

Anatomic study of the lumbar lamina for safe and effective placement of lumbar translaminar facet screws

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Abstract

Objective: To evaluate the anatomic characteristics of the lumbar lamina and suggest a safe and effective strategy for setting lumbar translaminar facet screws.

Methods: The width and length of the lumbar lamina, screw path, lateral angle of the lamina, and maximum and minimum caudal angles of the lamina from L3 to L5 were measured with Mimics software using 32 patients' computed tomographic data.

Results: The optimal screw entry point was located at the median of the spinous process base or slightly lower. The ideal screw trajectory was from the entry point to the base of the transverse process and across the center of the facet joint. A length of 35 to 45 mm was suitable for L3 to L4 in most cases, and a length of 45 to 50 mm was safe for L5 in most cases. The screw should be inserted at an angle of 49.4° to 59.29° laterally and 43.68° to 57.58° caudally at L3 to L5. For the ideal caudal angle, error of <3° was considered safe.

Conclusion: The optimal entry point, ideal screw trajectory, ideal screw-setting angles, and safest range of the angle and length of the lumbar lamina were identified in this anatomical study.

Keywords

Anatomy, lumbar lamina, lumbar translaminar facet screw, Mimics, screw trajectory, screw entry point, computed tomography

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Introduction

Lumbar translaminar facet screw (LTLFS) fixation is a method of posterior lumbar spine fixation that was first introduced in



1984 by Magerl.¹ LTLFS fixation is a modification of the Boucher technique, which itself is a modification based on the facet joint screw technique described by King.² LTLFS fixation has been proposed for the treatment of segmental dysfunction, lumbar spinal stenosis with painful degenerative changes, lumbar disc herniation changes, and segmental revision surgery after discectomy.³⁻⁵ Biomechanical studies have shown that LTLFS fixation can provide stability similar to that provided by pedicle screws.⁶⁻⁸ Additionally, clinical studies have revealed that LTLFS fixation is a minimally invasive and highly effective posterior fixation technique with a high fusion rate.⁹⁻¹¹ However, spinal cord tissue is present anterior to the lamina, and a nerve and artery course across the intervertebral foramen (Figure 1(a)). When the screws break out of the bone, injury easily occurs. Previous reports have described complications of nerve injury in which the nerves were persistently compressed by an LTLFS or were injured during screw placement.^{12,13} Several methods for safe and effective screw placement have been reported, but details of the anatomy of the lamina in the vicinity of the LTLFS are lacking. The anatomy plays an important

role in guiding safe and effective screw placement.

With the aim of developing a safe, effective, and accurate LTLFS placement technique, Lu et al.¹⁴ performed an anatomic study of LTLFS placement using specimens in 1998; however, the results may not be precise enough for the current medical era. In 2003, Jang et al.¹⁵ designed a nail-guiding device that was useful but not adequately safe or suitable for every patient. Later, in 2004, Phillips et al.¹⁶ proposed X-ray evaluation criteria for safe screw placement; however, these criteria focused on the results of the procedure and could not be used to guide the intraoperative screw-setting process. Lieberman et al.¹⁷ suggested the application of a bone-mounted miniature robotic guidance technique in the placement of LTLFS. Although this method was precise, expensive equipment was needed and it was not suitable for many medical institutions. Amoretti et al.¹⁸ suggested a screw-setting method using computed tomography (CT) and fluoroscopic guidance in 2013. This method was safe and effective, but it was also time-consuming and involved X-ray exposure. Finally, Shao et al.¹⁹ recently suggested the use of a three-dimensional navigation

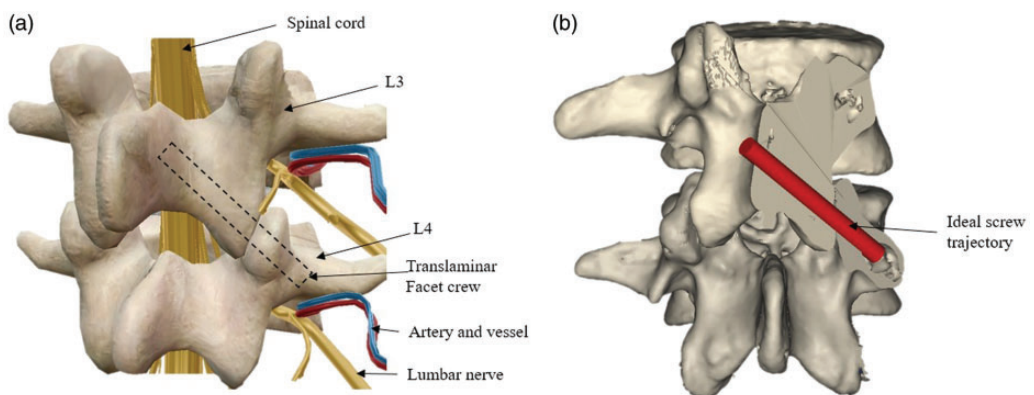


Figure 1. Screw trajectory and surrounding structures. (a) The spinal cord, nerve, and vessel surrounding the screw. (b) The ideal screw trajectory.

template to guide the translaminar facet screw, resulting in accurate insertion. However, this method was expensive and time-consuming.

Although many screw-setting techniques have been proposed, their disadvantages include their high cost, X-ray exposure, or time-consuming nature. A precise anatomic study of the lumbar lamina would be meaningful because it could guide the screw-setting procedure without the involvement of X-ray exposure, and doctors of all experience levels could learn the anatomy-based screw-setting technique.

The present anatomic study was performed to provide precise anatomic data for the performance of LTLFS fixation from L3 to L5. The laminar anatomic data were precisely measured using Mimics software (Materialise NV, Leuven, Belgium). The width of the lamina was measured at different sites to determine the characteristics of the lamina, and the optimal entry point and ideal screw trajectory were proposed. Additionally, the length of the lamina and ideal screw trajectory were measured, and the optimal screw length and safety range were suggested. Finally, the screw-setting angle and safety range were proposed after measurement of various angles.

Materials and methods

Human samples

All procedures involving human participants were performed in accordance with the ethical standards of our institutional and national research committees and with those of the 1964 Helsinki Declaration and later amendments thereof or comparable ethical standards. Formal ethics board approval of this study was obtained. All patients provided written informed consent for publication of their information and images.

Patients who underwent volumetric CT scanning (Philips Brilliance 64 CT system; Philips Medical Systems, Amsterdam, The Netherlands) with a 0.625-mm slice thickness from December 2018 to March 2019 in our hospital were included in this study. The inclusion criteria were an age of 20 to 80 years and the performance of a CT scan for low back pain or motor or sensory deficits of the lower extremities. Patients with any evidence of abnormal lumbar anatomy such as congenital spine anomalies; neoplastic, traumatic, or severe degenerative changes; or surgical or medical pathology of the lumbar spine were excluded. Every CT scan consisted of axial scans with coronal and sagittal reconstruction and was stored in Digital Imaging and Communications in Medicine format.

Measurement method

Mimics software 15.0 (Materialise NV) was used to analyze the three-dimensional lumbar lamina measurements with the CT data. The axial view and the coronal and sagittal reconstruction views were assessed for each CT scan. An axis system was built to improve the precision of the anatomical measurements among different patients. The coordinate origin (point O) of the three axes in space coincided with the inferior crossing point of the lamina and spinous process. From this starting point, the y-axis was parallel to a line connecting the lowest points of the anterior and posterior aspects of the inferior border of the vertebral body in the median sagittal plane. The x-axis passed through point O and lay perpendicular to the y-axis in the transverse plane. The z-axis passed through point O and lay perpendicular to the x-axis and y-axis (Figure 2).

Assessment focused on the lamina from L3 to L5. To explore the anatomical features of the lumbar lamina, measurements included the laminar width, laminar length

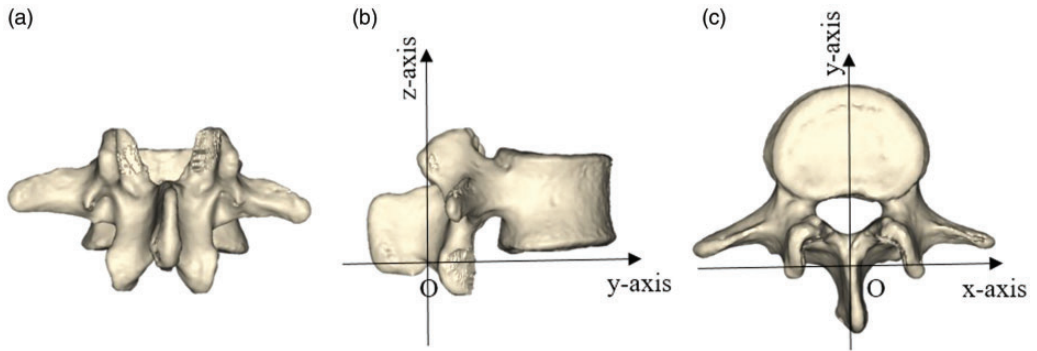


Figure 2. Lumbar axis system. (a) Three-dimensional reconstruction of lumbar vertebrae. (b) The y-axis and z-axis in the median sagittal plane. (c) The x-axis and y-axis in the transverse plane.

(L), length of the screw path (λ), lateral angle (α), and caudal angle (β). An osteotomy procedure was used to make eight cutting planes that were designed and placed by the operator: *Plane 1*, *Plane 2*, *Plane 3*, *Plane of initial (I)*, *Plane of median (M)*, *Plane of distal (D)*, *Up*, and *Down* (Figure 3(a)). The spinous process and part of the lamina were intercepted, and the Plane of the spinous process and Plane of the lamina were determined (Figure 3(b)). *Plane 2* was through the midpoint at the base of the spinous process and inferior articular process and perpendicular to the Plane of the lamina. *Plane 1* was through the one-quarter point of the inferior articular process and parallel to *Plane 2*. *Plane 3* was through the three-quarter point of the inferior articular process and parallel to *Plane 2*. The *Up* plane was through the superior aspect of the articular facet and the *Down* plane was through the inferior aspect of the articular facet, and both were parallel to *Plane 2* (Figure 3(c)). The *Plane of initial (I)* was positioned at the initial part of the lamina and parallel to the Plane of the spinous process. The *Plane of median (M)* was positioned at the median aspect of the lamina and parallel to the Plane of the spinous process. The *Plane of distal (D)* was positioned at the distal part of the lamina and parallel to the Plane of the spinous

process (Figure 3(d)). The laminar width was measured and marked with the symbol of each plane (Figure 3(e)). L was measured from the edge of the spinous process base to the inferior articular facet at *Plane 2* (Figure 3(f)). λ was measured from the edge of the spinous process base to the base of the transverse process at *Plane 2* (Figure 3(g)). α was the angle between the lamina and median sagittal plane in the transverse plane of the lumbar spine, consisting of the x-axis and y-axis (Figure 3(h)). β was the angle between the lamina and median sagittal plane in the coronal plane of the lumbar spine, consisting of the x-axis and z-axis. All angles and lengths (accuracy of length measurements, 0.01 mm; accuracy of angle measurements, 0.01°) were calculated by Mimics software. When using Mimics software to obtain measurements, the image was amplified by four times on the screen and gauged twice by three spine surgeons.

To elucidate the morphological features of the lamina, the laminar width was measured at the initial, median, and distal aspects of the lamina. The measurements of laminar width were taken from three planes. *Plane 2* was through the midpoints of the base of the spinous process and inferior articular process, which was perpendicular to the *Plane of lamina*. *Plane 1* was

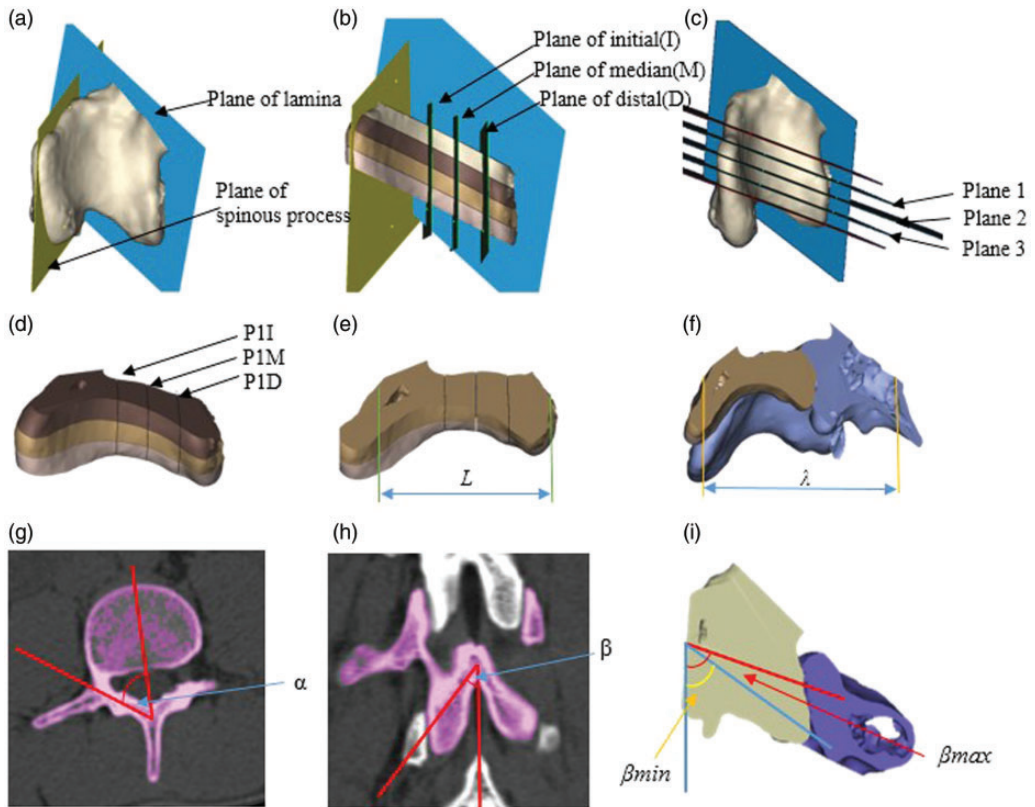


Figure 3. (a) The lamina was split. (b, c) *Plane 1*, *Plane 2*, *Plane 3*, *Plane of initial (I)*, *Plane of median (M)*, and *Plane of distal (D)* were positioned. (d) The laminar width was measured and marked. (e, f) L and λ were measured in *Plane 2*. (g, h, i) α , β , β_{max} , and β_{min} were measured.

through the one-quarter point of the inferior articulate process and was parallel to *Plane 2*. *Plane 3* was through the three-quarter point of the inferior articulate process and was parallel to *Plane 2* (Figure 3(b)). The measurements were termed P1I, P1M, P1D, P2I, P2M, P2D, P3I, P3M, and P3D.

L : distance from the edge of the spinous process base to the inferior articular facet at *Plane 2* (Figure 3(e)).

λ : distance from the edge of the spinous process base to the base of the transverse process at *Plane 2* (Figure 3(f)).

α : angle between the lamina and median sagittal plane in the transverse plane of

the lumbar spine, consisting of the x-axis and y-axis (Figure 3(g)).

β : angle between the lamina and median sagittal plane in the coronal plane of the lumbar spine, consisting of the x-axis and z-axis (Figure 3(h)). The maximum caudal angle (β_{max}) and minimum caudal angle (β_{min}) were measured at the lamina plane (Figure 3(i)).

Statistical analysis

SPSS software package version 15.0 (SPSS Inc., Chicago, IL, USA) was used to perform the statistical analysis. Values are expressed as mean \pm standard deviation

and range as appropriate. The statistical significance of the data was determined using Students' *t* test. Paired *t* tests were performed to identify any statistically significant differences in measurements taken from the left versus right sides. Sex-related differences were assessed using a two-sample *t* test with equal variances. The differences in the laminar width at different planes were compared using a randomized block design of analysis of variance followed by the post hoc Student–Newman–Keuls *q* test for individual comparisons. The level of significance was set at $P < 0.05$ for all statistical analyses.

Results

Thirty-two patients were included in this study. They comprised 16 men (age range, 27–65 years; mean, 31.5 years) and 16 women (age range, 26–68 years; mean, 33.3 years) with an average age of 32.4 years (range, 26–68 years). The bilateral lumbar lamina of L3 to L5 was assessed on the CT scans of all 32 patients. No significant differences in the CT parameters were found between the right and left sides of the lower lumbar lamina. Additionally, the laminar measurements showed no significant difference between

men and women; thus, the left- and right-side measurements and the male and female measurements were mingled for all further statistical analysis. The statistical results of the laminar width are shown in Table 1. The laminar width increased from superior to inferior in the initial part of the lamina, and the distal part of the lamina was wider in the middle. The results of comparison among the groups are shown in Table 2, L and λ are shown in Table 3, and α and β are shown in Table 4. α was measured in the transverse plane of the lumbar spine, consisting of the *x*-axis and *y*-axis. β was measured in the coronal plane of the lumbar spine, consisting of the *x*-axis and *z*-axis. β_{max} and β_{min} are shown in Table 5.

Discussion

LTLFS fixation is a minimally extensive posterior fixation technique.²⁰ Clinical and biomechanical studies have shown good outcomes.^{21–23} However, unsafe screw placement is associated with a risk of injury to the blood vessels, spinal cord, and nerves. To minimize this risk, several methods have been reported for safe and effective screw placement. However, these methods were expensive, time-consuming, or limited by specialized equipment.

Table 1. Laminar width for each lumbar lamina.

	L3		L4		L5	
	Mean \pm SD	Range	Mean \pm SD	Range	Mean \pm SD	Range
P1I	7.79 \pm 0.88	5.66–9.72	7.55 \pm 1.20	4.79–9.93	6.59 \pm 1.20	3.66–8.60
P1M	7.60 \pm 0.66	6.11–9.45	7.28 \pm 1.04	5.15–9.34	6.66 \pm 0.87	4.08–8.61
P1D	9.86 \pm 0.77	8.00–11.45	9.73 \pm 0.95	6.93–11.97	8.84 \pm 1.12	6.67–11.02
P2I	8.48 \pm 1.00	6.44–11.42	7.43 \pm 1.50	4.73–10.55	7.69 \pm 1.20	4.92–10.28
P2M	7.95 \pm 0.64	6.38–9.63	7.25 \pm 0.97	5.37–9.14	6.30 \pm 1.01	4.44–8.88
P2D	10.26 \pm 0.84	8.37–11.83	10.21 \pm 1.29	6.62–13.66	8.23 \pm 1.33	5.77–10.39
P3I	9.18 \pm 1.12	6.84–11.21	8.59 \pm 1.60	5.87–13.09	9.11 \pm 1.37	5.94–11.68
P3M	8.46 \pm 1.29	5.92–11.74	7.49 \pm 1.04	5.29–9.96	6.08 \pm 1.37	4.36–9.48
P3D	9.74 \pm 0.97	7.88–12.45	9.61 \pm 1.18	6.50–12.84	7.46 \pm 1.25	4.46–9.41

All measurements are given in millimeters. SD, standard deviation.

Table 2. Comparison of laminar width within the groups.

Groups	L3					L4					L5				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
P1I	7.7898					7.5527					6.5861				
P1M	7.6042					7.2858					6.6598				
P1D				9.8624				9.7294							8.8448
P2I		8.4727				7.4315					6.3035		7.6921		
P2M	7.9505					7.2542									
P2D					10.2647				10.2144					8.2294	
P3I			9.18					8.5865							9.1119
P3M		8.4585				7.4934					6.0858				
P3D				9.741				9.6081					7.4631		
P	0.097	0.932	1.000	0.468	1.000	0.65	1.000	0.579	1.000	1.000	0.054	0.226	0.289	1.000	0.217

Data were derived with the post hoc Student–Newman–Keuls q test for individual comparison. The items in the same line were not significantly different. Statistical significance was set at $P < 0.05$. All measurements are given in millimeters.

A precise anatomical study was needed to examine a safe and effective screw-setting technique. Therefore, we designed the present study to evaluate the anatomic characteristics of the lumbar lamina. The lumbar lamina from L3 to L5 was measured using Mimics software with the CT data of 32 patients. The width of the lamina was measured in each cutting plane. L , λ , α , β , β_{max} and β_{min} of the lumbar lamina were also measured. Precise laminar anatomic data were obtained using Mimics software, and the optimal screw entry point and trajectory for LTLFS fixation were determined.

To reduce the risk of neurovascular injury, the width of the lamina at the entry point and site of screw penetration should be as wide as possible. Thus, an anatomic study of the laminar width was necessary. Lu et al.¹⁴ measured the lumbar lamina thickness, length of the screw path, lateral angle, and caudal angle (defined as the angle of the screw path in relation to the transverse plane). Based on these lumbar measurements in 30 cadavers, the authors found that the mean thickness of the superior border was thinner than the thickness of the inferior border and that it increased from L1 to L5. A trajectory was designed between the one-third point at the base of the spinous process and the end at the base of the transverse process. However, the authors did not explain why they chose the one-third point at the base of the spinous process as the entry point, and only the widths in the middle of the lamina were measured. Xu et al.²⁴ measured the thickness of the lamina at three points: 2 mm below the superior laminar margin, 2 mm above the inferior laminar margin, and the point equidistant between these two points. In their study, the mean thickness of the lumbar lamina decreased from superior to inferior in L1, L2, and L3, but the mean measurements increased from superior to inferior in L4 and L5.

Table 3. Safety range of screw length.

	L3		L4		L5	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
<i>L</i>	28.84 ± 1.69	25.19–31.87	29.30 ± 2.13	24.92–34.07	31.15 ± 2.92	25.44–37.47
<i>λ</i>	48.84 ± 2.73	47.44–57.42	51.30 ± 3.32	48.21–57.55	53.69 ± 2.20	47.32–59.28

All measurements are given in millimeters. SD, standard deviation.

Table 4. Screw-setting angles.

	L3		L4		L5	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
<i>α</i>	49.40° ± 3.85°	42.14°–56.89°	55.31° ± 5.17°	45.04°–66.78°	59.29° ± 3.78°	52.54°–66.77°
<i>β</i>	43.68° ± 6.49°	35.16°–60.08°	52.01° ± 5.86°	43.50°–66.44°	57.58° ± 2.65°	51.04°–64.71°

SD, standard deviation.

Table 5. Safety range of caudal angle (*β*).

	L3		L4		L5	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
<i>β_{max}</i>	45.79° ± 5.54°	38.16°–62.98°	54.41° ± 3.67°	49.50°–67.23°	60.45° ± 3.42°	54.32°–66.61°
<i>β_{min}</i>	40.68° ± 4.49°	33.16°–56.08°	45.21° ± 7.23°	39.58°–55.35°	53.96° ± 3.87°	48.54°–61.43°

SD, standard deviation.

This difference may have been due to the irregular shape of the lamina. Additionally, their study focused only on the lamina anatomy; they did not discuss the trajectory of the LTLFS. To obtain more objective results, we used the measurements of the laminar width to evaluate the change trend of the laminar width and determine the optimal entry point and screw trajectory (Table 1). By comparing the laminar width in the same plane, we elucidated the trend from superior to inferior in the initial, median, and distal regions of the lamina. In the *Plane of initial*, the mean value of P3I for L3, L4, and L5 was 9.18, 8.59, and 9.11 mm, respectively, which were significantly greater than those of P1I and P2I for each lumbar site ($P < 0.05$). The

value of P2I was significantly greater than P1I in L3 and L4 ($P < 0.05$) (Figure 4(a)). Thus, the width of the lamina showed an increasing trend from superior to inferior in the initial region of the lamina. The optimal entry point was located at the inferior aspect of the base of the spinous process. We also measured the widths of the median and distal aspects of the lamina. The measurements varied in the *Plane of median*. No significant difference was found between the values of most measurements (Figure 4(b)). In the *Plane of distal*, the mean value of P2D was significantly greater than P1D and P3D in L3 and L4 ($P < 0.05$). In L5, the mean measurements of the *Plane of distal* significantly decreased from P1 to P3 ($P < 0.05$). Thus, the width in

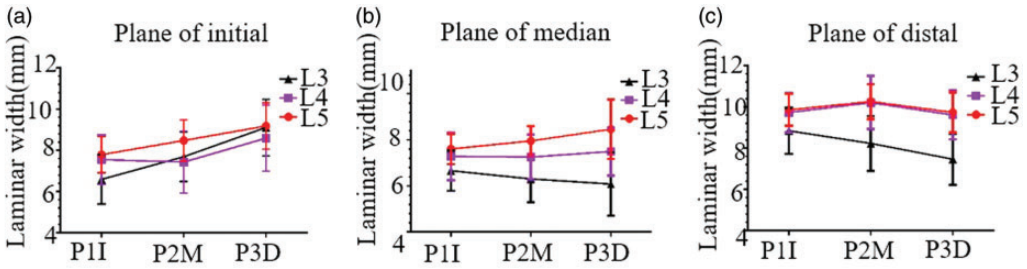


Figure 4. Scatter plots showing the mean values of laminar width of L3, L4, and L5 in the *Plane of initial (I)*, *Plane of median (M)*, and *Plane of distal (D)*.

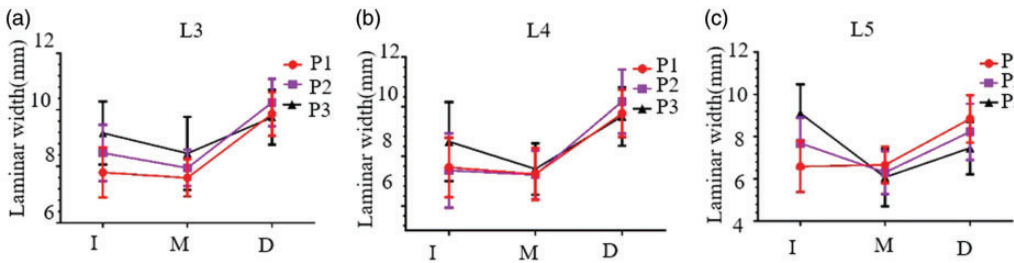


Figure 5. Scatter plots showing the mean values of laminar width of *Plane 1*, *Plane 2*, and *Plane 3* in different lumbar regions [*Plane of initial (I)*, *Plane of median (M)*, and *Plane of distal (D)*].

the distal lamina showed a decreasing trend from the middle to the side (Figure 4(c)). Considering the change in the lumbar laminar width, the optimal screw entry point was located at the median of the base of the spinous process or slightly lower, and the optimal screw path was from the entry point to the base of the transverse process and across the center of the facet joint (Figure 1(b)). Using this entry point and screw path, the entry point would be located in a wide part of the base of the spinous process, and the screw would advance through the wider part of the lamina; thus, the risk of breaking the laminar wall and injuring the spinal cord or nerve would decrease.

A screw diameter of 4.5 or 4.0 mm was used in some studies.^{25,26} In the present study, when comparing the measurements in each plane, the mean values of the *Plane of median* were the lowest among all

three planes (*Plane of initial*, *Plane of median*, and *Plane of distal*) ($P < 0.05$). This would help the surgeon to choose the most appropriate screw diameter by measuring the middle part of the lamina before surgery (Figure 5). A screw with a 4.5-mm diameter is safe enough for almost all regions of the lamina, and screws with a 5.0-mm diameter can be used for some lamina. In L5, however, a screw diameter of 4.0 mm would be safest.

With respect to the LTLFS length, Lu et al.¹⁴ reported that the mean length of the screw path increased from 41 to 54 mm, and they measured the screw path from one-third point at the base of the spinous process to the base of the transverse process. Xu et al.²⁴ only measured the length of the lamina. In our analysis of the ideal entry point and screw trajectory, we measured the screw path from the

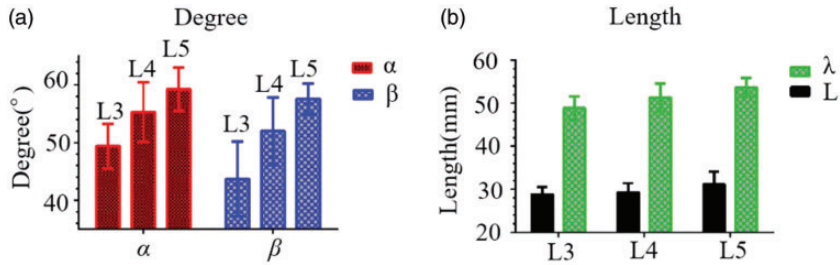


Figure 6. Angle and length. (a) Histogram showing the mean α and β of L3, L4, and L5. (b) Histogram showing the mean L and λ of L3, L4, and L5.

middle of the base of the spinous process to the base of the transverse process, across the center of the facet joint. The mean λ increased from L3–L4 to L5–S1 (48.84 ± 2.73 mm, 51.30 ± 3.32 mm, and 53.69 ± 2.20 mm), and the mean L increased from L3 to L5 (28.84 ± 1.69 mm, 29.30 ± 2.13 mm, and 31.15 ± 2.92 mm) (Figure 6(b)). Considering the length of the lamina, an LTLFS with a length of 45 to 50 mm should be used at the L3 to L5 level. A 45-mm-long screw may be suitable for the L3 to L5 level in most cases. Additionally, to transfer the facet joint, the screw should be longer than L and less than λ . Thus, the screw should not be shorter than 35 mm in most cases, and a screw longer than 40 mm is more secure at the L5 level. A screw length of 35 to 45 mm is suitable for the L3 to L4 level in most cases, and a length of 45 to 50 mm is safe at the L5 level in most cases.

In terms of the screw setting angle, Lu et al.¹⁴ suggested that the lateral angle gradually increased from the L1–L2 to L5–S1 levels (39° to 60°) and that the caudal angle of screw placement relative to the transverse plane gradually decreased from the L1–L2 to L5–S1 levels (60° to 38°). However, the authors only suggested the screw setting angle without reporting the safety range. We measured both the best placement angle and the safety range. In our study, the mean α and β relative to

the coronal plane increased from L3 to L5. As shown in Figure 6(a), α is $49.40^\circ \pm 3.85^\circ$, $55.31^\circ \pm 5.17^\circ$, and $59.29^\circ \pm 3.78^\circ$, respectively, and β is $43.68^\circ \pm 6.49^\circ$, $52.01^\circ \pm 5.86^\circ$, and $57.58^\circ \pm 2.65^\circ$, respectively. An LTLFS should be inserted at an angle of 49.40° to 59.29° laterally and 43.68° to 57.58° caudally at the L3 to L5 levels.

β_{max} and β_{min} were measured to assess safety in this study; these parameters have not been measured in previous studies. If the angle was too large or too small, the screw would break through the facet joint and injure the blood vessel or nerve. Thus, the caudal angles between δ and γ were safe. This would help the surgeon to judge whether the screw was safely placed during the screw-setting procedure or reading of the radiograph during the surgery. Comparison of the ideal caudal angle in the present study showed that an angle of $<3^\circ$ was safe.

Conclusion

This study defined the anatomical features related to LTLFS placement to ensure safe screw insertion. The optimal insertion point, insertion direction, and screw length for LTLFS fixation and the safest range of the screw length were suggested. This study provides surgeons an optimal placement strategy with an ideal starting point and

angle of insertion. However, the lumbar lamina anatomy is variable; for more secure and effective instrumentation, the results of this study must be combined with a customized surgical plan.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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