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Original Article

Magnetic resonance imaging-based anatomical study of the multifidus-longissimus cleavage planes in the lumbar spine

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Abstract: Purpose: The Wiltse approach allows spinal surgeries to be performed with minimal soft tissue trauma. The purpose of this study was to investigate the anatomy of the natural cleavage plane between multifidus and longissimus at different levels based on MRI images. Methods: MRI cross-sectional scans from L1 to S1 were collected from 205 out patients (103 males, 102 females). Based on the images, some parameters were defined and measured to describe the locations, curvature and directions of Wiltse approach. Besides, differences of these parameters between genders and segments were compared. Results: Among the total of 2460 one-sided images, cleavage planes between multifidus and longissimus were not able to be identified in 105 images. The locations, directions and curvature of the cleavage plane differed significantly among different segments but followed some regular pattern from L1-S1. The simultaneous rotation of the plane around its deepest points to the midline from S1 to L1 and the plane seemed to be the most curved at L3 and relatively straight for L5 and S1. Conclusions: With a better understanding of the natural cleavage plane between multifidus and longissimus, performers can correctly plan the distance of skin incisions from the midline and the direction of muscle dissection at each vertebral level, thus reducing trauma in the operation.

Keywords: Wiltse, minimal invasive, anatomy, lumbar spine, MRI

Introduction

In 1968, Wiltse first described the paraspinal sacrospinalis-splitting approach to the lumbar spine which was associated with advantages of less trauma compared with posterior median approach [1-4]. The original description of Wiltse approach was related to spinal fusion, especially for treatment of lumbosacral spondylolisthesis [5].

It has now been widely used in various spinal surgeries, such as spinal canal decompression [6], internal fixation of pedicle screws, discectomy for patients with far lateral disc herniation [7], etc. Previous studies indicated that dissection and retraction of the paraspinal musculature through a midline approach resulted in denervation and atrophy, thus increasing the risk of chronic back pain and failed back surgery syndrome [8-11]. Evidence has demonstrated that the Wiltse approach significantly reduced intraoperative muscle retraction to posterior paraspinal muscle [12], effectively shortened exposure and implantation time, protected the integrity of the erector spinae, decreased the likelihood of heat and retraction injuries to paraspinal muscles [13], and promoted the retention of postoperative lumbar muscle strength and recovery compared with traditional midline approach [14, 15]. In recent years, percutaneous fixation technique was known to have better effects in preserving paraspinal muscles for fusion-required cases [16-18]. However, compared to Wiltse approach, percutaneous techniques are associated with-higher doses of radiation exposure but no bet-

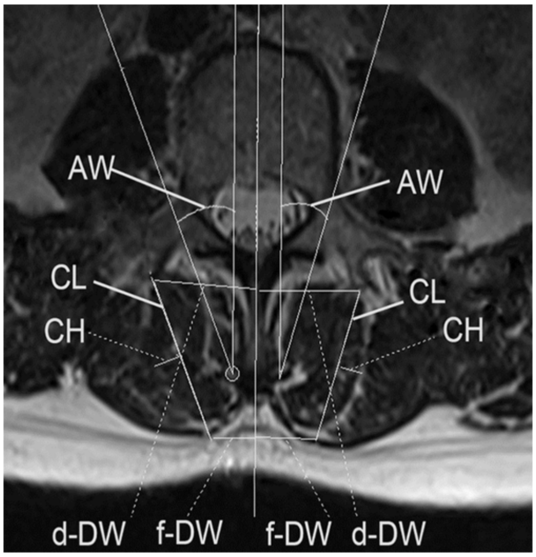

Figure 1. Measurement items of sacrospinalis-splitting approach. d-DW: Distance between the midline and deep-most points of the intermuscular planes; f-DW: Distance between the midline and the superficial-most points intersecting with fascia of the intermuscular planes; AW: Angulation between midline and linear connecting the superficial-most points and deep-most points of intermuscular planes; CH: Curve height of intermuscular planes incross-section plane; CL: Chord length between the deep-most points and superficial-most points of intermuscular planes in cross-section plane; CW: Curve curvature of the intermuscular planes in coronal planecalculated from CH and CL.

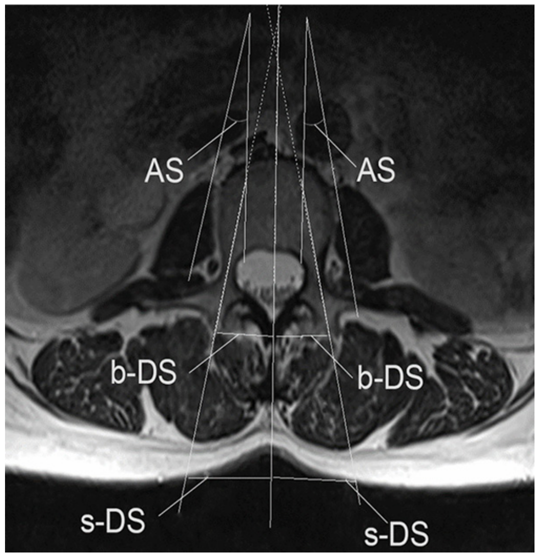

Figure 2. Measurement items of optimal pedicle screw trajectory. AS: Angulation between trajectory of optimal pedicle screw and midline; b-DS: Distance between the midline and the pedicle screw's entry point of bone; s-DS: Distance between the midline and the pedicle screw's entry point of skin.

Table 1. Patient characteristics

	N	Age (years)	BMI (kg/m^2)
Female	102	51.6±11.00	22.9±3.1
Male	103	49.1±13.76	24.7±3.3
Overall	205	50.3±12.5	23.8±3.3

ter therapeutic outcomes [19]. At present, Wiltse approach was still an option in posterior-surgeries for many spinal surgeons. Wiltse's 1988 article notes that the cleavage plane between the multifidus and longissimus was closer to the midline proceeding superior along the lumbar spine [2].

The intermuscular plane is curvilinear in the axial plane with its concavity facing the spinal elements and its convexity facing the lateral spine [20]. However, until now, data about this approach was almost obtained based on European populations, and in these studies, except for the distance of superficial points of the intermuscular plane and the midline [20, 21], no description of direction or curvature of this cleavage plane in each segment was available. Its correlation to surgical procedure has yet to be described.

The purpose of this study was to investigate detailed morphology of Wiltse approach for each segment in East Asians and to explore the relationship between the expected trajectory of the pedicle screw in the soft tissue and Wiltse approach.

Materials and methods

This clinical study was approved by Ethical Committee of the First Affiliated Hospital of Nanjing Medical University (Ethics No. 2013-SR-130), and written informed consents were obtained from all 205 patients (103 males, 102 females), aged between 18 and 70 years. MRI imaging data of all patients were collected between November 15, 2013 and December 5, 2013 from outpatients with low back pain, regardless of lower radicular symptoms. MRI scans were taken with a 3-Tesla Siemens coil (Verio 3.0T, Siemens Corporation, Germany). Exclusion criteria were developmental abnormalities including cretinism, dwarfism, gigantism; vertebral abnormalities including lumbar

Table 2. Descriptive statistics for measurements of screw trajectory

Level		AS (°)	b-DS	s-DS
L1	Female	12.14±2.60	17.95±1.84	25.72±3.73
	Male	12.66±2.37	19.34±1.79	27.86±3.78
	Overall	12.40±2.50	18.66±1.94	26.81±3.89
L2	Female	12.00±3.35	18.20±1.67	26.93±4.04
	Male	13.21±2.17	19.71±1.94	29.51±3.62
	Overall	12.61±2.88	18.95±1.96	28.23±4.04
L3	Female	13.99±3.05	19.92±1.69	31.06±4.79
	Male	14.06±2.43	21.24±1.92	32.86±4.34
	Overall	14.02±2.75	20.58±1.93	31.97±4.65
L4	Female	14.95±3.12	21.33±2.12	34.32±5.26
	Male	15.33±2.88	22.85±2.25	36.69±5.19
	Overall	15.14±3.01	22.09±2.31	35.51±5.35
L5	Female	16.82±3.81	24.73±2.39	40.02±6.26
	Male	16.88±3.16	25.95±2.40	41.49±5.48
	Overall	16.85±3.49	25.35±2.46	40.75±5.92
S1	Female	13.10±3.62	25.73±2.73	38.47±6.37
	Male	13.79±2.89	26.90±2.47	40.27±5.52
	Overall	13.46±3.29	26.32±2.66	39.39±6.02

AS: angulation between trajectory of optimal pedicle screw and midline; b-DS: distance between the midline and the pedicle screw's entry point on the surface of the bone surface; s-DS: distance between the midline and the pedicle screw's entry point on the surface of the skin.

sacralization, sacrum lumbarization, hemivertebrae, wedged vertebrae, butterfly vertebrae, vertebral fusion, scoliosis, lordosis, kyphosis, spinal bifida; and patients with a history of lumbar surgery. All images were analyzed with Sky View PACS V3.3.1.5 (Yangtze River Ruiheng Software Ltd. Nanjing China). Two spinal surgeons with more than 10 years of experience measured the data about trajectory of optimal pedicle screw and two radiologists with more than 8 years of experience measured the data about paraspinal sacrospinalis-splitting approach. All images were numbered after shielding patients' information before analyses. All observers were blinded to the age, sex and BMI of the patients. It was consistent if two observers independently determined that muscle gap cannot be distinguished in MRI images, Contradiction between two observers was resolved through consultation.

All vertebral bodies were scanned through the pedicle and parallel to the upper vertebral endplate from L1 to the S1, with three tomographic imagesat each segment. We selected one of the tomographic images with the largest width of pedicle for precise measurements (**Figures 1**, **2**). We considered the muscle split as two approximately symmetrical arcs in cross section. We drew a midline bisecting the vertebral and spinous processes. The following indicators were defined and measured in each of the vertebrae from L1 to S1 (**Figure 1**): AW: angulation between midline and linear planes connecting the most superficial points and deepest points of intermuscular planes. A parallel line along the midline passed the deepest points of intermuscular planes and defined the positive angulation when muscle gap was outside of the line and negative inside; d-DW: distance between the midline and deepest points of the intermuscular planes; f-DW: distance between the midline and the most superficial points intersecting with fascia of the intermuscular planes; CH: curve height of intermuscular planes in cross-section. If curve faced outward, the height was defined as positive, the inward curve was defined as negative; CL: A straight line connecting between the deepest points and the most superficial points of intermuscular planes in cross-section; and CW: curvature of the intermuscular planes in cross-section section calculated from CH and CL. In order to compare the relationship between the expected approach of the pedicle screw in the soft tissue and the cleavage plane, trajectory measurement of optimal pedicle screw included (**Figure 2**): AS (angulation between trajectory of optimal pedicle screw and midline), b-DS (distance between the midline and the pedicle screw's entry point of bone), s-DS (distance between the midline and the pedicle screw's entry point of skin). Each value was the average of two measurements. Interobserver and intraobserver errors in distance and angle were determined, based on the measurements of five patients by two observers with three repetitions bilaterally on f-DW and AW at every lumbar level. Finally, the muscle gap of each segment was mapped according to the average measured value.

Statistical analysis

The data are presented as mean ± standard deviation. All data were analyzed by SPSS20.0. Differences of BMI and the measured items at each level between genders were examined by

Table 3. Descriptive statistics for sacrospinalis-splitting approach

Level		d-DW	f-DW	AW	CW
L1	Female	17.45±1.86	6.27±2.10	-28.61±14.15	23.38±27.75
	Male	19.15±2.48	7.48±7.06	-29.69±11.88	23.15±60.12
	Overall	18.32±2.34	6.89±5.30	-29.18±13.05	23.26±47.16
L2	Female	18.45±2.11	7.23±2.44	-25.35±8.88	31.67±18.62
	Male	20.12±2.16	7.94±2.69	-24.14±10.00	30.95±50.22
	Overall	19.28±2.29	7.59±2.59	-24.76±9.47	31.30±37.86
L3	Female	20.25±2.37	10.21±3.16	-18.49±9.08	38.53±18.64
	Male	21.94±2.63	11.43±4.07	-17.37±10.8	33.37±29.81
	Overall	21.10±2.64	10.82±3.70	-17.93±9.16	35.93±25.00
L4	Female	22.45±2.35	18.14±7.11	-7.44±11.97	34.84±26.01
	Male	23.98±2.51	20.47±6.07	-5.05±9.58	22.29±11.22
	Overall	23.22±2.54	19.30±6.70	-6.25±10.90	28.55±20.95
L5	Female	25.04±2.41	28.04±7.42	6.30±12.57	28.43±16.57
	Male	26.40±2.75	29.70±5.41	5.12±8.29	15.09±16.81
	Overall	25.72±2.67	28.87±6.55	5.72±10.67	21.91±17.95
S1	Female	26.65±2.63	32.72±8.49	10.74±14.24	28.17±18.38
	Male	26.98±2.78	32.37±5.27	8.72±8.56	15.08±15.62
	Overall	26.81±2.72	32.54±7.03	9.71±11.73	21.51±18.23

The means ±1 standard deviation of male, female and overall group are mentioned. The d-DW, f-DW, AWand CW differed significantly from each other at all segments (P < 0.01) in each sex, as well as in the overall group. d-DW: distance between the midline and deepest points of the intermuscular planes; f-DW: distance between the midline and the most superficial points intersecting with fascia of the intermuscular planes; AW: angulation between midline and linear planes connecting the most superficial points and deepest points of intermuscular planes; CW: curvature of the intermuscular planes in cross-section section.

independent t-tests. ANOVA, in conjunction with LSD (Least-Significant Difference) was used to examine the differences among six segments. Pearson tests were performed for correlation analyses. P < 0.05 was considered statistically significant.

Results

MRI images obtained from 205 patients were used for further analysis. Detailed data of patient characteristics were shown in **Table 1**. Among the total of 2460 one-sided images, MRI was unable to distinguish 105 muscle gaps (35, 17, 28, 5, 9 and 11 from L1 to S1 respectively). Inter observer error in distance averaged ±1.22 mm and intra observer error averaged ±1.08 mm; Inter observer error in angle measurement averaged ±1.32 and intra observer error averaged ±1.01. **Table 2** shows descriptive statistics for measurements of screw trajectory and **Table 3** shows descriptive statistics for sacrospinalis-splitting approach.

Differences between segments

In both genders, as well as in the overall group The AW, d-DW, f-DW, and CW of muscle gaps differed significantly from each other at all segments (P < 0.01).

Differences between genders

Between females and males, d-DW and f-DW significantly differed at all segments (P < 0.01) except S1 while AW differed significantly only at L4 (P < 0.05). The CW significantly (P < 0.05) differed at L3, L4, L5, and S1 and not at L1 or L2 (P > 0.05).

Correlation analysis

BMI significantly correlated with d-DW and but not with f-DW at L1-S1 (P < 0.01).

D-DW significantly correlated with b-DS, from L1 to S1 with correlation coefficients 0.329, 0.432, 0.514, 0.581, 0.602 and 0.491, respectively.

Discussion

Wiltse in 1968 first described the paraspinal sacrospinalis-splitting approach to the lumbar spine. To date, only the distance of superficial points of the intermuscular plane and the midline (f-DW) have been described in Europeans by some articles. In a cadaveric study [21], the lateral cleavage plane distances of 50 cadavers were measured at the level of the spinous process of L4. Findings suggested a range of 24 to 70 mm and a mean lateral distance of 40.4±7.4 mm at the L4 level. At the same level in our study, we observed an f-DW range of 17.21 to 30.90 mm and a mean distance of 19.30±6.70 mm. Ethnic differences were a factor underlying the differences between the two studies. Deformable embalmed cadaver was another important factor. The paraspinal muscle was inevitably pressured and changed in shape,

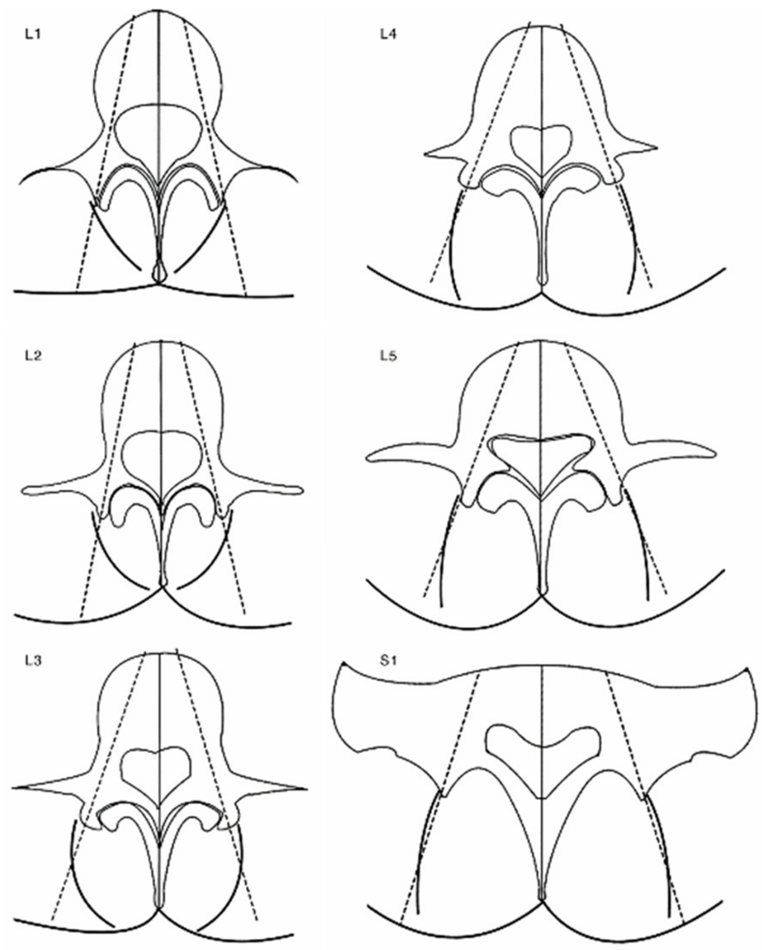

Figure 3. The sacrospinalis-splitting map and optimal pedicle screw trajectory (dotted line) of each segment drawn according to the average measured value.

direction and curvature of the muscle gap in each segment were not the same. It is complex and variable as the maps illustrated in **Figure 3**. It means that if operators are not familiar with the anatomy of the muscle gap, deviation from the gap may happen in the process of blunt dissection which may lead to injury of multifidus and longissimus muscles. According to our measurements, we found the cleavage plane follows some regular pattern in different segments: the simultaneous rotation of the plane around its deepest points to the midline from S1 to L1 and the cleavage plane showed the maximum curvature on L3 segment but minimum curvature and more linear direction at L5 and S1 (**Table 3**). So for spinal surgeons, with a clear understanding of the cleavage plane, the original position of the muscle gap at deep fascia could be easily identified and deviation from the gap may beavoide dintraoperatively.

resulting in inaccurate data. MRI scans avoid such inaccuracies. In addition, a small sample size (50 cadavers) and old cadavers with atrophied muscles [21] may also weaken a study. Another study based on MRI scans of 200 patients measured f-DW [20].

The simple distance measurements of the study were not able to accurately describe the characteristics of the surgical approach.

In our study we found that in a total of 2460 one-sided images, 105 muscle gaps were not distinguishable in MRI images even at the L4 and L5 segments where Wiltse stated that the intermuscular cleavage plane was particularly identifiable [12]. This means muscle gap cannot be clearly identified in some patients, in addition, findings also suggested that location,

We also found BMI was not correlated with f-DW at all segments ($P > 0.05$) and surgeons can apply the distances (f-DW) without concern for BMI, which was the same as Daniel Kyle Palmer's study. In his study, He also suggested that in L1-L3, approaching through a single midline incision would yield better results over a dual-incision paraspinal approach. While in L3-S1, the dual-incision paraspinal approach would be convenient [20]. In our opinion, the choice of skin incision was not only related to f-DW but also to surgical exposure range. Therefore, two factors should be considered in determining cutaneous incisions. According to our study, the f-DW and b-DS (**Figure 4**) from L1 to L4 were relatively short, facilitating a middle incision. At L5 and S1, both b-DS and f-DW were significantly increased and far away from the midline. Therefore, a bilateral incision was

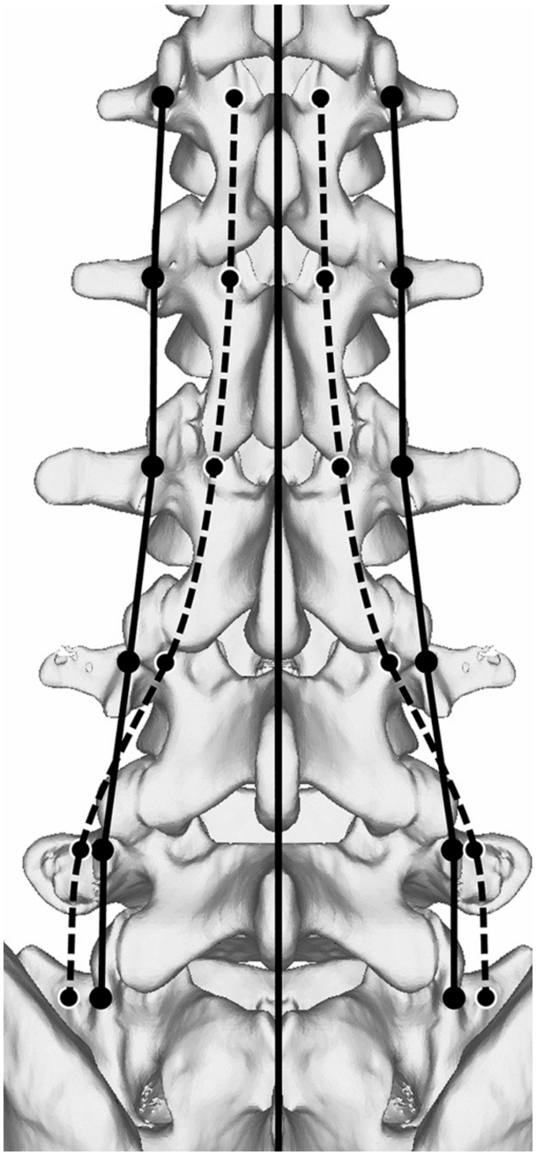

Figure 4. Viewed from the rear: Mean distances of b-DS (Solid line) and f-DW (Dashed line) from L1 to S1.

more appropriate than a middle incision in exposing the surgical field.

Comparing optimal trajectory of pedicle screw and muscle gap, we verified that d-DW and b-DS were highly consistent (**Figure 5**), suggesting that correctly blunt dissection along the muscular gap was to the outer edge of facet joints where is the entry point of the pedicle screw. As shown in **Figure 3**, during the percutaneous implantation of pedicle screw from L1 to L4, the guide pin usually entered into lateral multifidus. The intermuscular surgical approach

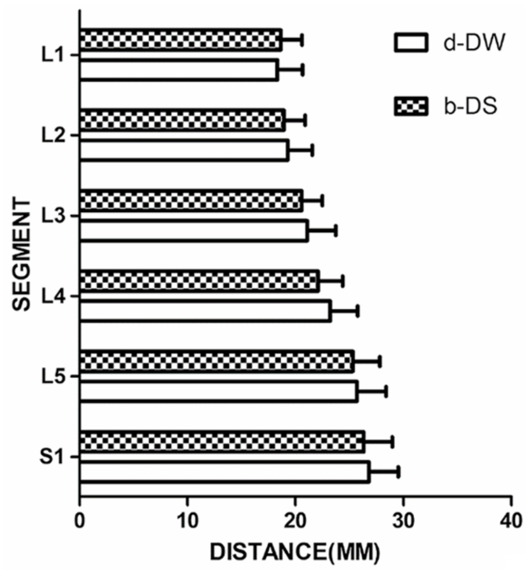

Figure 5. Mean distances of d-DW vs b-DS at each segment. A distance of 0 represents the midline. In every segment, d-DW and b-DS were highly consistent.

was associated with less injury than intramuscular approach. Referring from L1 to L4, using a small skin incision near to spinous process, followed the gap to pedicle screw entry point, then stretching out ward to place pedicle screw should be associated with less injury to longissimus muscle. Our experience showed that stretching outward was convenient, while stretching inward would arise a huge soft tissue tension due to blocking of spinous processes. The muscle gap was near the trajectory of optimal pedicle screwat L5 and S1. Due to minimum curvature and similar direction of AS, a small skin incision or percutaneous approach is also optional.

As the statistical analysis shows, cleavage planes from L1 to S1 are variable. We obtained some regular pattern of cleavage planes based on East Asian anatomical data and mapped each segment (**Figure 3**). Our findings were expected to provide assistance to spine surgeons regarding the correct preoperative incision technique without deviating from Wiltse approach, intraoperatively.

However, too much anatomic variability in patients with degenerative lumbar scoliosis [22], low back pain (LBP) [23] or even in those without a history of LBP [24] made it difficult to get definite conclusions about the utility of MRI analysis for the cleavage planes. Thus, analyzing the patient's lumbar MRI images carefully before surgery to determine the anatomy of interm uscular plane is also vital and desirable.

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Disclosure of conflict of interest

We declare no conflict of interest. The results included in the submission have not been published and is not under consideration for publication in any forms.

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