Camille et al, have focused on using the facet as an anatomic reference for lumbar pedicle screw placement.8–10 Although these techniques generalize the starting point for all lumbar levels, the relationship of the pedicle center to the facet changes with caudal progression.8 Hailong et al reported that the Roy-Camille et al10 technique of starting in line with the lateral margin of the facet joint has the highest risk of canal violation from L3–L5 because of a mediolateral starting point.11 Weinstein et al reported that the Roy-Camille technique was successful in the thoracolumbar junction (T11–L2), but resulted in medial pedicle breach in the lower lumbar spine (L3–S1); he recommended a more lateral starting point at the “nape of the neck,” which was defined as the lateral and inferior corner of the superior articular facet.12 Similarly, Hou et al advocated that the starting
point should move laterally with caudal progression, with L5 starting at a point lateral to one-third of the facet width. These studies suggest that pedicle footprints relative to the facets are unique in the lower compared to the upper lumbar spine.

Pedicle screw fixation is frequently used to provide stabilization after posterior neural decompression for degenerative disease. Since patients with degenerative disease have different facet orientations when compared to the normal population, these changes have been shown to alter the landmarks used for pedicle screw placement. In addition, facet osteophytes or “hypertrophy” also obscure the edge of the facet joint and distort the superior articular facet making these structures difficult to use as anatomic landmarks. In the setting of revision surgery, the facet joints are sometimes unidentifiable increasing the difficulty of free hand pedicle screw placement. Thus, preservation of the joint capsule and the presence of underlying osteophytes often prevents the facet joint to be used as a landmark. It is for this reason that Weinstein et al advocates placing the starting point of the pedicle screw in a more lateralized position.

We hypothesize that as an alternative or supplement to the facet, the mid-lateral pars (MLP) is a useful anatomic landmark in the lumbar spine to guide pedicle screw placement. The MLP is a distinct anatomic area, which is routinely visualized during posterior exposure and consists of dense cortical bone which does not become arthritic or deformed in the setting of degenerative disease. McCulloch et al has previously used this structure as an anatomic guide and described the relationship of the lateral pars to the medial edge of the pedicle in the lower lumbar spine to help understand the anatomy in the foraminal zone for a microdiscectomy.

To our knowledge, the relationship of the MLP to the pedicle center in the lower lumbar spine has not been previously described. The purposes of this study are to: (1) describe the location of the center of the pedicle relative to the MLP of L3–L5; (2) describe the dimensions and coronal pedicle tilt of the L4 and L5 pedicle footprints and how these affect screw starting points; (3) describe the axial pedicle screw insertion angles relative to axial facet angles; (4) describe the center of the pedicle in the superior-inferior direction relative to the transverse process.

### Materials and Methods

Thirty-seven embalmed sagittally split cadaveric lumbosacral spines (L3–S1 segments) were obtained from the Department of Anatomy at the Columbia University College of Physicians and Surgeons (New York, NY). The specimens were an average age of 81 year old with an equal distribution of males and females. Any samples with ankylosing spondylitis, scoliosis, pars defects, or transitional L5 vertebrae with a fused transverse process (Castellvi type 3 or 4) were excluded from the study. The soft-tissue attachments were dissected from the specimens and the vertebral bodies were separated from each other by sharp transection through the intervertebral disc and posterior elements. Care was taken to remove all of the remaining soft tissue particularly around the pars and the pedicles.

All linear measurements were made using a digital caliper with an accuracy of 0.025 mm (Chicago Brand, Fremont, CA). All angular measurements were made using a goniometer with an accuracy of 1° (Lafayette Instrument Co., Lafayette, IN). Statistical analysis was performed using a 2-tailed Student t test; statistical significance was taken at $P < 0.05$ with the SPSS statistical package (SPSS Inc., Chicago, IL).

The pedicle width, height, and minimum dimension were measured for each specimen (Figure 1). The minimum pedicle dimension was the smallest linear pedicle measurement in the coronal plane. The MLP was defined as the area of dense cortical bone at the most medial aspect of the lateral pars (Figure 2A). The distance from the center of the pedicle to the MLP in...
the medial-lateral direction was calculated from the distance of the MLP to the lateral wall of the pedicle and the pedicle width. On a lateral view, the distance from the center of the pedicle relative to the midline of the transverse process was calculated from the top of the transverse process to the bottom of the pedicle and the transverse process width. The coronal pedicle tilt is defined as the degree of coronal angulation of the pedicles relative to the midline and were measured at L4 and L5 (Figure 2B). The pedicle tilt of L3 was not measured as it has been previously demonstrated to have a clinically insignificant degree of tilt.19 The facet angles in the axial plane for L4–S1 as well as the axial pedicle screw insertion angle were measured and the differences between the 2 measurements were calculated (Figure 3).

■ Results
There were a total of 72 pedicles for final analysis consisting of 21 L3, 28 L4, and 23 L5 pedicles. Two specimens had ankylosing spondylitis and an unidentifiable pars interarticularis, which precluded use of it as a landmark. All of the remaining specimens had clearly defined areas of nonosteophytic cortical bone at the MLP (Figure 2A). The dimensions of the L3, L4, and L5 pedicles are
shown in Table 1. Figure 2B demonstrates the distance of the pedicle center to the MLP in the medial-lateral direction; the distance of the pedicle center to the midline of the base of the transverse process in the cranial-caudal direction; and the L4 and L5 coronal plane pedicle tilt. In all cases, the center of the pedicle was lateral to the MLP and superior to the midline of the transverse process in the coronal plane. The percentage of pedicle that extended lateral to the MLP was calculated to be 77% at L3, 71% at L4, and 64% at L5 (Figure 2C).

The axial superior facet angle, axial pedicle angle, and the average difference between the 2 angles at L4 through S1 are seen in Table 2. On examination of all of the L5 vertebrae, we recognized that the L5 pedicles had 2 morphologies, which we labeled type I and type II. Different types of pedicle morphology were not observed in any of the L3 or L4 vertebrae. A type I L5 pedicle is clearly distinct in terms of its anatomic relationship to its transverse process. A line drawn in the transverse plane along the lateral wall of the pedicle parallel to the central pedicle axis of a type II pedicle contacts the tip of the transverse process (Figures 5A, B). All of the L5 vertebrae were separable into these 2 types; it should be noted that unless the pedicle was clearly a type II, it was given a type I designation. The data for pedicle tilt, angle of insertion, and relative starting points for the type I and type II L5 pedicles were analyzed separately (Table 3). The percentage of pedicle extending lateral to the MLP was calculated to be 58% for a type I L5 pedicle and 70% for a type II L5 pedicle. The distance of the pedicle center to the MLP was 1.5 ± 2.1 and 4.5 ± 2.7 for a type I and type II pedicle, respectively. When a type I pedicle was compared to a type II pedicle, the statistically significant differences were a larger pedicle width and distance of the pedicle center to the MLP for a type II pedicle (Figures 4A, 5A).

### Discussion

Morphologic characteristics of lumbar pedicle dimensions have been well studied.6,7 Zindrick et al reported on the width of the pedicle in the transverse plane and found it to be, at its narrowest, 10.3, 12.9, and 18.0 mm from L3–L5, respectively. These values were similar to those reported by Ebraheim et al6 and similar to ours (11.0, 13.6, and 20.1 mm from L3–L5, respectively). The sagittal heights of the pedicles, at their narrowest diameter, reported by Zindrick et al from L3–L5 were relatively constant ranging from 14.0 to 14.9 mm, which were similar to our measurements ranging from 14.9 to 15.9 mm.7 Although information on the average height and width of the L4 and L5 pedicles is noteworthy, it is less clinically applicable because it does not represent the true minimum pedicle width. As Robertson and Stewart noted, the minimum pedicle widths, especially at L4 and L5, are smaller than the horizontal widths due to the degree of coronal pedicle tilt unique to L4 and L5.19 Knowledge of minimum pedicle width is critical as it represents guidelines for the maximum allowable diameter of a pedicle screw at that level. We found the average minimum widths of the L4 and L5 pedicles to be 10.9 and 12.4 mm, respectively, whereas Robertson and Stewart19 measured them to be 12.8 and 13.6 mm, respectively. Their measurements were slightly larger than those in

### Table 1. Dimensions of L3–L5 Pedicles

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<tr>
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<th>L3</th>
<th>L4</th>
<th>L5</th>
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<tbody>
<tr>
<td>N</td>
<td>21</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pedicle width</td>
<td>11.0 ± 2.6 mm</td>
<td>13.6 ± 3.0 mm</td>
<td>20.1 ± 3.7 mm</td>
</tr>
<tr>
<td>Pedicle height</td>
<td>15.9 ± 1.5 mm</td>
<td>14.9 ± 1.4 mm</td>
<td>15.2 ± 1.7 mm</td>
</tr>
<tr>
<td>Minimum pedicle width</td>
<td>10.9 ± 2.0 mm</td>
<td>12.4 ± 1.8 mm</td>
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our study likely due the fact that they used radiographic measurements of dry-bone specimens and not direct anatomic measurements. It is notable that in our study the minimum pedicle widths of L4 and L5 were similar to the L3 pedicle width of 11.0 mm.

Pedicle screw fixation is commonly used as an adjunct to spinal fusion following decompression for symptomatic degenerative disease. Facet arthrosis most commonly affects the L4–L5 levels with osteophyte formation on the lateral margin of the superior facet where the capsule is attached. These morphologic changes in the facets alter the starting point for pedicle screw placement. Rather than use the facets as a landmark for the medial-lateral starting point of the pedicle screw, we propose use of the MLP. The MLP was chosen because it is free of osteophytes and easily identifiable during posterior spinal exposures. Use of the MLP rather than the facet is also advantageous as it does not require violation of the facet joint of the most superiorly instrumented level. Preservation of these structures has the theoretical advantages of added biomechanical stability and possibly preventing adjacent level degeneration. In all but 2 specimens in this study, which had evidence of ankylosing spondylitis, the MLP was identified as a distinct structure. It is important to note that in some of the specimens with advanced degenerative disease, particularly at L5, a distinct edge of cortical bone was not visualized until overhanging osteophytes extending from the facets were removed. Clinically, removing osteophytes off of the facet should be meticulously performed if the MLP is going to be used as a landmark for pedicle screw placement.

The original descriptions of pedicle screw starting points were referenced from the facets and were used as guidelines for all lumbar levels. Subsequently, these techniques were found to be successful in the upper lumbar spine, but canal breaches from L3–S1 were identified leading to a recommendation of a lateralized starting point in the lower lumbar spine. We have noted that in the lower lumbar spine, the average distance of the pedicle center to the MLP was 2.9, 2.9, and 2.8 mm from L3–L5, respectively. This correlated to 77%, 71%, and 64% of the pedicle extending past the MLP from L3–L5 with the MLP consistently medial to the center of the pedicle. However, after the L5 pedicles were separated...
into 2 types, the distance of the pedicle center to the MLP was 1.5 and 4.5 mm for a type I and type II L5 pedicle, respectively. This correlated to 58% of a type I and 70% of a type II pedicle extending past the MLP. For simplicity, use of a starting point 3 mm lateral to the MLP for L3 and L4, and a point 1.5 and 4.5 mm lateral to the MLP for a type I and type II L5 pedicle, respectively, would be accurate starting points in the medial-lateral direction.

McCulloch described the location of the lateral pars to be at the medial edge of the pedicle for L1 through L4 and at the center of the pedicle at L5.16,17 While useful as a general guide, these relationships were not based on anatomic or radiographic studies. We determined that at L3 and L4, the medial aspect of the pedicle is not at the lateral pars, but rather 23% and 29% of the pedicle is medial to the lateral pars at L3 and L4 respectively. At L5, we found that 42% and 30% of the pedicle is medial to the lateral pars for a type I and type II L5 pedicle, respectively.

Most authors use the midline of the base of the transverse process as a cranial-caudal guide to screw placement in the coronal plane.9,10 Ebraheim et al described the relationship of the pedicle center to the midline of the transverse process from L1–L5 and found that with caudal progression, the starting point became slightly more inferior to the transverse process midline.9 Their study reported that the starting point relative to the transverse process midline was 1.4 mm superior at L3, midline at L4, and 1.5 mm inferior at L5.6 In our study, all of the starting points were slightly superior to the midline of the transverse process; 1.1 at L3, 1.6 at L4, and 0.9 mm at L5. For simplicity, a point 1 mm superior to the midline of the transverse process base may be used as a guide for the superior-inferior level of screw placement in the lower lumbar vertebrae in the coronal plane.

One of the most significant morphologic differences between the L4 and L5 pedicles compared with those of the upper lumbar spine is their degree of coronal tilt and their unique elliptical footprints. Robertson and Stewart reported pedicle tilts of L4 and L5 to be 32° and 53° respectively, while the more proximal lumbar spine levels had tilts of 0°, 2°, and 6° at L1, L2, and L3, respectively.19 These values are similar to those reported in our study of 36° and 55° for L4 and L5, respectively. As the degree of tilt increases, the elliptical footprint causes the pedicle width in the horizontal plane to increase even though the minimum pedicle width remains constant. The increasing pedicle tilt at L4 and L5 results in the lateral half of the pedicle to be inferior to the medial half. This is clinically important as it alters the location of the superior-inferior starting point if a more lateral starting point, such as one advocated by Weinstein et al is used.12 In order to remain on the center axis of the pedicle ellipse, a lateral starting point requires a more inferior starting point rather than the traditional midline of the transverse process at L4 and L5. Similarly, a medial starting point as described by Roy-Camille et al technique10 requires a more superior starting point than the transverse process midline at L4 and L5. Assessment of the degree of pedicle tilt at L4 and L5 can be done before surgery with coronally reconstructed computed tomography (CT) images.

An important component of this study was the identification of 2 unique types of L5 pedicles (Figures 4A, B; 5A, B). Unless a pedicle was clearly a type II pedicle, it was designated as a type I pedicle. There were no differences between the superior-inferior starting points or the minimum pedicle widths between a type I and type II L5 pedicle. However, a type II pedicle had a significantly larger width and therefore a pedicle center that extended more lateral to the MLP (Figures 4A, 5A). The distance from the medial wall of the pedicle to the MLP was approximately 7.0 mm for both type I and type II pedicles indicating that the medial wall of the pedicles are in similar locations relative to the MLP. Therefore, it would be possible to use the same starting point for a type I pedicle and a type II pedicle without breaching the medial wall although it would result in an eccentrically placed screw in the type II pedicle. Moshirfar et al reported that cephalad facet joint violations in pedicle screw fixation were more frequent at the L5 level with 44% of all violations at this level.14 The different types of L5 pedicles described in this study have clinical significance as preoperative identification of a type II L5 pedicle would allow for a lateralized starting point at L5 thereby avoiding L4–L5 facet joint violation in short segment L5–S1 fusions. Use of the MLP as a landmark for the pedicle center, along with a summary of traditional lumbar pedicle screw starting points is seen in Figure 6.

Our description of the type II pedicle has some similarities to the description of a type 1 transitional L5

### Table 3. Dimensions of L5 Vertebrae After Being Separated Into Type I or Type II L5 Pedicles

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Type I L5 Pedicle (N = 15)</th>
<th>Type II L5 Pedicle (N = 9)</th>
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<tbody>
<tr>
<td>Pedicle width</td>
<td>18.1 ± 2.9 mm</td>
<td>22.8 ± 3.2 mm</td>
</tr>
<tr>
<td>Pedicle height</td>
<td>14.7 ± 1.9 mm</td>
<td>15.7 ± 1.3 mm</td>
</tr>
<tr>
<td>Minimum pedicle width</td>
<td>11.7 ± 1.7 mm</td>
<td>13.3 ± 1.7 mm</td>
</tr>
<tr>
<td>Pedicle tilt</td>
<td>53.1° ± 14.7°</td>
<td>99.4° ± 9.5°</td>
</tr>
<tr>
<td>Axial facet angle</td>
<td>37.0° ± 9.3°</td>
<td>40.3° ± 10.4°</td>
</tr>
<tr>
<td>Axial pedicle angle</td>
<td>27.8° ± 8.3°</td>
<td>34.7° ± 5.8°</td>
</tr>
<tr>
<td>PC to MLP*</td>
<td>1.5 ± 2.1 mm lateral</td>
<td>4.5 ± 2.7 mm lateral</td>
</tr>
<tr>
<td>PC to midline TP</td>
<td>0.9 ± 1.9 mm superior</td>
<td>0.9 ± 1.5 mm superior</td>
</tr>
<tr>
<td>TP width</td>
<td>11.9 ± 1.6 mm</td>
<td>13.0 ± 2.3 mm</td>
</tr>
</tbody>
</table>

*P < 0.05.

PC to MLP indicates distance of pedicle center to the mid-lateral pars; PC to midline TP, distance of pedicle center to midline of the base of the transverse process; TP, width, transverse process width.
vertebrae, which has previously been described as having a larger transverse process width with a triangular shape measuring at least 19 mm in width. However, the transverse process widths for both pedicle types in this study were less than 19 mm (11.9 mm for type I, 13 mm for type II) and were not significantly different, thereby precluding use of the transverse process width to distinguish between type I and type II pedicle. Preoperative CT imaging in the axial plane would be useful to differentiate between type I from type II L5 pedicle.

The angle of screw insertion in the axial plane has been described by others authors and found to increase with progression from L1–L5. Ebraheim et al. reported axial pedicle angles of 33° and 40° for L4 and L5, respectively while Zindrick et al. reported angles of 18° and 30° for L4 and L5, respectively. These values were similar to those in our study, which were 25° and 30° for L4 and L5, respectively. We also measured the axial pedicle angle of S1, which measured 41° and was larger than L4 and L5. There were no differences in screw insertion angles in the axial plane between a type I and type II L5 pedicle. In addition to axial pedicle angles, we measured the corresponding superior facet angles. The pattern of an increasingly horizontal facet with caudal progression as described by previous authors was also seen in this study with the transverse facet angles measuring 30°, 38°, and 46° from L4–S1. The differences between the pedicle insertion angles and the axial superior facet angles were approximately 8° for L4–S1. This small difference indicates that if the superior facet has been exposed during posterior neural decompression, it can be used as a guide for the axial pedicle screw insertion angle from L4–S1. The similarity between these 2 angles may be an indication of the intimate developmental relationship of the superior articular facet to its pedicle in the lower lumbar spine.

This study describes a new technique for lumbar pedicle screw placement using the MLP as a landmark for a pedicle screw medial-lateral starting point. It also describes the degree of pedicle tilt of the L4 and L5 pedicles and how their unique footprints relate to pedicle screw starting points. Lastly, 2 types of L5 pedicles are described, which have different pedicle widths and starting points relative to the MLP. Further work should focus on the clinical application of this technique and evaluation of its accuracy compared to
other methods of determining pedicle starting points in the lower lumbar spine.

Key Points

- The MLP is a distinct area of cortical bone, which can be used as a reference point for the pedicle center. In the medial-lateral direction, the pedicle center is 2.9 mm lateral to the MLP at L3 and L4. At L5, it is 1.5 and 4.5 mm lateral to the MLP for a type I and type II L5 pedicle, respectively.
- The percent of pedicle lateral to the MLP is 77% and 71% at L3 and L4. At L5, it is 58% and 70% for a type I and type II pedicle, respectively.
- In the superior-inferior direction, the pedicle center is 1 mm superior to the midline of the transverse process base for all lower lumbar levels.
- The pedicles of L4 and L5 have a unique elliptical footprint with pedicles that are tilted 36° and 55° at L4 and L5, respectively. The superior-inferior starting point needs to be adjusted if a more lateral starting point is used at these levels. The clinically significant pedicle width is the minimum pedicle width, which is 10.9 and 12.4 mm for L4 and L5, respectively. The width of L3 is 11.0 mm.
- At L5, it is important to use preoperative CT scanning to distinguish a type I from a type II pedicle because a type II pedicle has a larger distance of the pedicle center to the MLP allowing for more lateral placement of a pedicle screw.
- The axial superior articular facet angle can be used as a reference guide for the pedicle screw insertion angle from L4–S1 as the difference between the angles is only 8°.

References
