Comprehensive Anatomic and Morphometric Analyses of Triangular Working Zone for Transforaminal Endoscopic Approach in Lumbar Spine: A Fresh Cadaveric Study

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OBJECTIVE: **The aim of this study is to provide essential information for endoscopic transforaminal approach by performing morphometric analysis of the triangular working zone (TWZ) in fresh cadavers.**

METHODS: **Fifteen fresh human cadavers (9 women and 6 men) with no history of spinal surgery were used in this study. Anatomic dissection of 150 foraminal levels were performed. Significant surgical landmarks constructing TWZ were measured bilaterally from L1–2 to L5–S1 on 15 fresh cadavers. The relationship between traversing roots and intervertebral discs was defined.**

RESULTS: **Base, height, and hypotenuse measurements of TWZ were longer as the level lowered. Mean base height and hypotenuse of TWZ were 12.15 mm, 11.29 mm, and 16.69 mm (L1–2); 17.94 mm, 17.18 mm, and 28.03 mm (L5–S1), respectively. TWZ was triangular shaped at the upper lumbar levels (L1–2, L2–3, and L3–4), and trapezoid at the lower lumbar levels (L4–5 and L5–S1). Going down the levels, the exiting root angle was narrower, the mean exiting angle of the L5 root being 28.23°. All L2 and L3 traversing roots and nearly all L4 traversing roots (86.7%) originated from below the disc level. Forty percent of L5 traversing roots originated above the disc level, and 53.3% originated at the disc level. Most S1 traversing roots originated at the proximal margin of the disc level (80%).**

CONCLUSIONS: **Our study reveals a detailed morphometric analysis of TWZ. Understanding the foraminal anatomy is crucial for safely performing transforaminal endoscopic surgery. The learning curve of transforaminal surgery can be reduced by garnering knowledge of TWZ anatomy.**

INTRODUCTION

Several minimally invasive methods have been recently developed in spinal surgery. A triangular zone was proposed by Kambin and Gellmann[1] in 1983 (called Kambin's triangle) for safely accessing the intervertebral disc through a transforaminal approach. Since then, this approach has gained wide acceptance not only for percutaneous endoscopic lumbar discectomy but also for epidural injections, lumbar interbody fusion techniques, and surgeries for extradural tumors of this region.

Kambin's triangle or the triangular working zone (TWZ) is considered as a secure location in the posterolateral corner of the intervertebral disc to pass the instruments safely with minimal risk of injuring the exiting nerve root. The TWZ base is described as the superior endplate of the inferior vertebral body from the dural sac to the medial border of the exiting nerve. The TWZ height is the lateral margin of the dura reaching from the axilla of the exiting nerve superiorly to the inferior border of the intervertebral disc inferiorly. The hypotenuse of the TWZ is the exiting nerve root itself.[2] Notably, when performing transforaminal surgeries, it is extremely crucial to be extra cautious regarding the borders of this triangle, particularly the hypotenuse.

Key words
- Exiting nerve root
- Foraminal anatomy
- Lumbar spine
- Spinal morphometry
- Transforaminal endoscopic discectomy
- Triangular working zone

Abbreviations and Acronyms
POD: Postoperative dysesthesia
TWZ: Triangular working zone

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Mirkovic et al.[2] and Min et al.[3] described the anatomic borders and their measurements of the working zone. Mirkovic et al.[2] reported the TWZ measurements on a coronal plane, whereas Min et al.[3] reported it on a sagittal plane. The objective of this study was to confirm the already described borders of the TWZ, using fresh cadavers, by performing morphometric calculations and finding the most accurate measurements to provide the safest approach for surgeons.

METHODS

The cadaveric work was carried out at the Turkish Republic, Ministry of Justice, Forensic Medicine Institution. Fifteen fresh human cadavers (9 women and 6 men) with no history of spinal surgery were included in the study. The mean age was 43.4 years (range, 28–63 years). Cadavers with congenital or acquired spinal abnormalities were excluded. All procedures were performed in prone position.

Paraspinal muscles and fascias were dissected from L1–S1 to expose posterior spinal structures bilaterally. All soft tissues were carefully removed to reveal spinous and transverse processes. Meticulous attention was given to protect bony and neural structures and their connections during the dissection and removal of intertransverse fascia and muscles. Partial resection of facets, pars interarticularis, and iliac crest revealed the foraminal anatomy and exiting and traversing roots from L1–2 to L5–S1. Overall, 150 foraminal areas were studied. Each level was digitally photographed with a marker for the scaling and was further evaluated using the digital Image J program (National Institutes of Health, Bethesda, Maryland, USA).

Measurements of the structures forming the TWZ were performed. They were recorded as follows:

1) Length of the exiting nerve root (creates the hypotenuse of the TWZ, part of the root extending from dural exit to superior endplate of the inferior vertebra)
2) The base of the TWZ (superior endplate of the inferior vertebral body between the lateral border of the dural sac and the medial border of the exiting nerve)
3) The height of the TWZ (lateral margin of the dura extending from exiting root axilla superiorly to the lower border of the intervertebral disc inferiorly)
4) Disc height (distance between the upper and lower margins of the intervertebral disc lateral to the dura)
5) Exiting nerve root width distal to the ganglion.
6) The exit angle of the nerve root
7) Between L1–2 and L5–S1 disc levels, the distance of origin for traversing roots from intervertebral disc according to the zone groups are as follows:

   zone a: proximal margin of the intervertebral disc

   zone b: upper half of the intervertebral disc

   zone c: lower half of the intervertebral disc

   zone d: distal margin of the intervertebral disc.

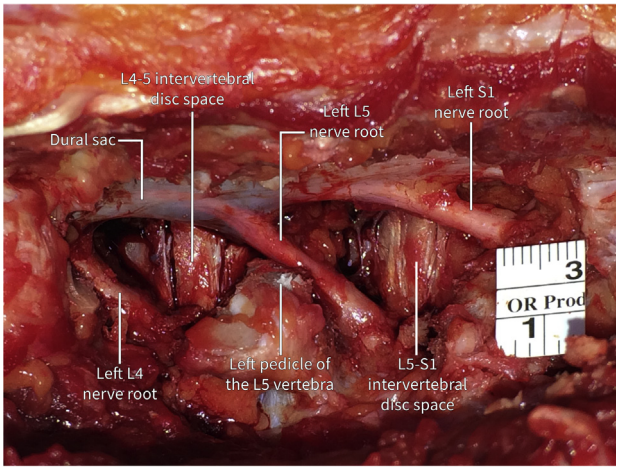

Figure 1. Fresh cadaver section showing the 2 adjacent triangular working zones and their anatomic components and exit levels of traversing roots according to intervertebral disc spaces.

RESULTS

In 15 fresh cadavers, measurements of structures forming the TWZ were performed in 150 foraminal areas, besides measuring nerve widths, disc heights, and nerve root exit angles. The relationship between the exit of the traversing root and intervertebral disc from L1–2 to L5–S1 was demonstrated (Figure 1). The values are shown in Tables 1–4.

Nerve Root Length

Exiting nerve root forming the hypotenuse became longer at each level going from L1–2 to L5–S1. The longest hypotenuse was at the L5–S1 level (mean 28.03 mm), and the shortest hypotenuse was at the L1–2 level (mean 16.69 mm) (Table 1).

Base of the TWZ

The base of the TWZ is formed by the superior endplate of the inferior vertebral body between the lateral of the dural sac and the medial of the exiting nerve. The TWZ base distance increased in length from L1–2 to L5–S1. The longest length was at the L5–S1 level (mean 17.94 mm), and the shortest length was at the L1–2 level (mean 12.15 mm) (Table 1).

Height of the TWZ

Length of the dural sac part forming the TWZ height increased at each level from L1–2 to L5–S1. The longest and shortest heights were measured at L5–S1 (mean 17.87) and L1–2 (mean 11.29), respectively (Table 1).

Disc Height

Height of the intervertebral disc increased from L1–2 to L4–5 levels, but at the L5–S1 level, it decreased again. The intervertebral disc height was the shortest at the L1–2 level (mean 4.72 mm), and was the longest at L4–5 (mean 7.74 mm) (Table 2).

Table 1. Measurements of the Triangular Working Zone

	Base (mm)			Height (mm)			Hypotenuse (mm)		
Level	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
L1-2	12.15	2.44	8.25–16.60	11.29	1.71	8.25–14.25	16.69	2.09	12.70–21.10
L2-3	13,24	2.18	10.40–17.40	12.58	2.11	9.05–16.65	18.43	2.42	14.05–22.60
L3-4	14.12	2.23	10.85–18.30	14.33	1.79	12.20–17.75	20.28	2.54	15.45–25.25
L4-5	15.76	2.19	11.90–19.65	16.01	1.75	12.60–19.20	24.54	3.01	18.15–28.20
L5-S1	17.94	2.28	13.70–22.45	17.87	1.96	13.85–20.30	28.03	3.45	19.50–32.75

SD, standard deviation.

Nerve Root Width

The thickness of the exiting nerve root, which forms the hypotenuse of TWZ, increased from L1–L5 gradually. The thinnest exiting nerve root was the L1 root (mean 4.23 mm), and the thickest was L5 (mean 6.35 mm) (Table 3).

Exiting Nerve Root Angle

Exit angles of nerve roots reduced from L1–L5. The widest angle was of L1 roots (mean 41.56°), whereas the narrowest angle was of L5 roots (mean 28.23°) (Table 3).

Exit Distances of Traversing Roots from Intervertebral Disc

All L2 traversing roots (100%) and all L3 traversing roots (100%) originated from zone d. L4 traversing roots originated in 13 cadavers from zone d (86.7%), and in 2 cadavers from zone c (13.3%). L5 traversing roots originated in 6 cadavers from zone a (40%), in 5 cadavers from zone b (33.3%), in 3 cadavers from zone c (20%), and in 1 cadaver from zone d (6.7%). S1 traversing roots originated in 12 cadavers from zone a (80%), in 2 cadavers from zone b (13.3%), and in 1 cadaver from zone c (6.7%) (Table 4).

DISCUSSION

Several favorable surgical results have been reported for transforaminal endoscopic lumbar discectomy since 1980.[4,5] However, the risk of perioperative complications, such as injury to the neurovascular and internal abdominal structures, has prevented more widespread use of transforaminal endoscopic lumbar discectomy. Minimally invasive surgeries for lumbar disc herniations have higher nerve root injury rates compared with the traditional open surgeries. Exiting nerve injury is the most devastating complication of percutaneous endoscopic lumbar discectomy. Postoperative dysesthesia (POD) and motor weakness related to exiting root injury can decrease motor functions and postoperative satisfaction of patients. In 2002, Yeung and Tsou[5] reported their surgical results and complications. They reported a POD rate of 1.9% with a 6-mm scope. Ruetten et al.[6] reported a POD rate of 1.8% with an 8-mm cannula under general anesthesia. The incidence of exiting nerve root injury has been reported to vary from 1%–6.7%.[2,5-9] Exiting nerve root is prone to injury when it is close to the TWZ, which is also known as the Kambin's triangle. TWZ was initially proposed for transforaminal endoscopic discectomy procedure but has also been used for transforaminal lumbar interbody fusion.[10] The hypotenuse of this triangle is formed by the exiting nerve root[11] and needs to be borne in mind when working in the TWZ, regardless of the type of surgery, to avoid injuring the exiting root. Two cadaveric studies reported a morphometric analysis of the TWZ.[2,3] Preoperative radiologic measurements may also be helpful for surgical planning.[12]

Ozer et al.[13] studied and categorized the Kambin's triangle according to preoperative and cadaveric view of the TWZ. Min

Table 2. Measurements of the Disc Height

Disc Height (mm)			
Level	Mean	SD	Range
L1-2	4.72	0.53	3.80–5.50
L2-3	5.54	0.71	4.50–6.80
L3-4	6.35	0.71	4.90–7.60
L4-5	7.74	0.76	6.70–9.20
L5-S1	6.39	0.61	5.30–7.40

SD, standard deviation.

Table 3. Measurement of the Nerve Root Width and Angle

	Nerve Root Width (mm)			Nerve Root Angle (°)		
Nerve Root	Mean	SD	Range	Mean	SD	Range
L1	4.23	0.55	3.25–5.05	41.56	6.89	32.75–57.30
L2	4.67	0.58	3.70–5.70	37.07	5.76	29.90–48.40
L3	5.11	0.61	4.30–6.20	34.36	5.67	27.70–45.55
L4	5.86	0.44	5–6.55	33.08	5.12	25.80–45.35
L5	6.35	0.41	5.80–7.15	28.23	4.51	22.75–37.90

SD, standard deviation.

Table 4. The Relationship Between Traversing Root Exit and Intervertebral Disc (Zone a: Proximal Margin of the Intervertebral Disc; Zone b: Upper Half of the Intervertebral Disc; Zone c: Lower Half of the Intervertebral Disc; and Zone d: Distal Margin of the Intervertebral Disc)

Number of Cadavers				
Traversing Root	**Zone a**	**Zone b**	**Zone c**	**Zone d**
L2				15
L3				15
L4			2	13
L5	6	5	3	1
S1	12	2	1	

et al.[3] reported that the actual working zone was somewhat trapezoid rather than a typical right-angled triangle because of the absence of a real apex. They defined superior and inferior borders through the imaginary lines drawn from the posterior margin of nerve root to the superior articular process parallel to inferior and superior endplates. The posterior border was defined as the superior articular facet and anterior border of the exiting root itself, running obliquely. Our study observed that the TWZ was more triangular shaped at the upper lumbar levels (L1–2, L2–3, and L3–4), and trapezoid at the lower lumbar levels (L4–5 and L5–S1) (**Figure 2**). At L1–2, L2–3, and L3–4 spinal levels, traversing roots generally originated distal to the intervertebral disc, whereas, at L4–5 and L5–S1 levels, they originated proximally to the intervertebral disc or at the disc level (but at various zones of it).

Mirkovic et al.[2] reported a slight increase in the dimensions of the triangular zone when going down the disc levels caudally from L2–3 to L5–S1. Their measurements of the TWZ revealed the following mean values: width 18.9 mm, height 12.3 mm, and hypotenuse 23.0 mm. Min et al.[3] made the measurements of the TWZ in the sagittal plane. The mean diameter of the base of TWZ was 11.6 ± 4.6 mm; the values increased caudally down the levels and reached the longest at the L5–S1 level. However, they also mentioned that having the widest base of the TWZ did not mean that L5–S1 was the safest level because other factors, like iliac crest, also contribute to the safety and success of the procedure. The results of our study are comparable to the results of Min[3] et al. and Vialle[14] et al., as TWZ dimensions gradually increased in lower levels. However, that at the L5–S1 level, besides the increased height of the iliac crest as stated earlier, the short distance between L5 transverse process, the sacral ala, and the wider pars interarticularis of L5 lamina may contribute to the narrowing of the operative corridor.

In their cadaveric study, Mirkovic et al.[2] measured the disc heights to be 5.2 mm at L2–3, 6.3 mm at L3–4, 5.9 mm at L4–5, and 4.8 mm at L5–S1 levels. Using computed tomography imaging, Bach et al.[15] showed that the mean lumbar disc height increased from L1–2 to L4–5, and slightly decreased in the L5–S1 level. We also found this pattern of increase and decrease in our measurements (**Table 2**). Disc height is one of the most crucial factors affecting the success of transforaminal endoscopic disc surgery. Its measurement is crucial for determining cage size in endoscopic transforaminal interbody fusion surgery.

In their study of 7 cadavers, Güvençer et al.[16] measured nerve root diameters and determined the following mean values: L1, 4.9 ± 0.5 mm; L2, 5.5 ± 0.6 mm; L3, 6.5 ± 07 mm; L4, 7.2 ± 0.9 mm; and L5, 7.5 ± 1.0. In another study, Attar et al.[17] reported the following mean values of nerve root diameter: L1, 3.3 ± 0.4; L2, 3.5 ± 0.4; L3, 3.9 ± 0.4; L4, 3.9 ± 0.5; and L5,

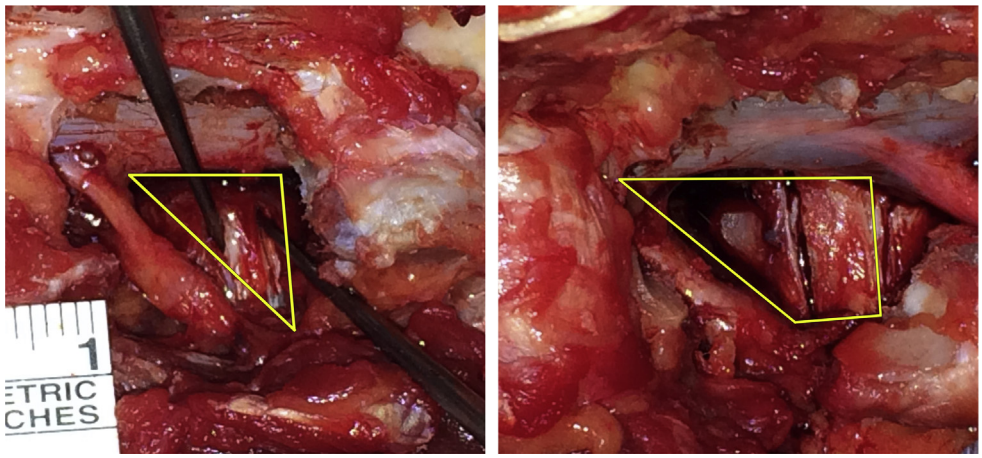

Figure 2. *Left*: Fresh cadaver section showing the anatomic landmarks of the triangular working zone (TWZ) and real triangular shape of TWZ at the upper lumbar region (L1-2 level). *Right*: Fresh cadaver section showing the trapezoid shape of TWZ at the lower lumbar region (L4-5 level).

3.9 ± 0.4 mm. Likewise, we observed that the nerve root diameter increased gradually from L1–L5 (Table 3).

Lien et al.[18] determined the following mean exiting nerve root angles: left L1 root 40.2°, right L1 root 40°, left L2 root 38°, right L2 root 38°, left L3 root 35.4°, right L3 root 37.8°, left L4 root 37.2°, right L4 root 40.04°, left L5 root 28.6°, and right L5 root 29°. Similarly, Güvençer et al.[16] reported the mean exiting nerve root angles as follows: L1 of 36.1°, L2 of 36°, L3 of 38.5°, L4 of 38.6°, and L5 of 40.4°. Using fresh cadavers, Suh et al.[19] reported the mean exit angles as 45°, 39°, 32°, 27°, and 23° from L1–L5, respectively. Although the results of our study differ from that of the Lien et al.[18] and Güvençer et al.[16] studies, they are identical to that by Suh et al.[19] Suh et al.[19] pointed out that root exit angles were decreased from L1–L5, respectively, and this finding is concordant with our results (Table 3).

The results of our study revealed that all L2 and L3 traversing roots, and most of the L4 traversing roots (86.7%), originated below the disc level. Approximately 40% of the L5 traversing roots originated above the disc level, 53.3% originated at the disc level (33.3% at the upper half, 20% at the lower half of the disc), and 6.7% originated below the disc level. Most of the S1 traversing roots originated above the disc level (80%), and very few originated at the disc level (20%). We believe that awareness of the exit level of traversing roots may reduce root injuries. Furthermore, we can infer from these results that herniations at L1–2, L2–3, and L3–4 levels are more prone to compress dural sac, whereas herniations at L4–5 and L5–S1 levels often compress nerve roots directly. These results may help us to explain why disc herniations at L4–5 and L5–S1 levels frequently cause radicular symptoms.

When the superomedial part of the inferior pedicle is targeted, and the procedure is done within the limits of the TWZ, the risk of nerve damage can be lowered considerably. The endoscopic working cannula should be inserted as close to the facet as possible. In addition, inserting an endoscope becomes difficult when the height of the disc is low, and excessive manipulations will increase the rate of exiting root injury. Therefore care must be taken to avoid traversing roots to prevent injury, especially during lower lumbar level entry because L5 and S1 traversing roots originate at the disc level or above.

CONCLUSIONS

The thickness of the nerve root and the dimensions of the TWZ increased as the level lowered. The TWZ was more triangular shaped at the upper lumbar levels, and trapezoid at the lower lumbar levels. All L2 and L3 traversing roots and nearly all L4 traversing roots (86.7%) originated from below the disc level. Among L5 traversing roots, 40% originated above the disc level, and 53.3% originated at the disc level. Most S1 traversing roots originated at the proximal margin of the disc level (80%). Our study reveals a detailed morphometric analysis of the TWZ. Understanding the foraminal anatomy is crucial for safely performing transforaminal endoscopic surgery. The learning curve of transforaminal surgery can be reduced by garnering knowledge of the TWZ anatomy.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Halil Can: Data curation, Conceptualization, Investigation, Writing - original draft. **Tugrul Cem Unal:** Writing - review & editing, Visualization. **Ilyas Dolas:** Formal analysis. **Gucluhan Guclu:** Visualization. **Furkan Diren:** Visualization. **Duygu Dolen:** Visualization. **Cengiz Gomleksiz:** Visualization. **Aydin Aydoseli:** Supervision. **Erdinc Civelek:** Supervision. **Altay Sencer:** Supervision.

REFERENCES

1. Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine. A preliminary report. *Clin Orthop Relat Res*. 1983;174:127-132.
2. Mirkovic SR, Schwartz DG, Glazier KD. Anatomic considerations in lumbar posterolateral percutaneous procedures. *Spine (Phila Pa 1976)*. 1995;20:1965-1971.
3. Min JH, Kang SH, Lee JB, Cho TH, Suh JK, Rhyu IJ. Morphometric analysis of the working zone for endoscopic lumbar discectomy. *J Spinal Disord Tech*. 2005;18:132-135.
4. Hermantin FU, Peters T, Quartararo L, Kambin P. A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy. *J Bone Joint Surg Am*. 1999;81:958-965.
5. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976)*. 2002;27:722-731.
6. Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. *Spine (Phila Pa 1976)*. 2008;33:931-939.
7. Ahn Y, Lee SH, Park WM, Lee HY, Shin SW, Kang HY. Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases. *Spine (Phila Pa 1976)*. 2004;29:E326-E332.
8. Ruetten S, Komp M, Merk H, Godolias G. Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach. *J Neurosurg Spine*. 2007;6:521-530.
9. Ahn Y, Lee SH, Lee JH, Kim JU, Liu WC. Transforaminal percutaneous endoscopic lumbar discectomy for upper lumbar disc herniation: clinical outcome, prognostic factors, and technical consideration. *Acta Neurochir (Wien)*. 2009;151:199-206.
10. Tumialán LM, Madhavan K, Godzik J, Wang MY. The history of and controversy over kambin's triangle: a historical analysis of the lumbar transforaminal corridor for endoscopic and surgical approaches. *World Neurosurg*. 2019;123:402-408.
11. Kambin P. Arthroscopic microdiskectomy. *Mt Sinai J Med*. 1991;58:159-164.
12. Choi I, Ahn JO, So WS, Lee SJ, Choi IJ, Kim H. Exiting root injury in transforaminal endoscopic discectomy: preoperative image considerations for safety. *Eur Spine J*. 2013;22:2481-2487.
13. Ozer AF, Suzer T, Can H, et al. Anatomic assessment of variations in Kambin's triangle: a surgical and cadaver study. *World Neurosurg*. 2017;100:498-503.
14. Vialle E, Vialle LR, Contreras W, Jacob C. Anatomical study on the relationship between the dorsal root ganglion and the intervertebral disc in the lumbar spine. *Rev Bras Ortop*. 2015;50:450-454.
15. Bach K, Ford J, Foley R, et al. Morphometric analysis of lumbar intervertebral disc height: an imaging study. *World Neurosurg*. 2019;124:e106-e118.
16. Güvençer M, Naderi S, Kiray A, Yilmaz HS, Tetik S. The relation between the lumbar vertebrae

and the spinal nerves for far lateral lumbar spinal approaches. *J Clin Neurosci*. 2008;15:192-197.

17. Attar A, Ugur HC, Uz A, Tekdemir I, Egemen N, Genc Y. Lumbar pedicle: surgical anatomic evaluation and relationships. *Eur Spine J*. 2001;10:10-15.

18. Lien SB, Liou NH, Wu SS. Analysis of anatomic morphometry of the pedicles and the safe zone for through-pedicle procedures in the thoracic and lumbar spine. *Eur Spine J*. 2007;16:1215-1222.

19. Suh SW, Shingade VU, Lee SH, Bae JH, Park CE, Song JY. Origin of lumbar spinal roots and their relationship to intervertebral discs. *J Bone Joint Surg Br*. 2005;87:518-522.

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