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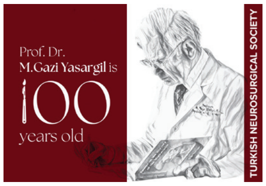

Simplifying Transforaminal Endoscopic Lumbar Discectomy (TELD) Through the Guiding Framework of Ten Landmarks

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ABSTRACT

AIM: To streamline the transforaminal endoscopic lumbar discectomy (TELD) technique to facilitate a shorter learning curve for novice surgeons by providing a comprehensive guide featuring ten crucial landmarks.

MATERIAL and METHODS: In this retrospective study, we reviewed patients diagnosed with lumbar disc herniation who underwent navigational TELD using ten landmarks from September 2021 to October 2022. We compared these patients with those who received conventional TELD from June 2020 to August 2021. A comprehensive account of the TELD surgical procedure, outlining each stage and introducing ten critical landmarks as surgical aids, is presented. Comparative analyses were conducted between the navigational and conventional groups, focusing on operation duration and fluoroscopic exposure.

RESULTS: There were no statistically significant differences observed between the navigational and conventional groups with regard to gender, age, and intraoperative VAS (visual analog scale) scores. The operation time and fluoroscopic exposures in the navigational group were notably reduced, measuring 56.33 ± 9.90 minutes and 4.97 ± 1.53, respectively, compared to 71.73 ± 17.80 minutes and 6.44 ± 1.52 in the conventional group ($p<0.05$). Both groups exhibited no significant disparity in VAS and ODI (Oswestry disability index) scores. Nevertheless, postoperatively, at both 1 day and 3 months, both groups demonstrated lower VAS and ODI scores in comparison to preoperative values. Notably, the scores at 3 months post-surgery were significantly lower than those recorded at 1 day post-surgery ($p<0.05$).

CONCLUSION: The implementation of guiding landmarks significantly streamlines and simplifies the TELD procedure. It substantially decreases operation duration, minimizes fluoroscopy usage, enhances surgical safety, and ensures consistent clinical effectiveness. These landmarks enable novice surgeons to master TELD more easily.

KEYWORDS: Transforaminal endoscopic lumbar discectomy, Lumbar disc herniation, Lumbar spinal stenosis, Navigational

ABBREVIATIONS: TELD: Transforaminal endoscopic lumbar discectomy, **VAS:** Visual analog scale. **ODI:** Oswestry disability index, **LDH:** Lumbar disc herniation, **LSS:** Lumbar spinal stenosis, **SAP:** Superior articular process, **DFLS:** Disk-flavum ligamentum space

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INTRODUCTION

After decades of refinement, spinal endoscopy has undergone remarkable progress, (15,23), advancing from the introduction of YESS technology (25), to the more sophisticated THESSYS technology (22). Transforaminal endoscopic lumbar discectomy (TELD) has evolved from addressing straightforward cases of lumbar disc herniation (LDH) to effectively managing more complex scenarios including migrated LDH (19), calcified LDH (3,4), various types of lumbar spinal stenosis (LSS), and conditions affecting the cervical and thoracic vertebrae (11,15,23). The distinct advantages of TELD—its minimally invasive nature, reduced intraoperative hemorrhage, swift postoperative recovery, and cost-effectiveness—have propelled its increasing adoption worldwide in the realm of spinal surgery (7,13,21). However, owing to the steep learning curve associated with this technique, a significant number of novices may discontinue their learning process prematurely (1,16). While recent years have witnessed a proliferation of reports on TELD technology and the utilization of visual aids, the majority of the literature predominantly focuses on clinical efficacy, with limited attention given to the intricacies of the surgical procedure (9,14,20). To facilitate the comprehension of the surgical technique and enhance the visualization of anatomical structures through endoscopy, the author has devised a set of ten guiding markers based on insights gleaned from over 2000 cases of TELD performed over a decade. Adhering to this marker-based navigation, the procedure can be executed in a systematic manner, thereby simplifying the learning curve and yielding consistently favorable clinical outcomes. The following study is presented to compare the advantages of our approach with traditional TELD surgery.

MATERIAL and METHODS

Statement of Ethics

This study was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. The study was approved by the ethical committee of the Second Affiliated Hospital of Xuzhou Medical University, and informed consent was obtained from patients (NO.XZKWJTZYY-AF-060/02.0).

Participants

In this retrospective study, we examined patients diagnosed with lumbar disc herniation who underwent navigational TELD using ten landmarks between September 2021 and October 2022, and those who received conventional TELD from June 2020 to August 2021. The inclusion criteria were as follows: 1) Unilateral lower limb radiating pain, numbness, or other symptoms attributed to single nerve root compression. 2) Symptoms should align with preoperative imaging, and lumbar disc herniation confirmed by magnetic resonance imaging (MRI). 3) Symptoms remained significantly unresolved after 8 weeks of conventional conservative treatment. Exclusion criteria encompassed: 1) Lumbar spinal infection, tumor, or spinal deformity. 2) Lumbar segmental instability. 3) Incomplete data or noncompliance with rehabilitation exercises. The criteria were based on clinical experience and refer to Wang et al (24).

Surgical Procedure

In accordance with the preoperative preparations and procedural steps, we have delineated and consolidated ten specific operational landmarks. These ten markers are systematically aligned with the surgical protocol, facilitating the expeditious and secure execution of transforaminal endoscopic lumbar discectomy (TELD). The detailed elucidation is as follows.

The first marker: Preliminary confirmation of the intervertebral space based on the iliac crest (Figure 1)

Preoperative lumbar MRI, CT scans, and radiographs should be standard procedure. The radiographic data was meticulously analyzed to establish the relationship between the intervertebral space and the highest point of the iliac crest (5,6). For cases involving the lumbar 4/5 region, it's common for the highest point of the iliac crest to align with the intervertebral space. By palpating and confirming the intervertebral space against the highest point of the iliac crest, a preliminary mark is made on the lower back. Subsequently, taking into account factors such as the patient's body weight, waist circumference, height of the iliac crest, protrusion site, and the direction of migrated discs, the primary entry point is identified and marked.

The second marker: Confirmation of intervertebral space by metal-rod fluoroscopy (Figure 2)

The metal rod was secured in place using a vascular clamp, positioning the clamp's tip upwards in alignment with the target intervertebral space. This placement on the surgical side aided in orienting the rod for fluoroscopic imaging.

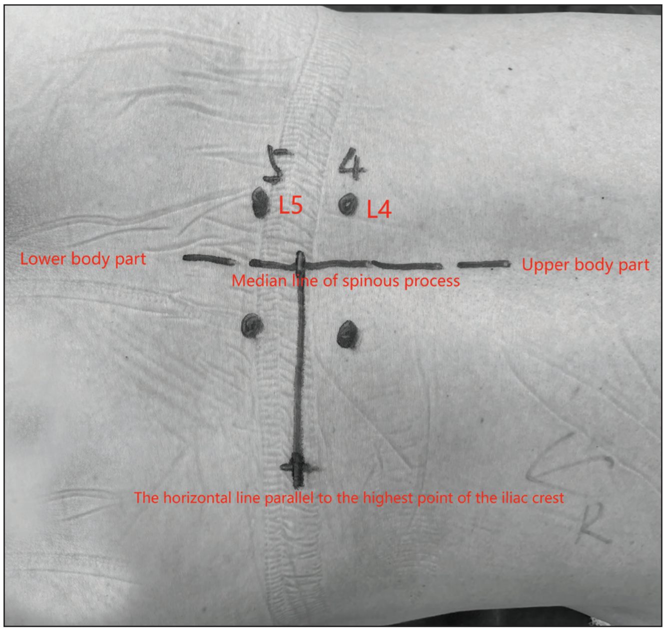

Figure 1: The parallel line of the iliac crest height and the surface marking line of spinous process. The highest point of the iliac crest typically aligns with the L4/L5 intervertebral space. To reference this, draw a horizontal line perpendicular to the body, intersecting the highest point of the iliac crest. Then, draw a vertical line parallel to the body along the direction of the spinous processes.

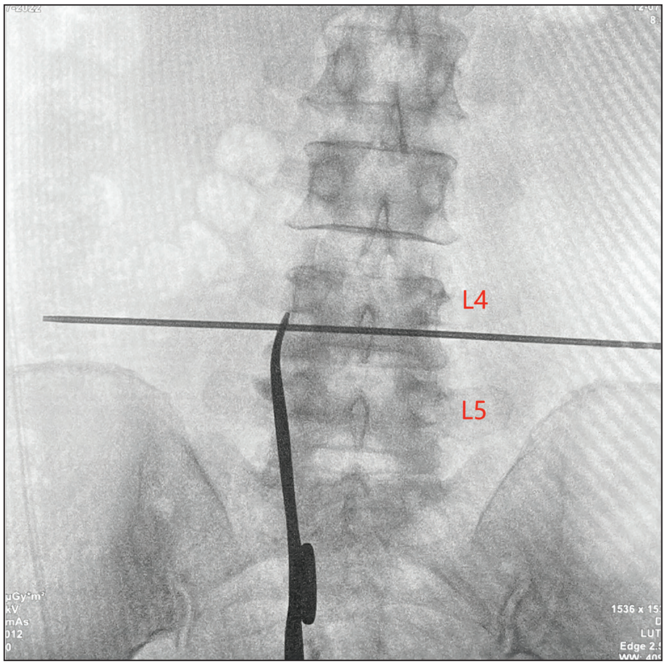

Figure 2: The fluoroscopy of metal-rod and intervertebral space. After placing the metal rod, perform X-ray fluoroscopy to determine the location of the intervertebral space.

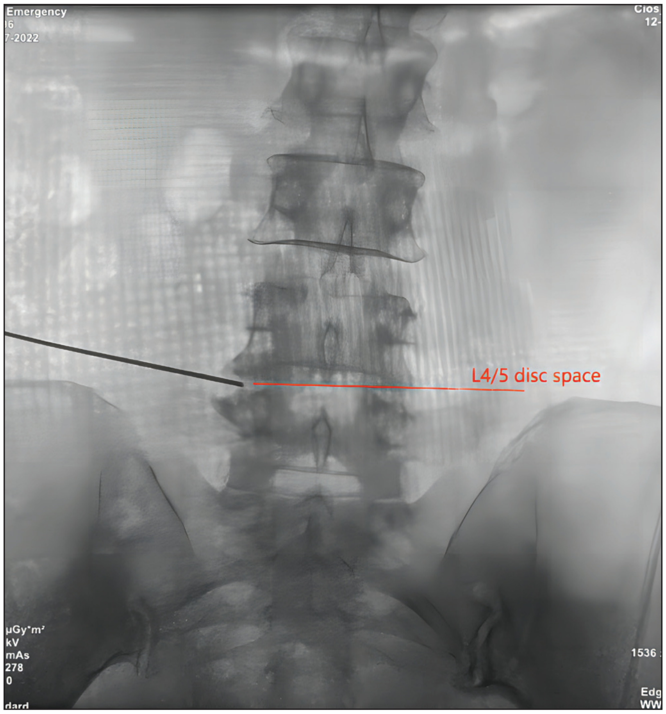

Figure 3: The fluoroscopy of puncture needle and intervertebral space. Advance the puncture needle while gradually injecting local anesthetic until it reaches the bony surface. Then perform X-ray fluoroscopy again to confirm the position of the puncture needle in relation to the intervertebral space.

Taking into account the patient's body weight, waist circumference, height of the iliac crest, protrusion site, and direction of displacement, the optimal entry point was determined and clearly marked. The authors advocate for specific distances from the midline of the spinous process for the puncture point, as follows: 7-9cm for L5/S1, 7.5-9.5cm for L4/5, and 6-7.5cm for the upper lumbar region.

The third marker: The puncture needle reconfirms the intervertebral space (Figure 3)

After meticulously preparing local anesthetic drugs, the skin and subcutaneous tissue were locally anesthetized. Subsequently, an 18-gauge spinal puncture needle, measuring 150mm in length, was employed to puncture the lateral surface of the superior articular process (SAP) at an angle of 40° to 50° relative to the coronal plane and 10° to 30° relative to the horizontal plane, ensuring contact with the bone surface. This specific location was denoted as the "Extraforaminal Landing" by Ahn et al. (2). To validate the accuracy of the procedure, fluoroscopy was once again utilized to confirm the precise positioning of the needle tip in relation to the intervertebral space.

The fourth marker: "L" point at the base of SAP (Figure 4)

At the ventral base of the superior articular process (SAP) and along the superior edge of the pedicle, an anatomical "L-shaped" inflection point is formed (12). This constitutes the lower inner vertex of the safety triangle (10) and represents the most secure operational position. The incision at the skin's entry point measures approximately 8 mm. For the L5/S1

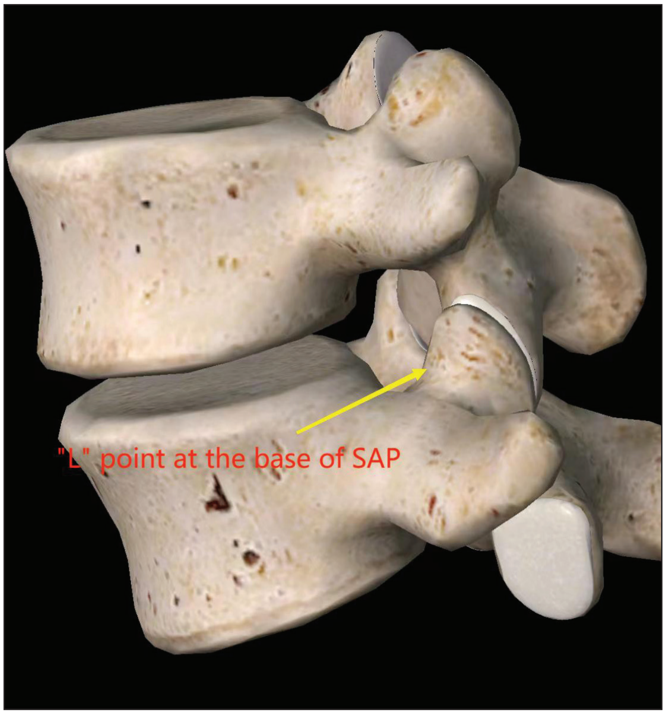

Figure 4: The "L" point at the base of SAP. In the anatomical model, the "L" point can be observed at the ventral base of the SAP and along the superior edge of the pedicle. SAP: superior articular process.

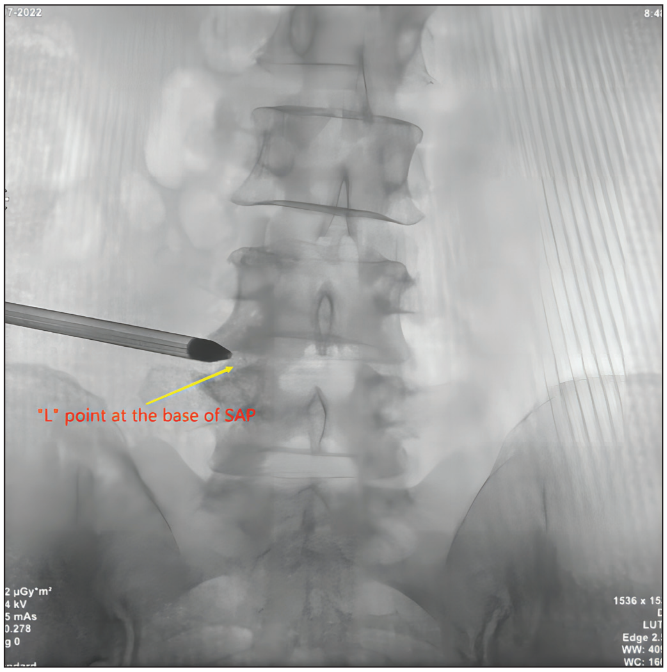

Figure 5: The anteroposterior fluoroscopy of guide rod and intervertebral space. After the guide rod is punctured to the L point, bluntly dissect the soft tissue and use X-ray to confirm the position of the guide rod in relation to the intervertebral foramen, ensuring it is located at the lower part of the foramen.

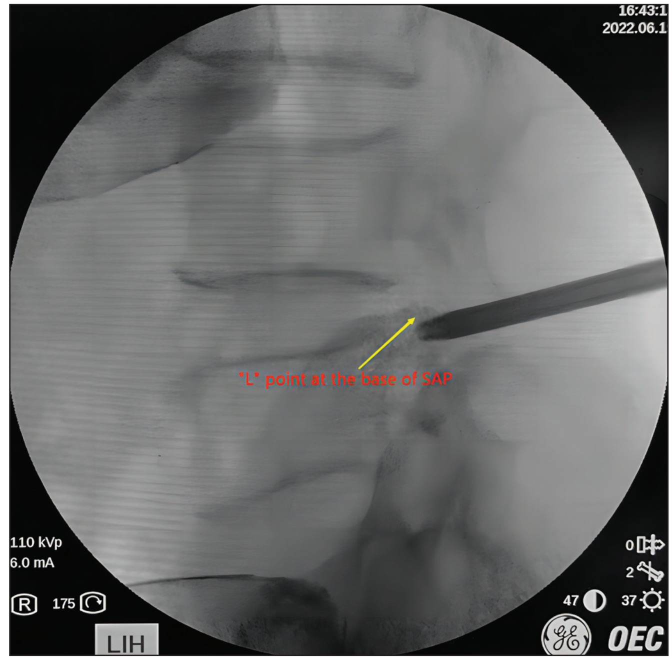

Figure 6: The lateral fluoroscopy of guide rod and intervertebral space. Confirm the position of the guide rod and the intervertebral foramen again using a lateral X-ray.

segment, a diagonal incision is made along the upper border of the iliac crest, while other segments are incised horizontally. The guide rod's orientation is adjusted in accordance with the trajectory of the puncture needle, ensuring its insertion to the "L" point. The guide rod's tip is then methodically maneuvered along the lateral edge of the SAP, facilitating the separation of soft tissue surrounding the SAP for enhanced clarity. An anteroposterior X-ray fluoroscopy (Figure 5) is conducted to confirm the precise positioning of the guide rod tip, verifying its placement just below the foramen. If necessary, the C-arm can be repositioned for lateral fluoroscopy (Figure 6) to further validate the guide rod tip's position.

The fifth marker: Smooth section of SAP (Figure 7)

Based on the endoscopic view of the anatomical structure, the lateral aspect of the superior articular process (SAP) was classified into three sections from top to bottom: the apical region, the swollen region, and the smooth region. The smooth region serves as a transitional area between the base of the SAP and the pedicle. It exhibits a firm bony texture and a sleek lateral surface, making it readily discernible under the endoscope. The working sleeve was carefully inserted into the designated target point, ensuring that the notch of the working cannula was oriented towards the lateral edge of the medial SAP.

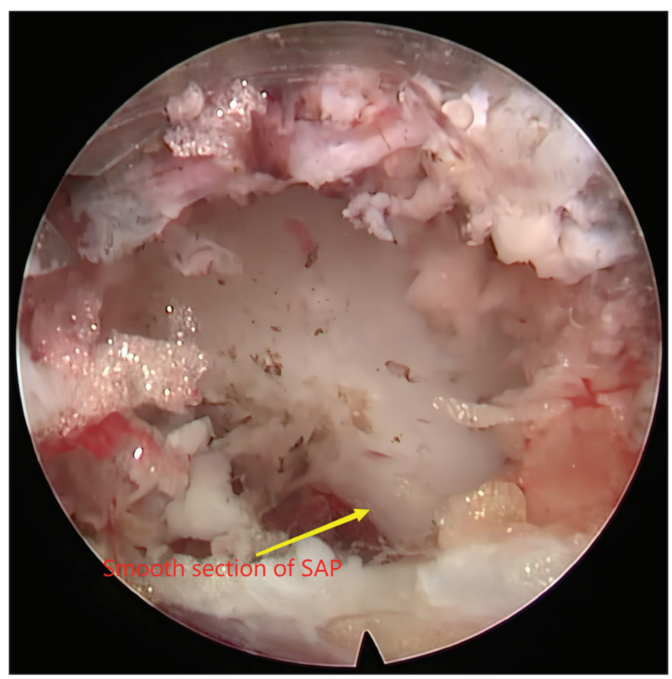

Figure 7: The smooth section of SAP (superior articular process) under the endoscope. Under the endoscope, identify the transition area between the base of the SAP and the pedicle, characterized by harder bone and a smooth lateral surface, to clearly determine the location under the endoscope. SAP: superior articular process

Subsequently, the visual ring saw was introduced into the cannula. The nucleus pulposus forceps were employed to meticulously clear the soft tissue on the lateral side of the foramen. Utilizing radiofrequency, the lateral side of the SAP was ablated to reveal the smooth section, which, when viewed under the endoscope, exhibited a distinctive “half-moon” shape. This allowed for access to the apex, the bulging area of the SAP, or the upper edge of the pedicle, facilitating further enlargement as needed (26).

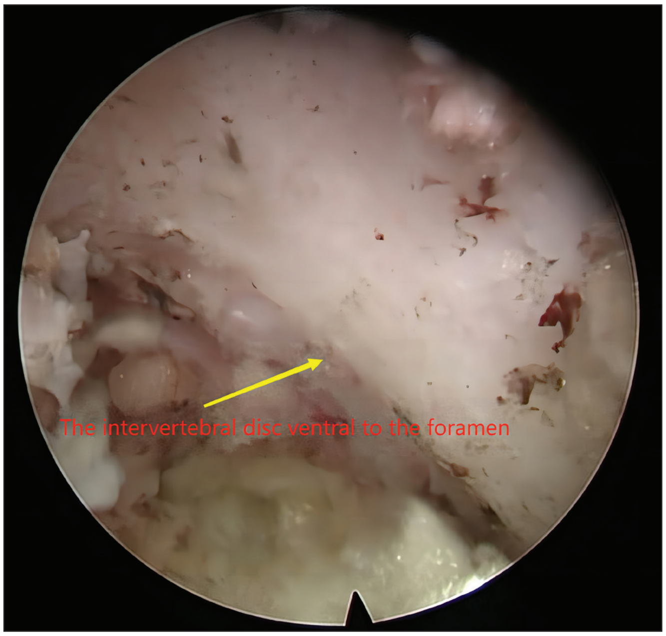

Figure 8: The intervertebral disc ventral to the foramen under the endoscope. Advance the working cannula ventrally to locate the intervertebral disc on the ventral side of the intervertebral foramen.

The sixth marker: The intervertebral disc ventral to the foramen (Figure 8)

The working cannula was gently advanced ventrally, and the soft tissue was meticulously cleared using nucleus pulposus forceps and radiofrequency, revealing the posterior edge of the disc. This area typically presented as a distinct white hue under the endoscope, setting it apart from surrounding tissues. Once the intervertebral disc was adequately exposed, the next steps were guided by the predetermined surgical plan, with reference to preoperative imaging to precisely determine the position of the endoscopic surgical target.

The seventh marker: First formed bony tunnel (Figure 9)

According to the location of the target, the ventral portion of SAP was excised for the first foraminoplasty. The front of SAP was exposed under the microscope, and the top of the working cannula was on the outside of SAP. The visual trephine resists the outer edge of the SAP, and the SAP account for half or two-thirds trephine. the first shaping is very important, and the bony tunnel left behind will serve as an important signpost to indicate the direction of the next operation. After the trephine drilled 2 to 3mm into the SAP bone structure, the working cannula was ventrally pushed down, and the ring saw and the ring saw continued rotating. After the trephine was drilled through the bone block, the bone block was separated and rotated simultaneously with the trephine (like unscrewing a bottle cap). After the bone mass in the ring saw was removed, the osseous tunnel and ligamentum flavum were seen under the endoscope. The ligamentum flavum acts as a natural barrier for protection, so visual shaping does not damage the nerve structure.

Figure 9: First formed bony tunnel under the endoscope. The initial formation of the SAP process determines the position and direction of the subsequent bone path and also marks the location for subsequent operations, facilitating localization under the endoscope. SAP: superior articular process.

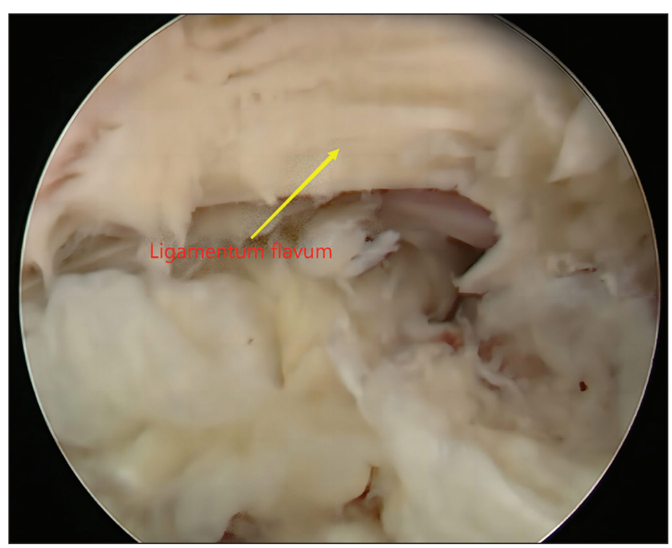

Figure 10: The ligamentum flavum under the endoscope. After the formation of the SAP, the ligamentum flavum will be visible under the endoscope. In most cases, the ligamentum flavum appears as light yellow and dark yellow in color.

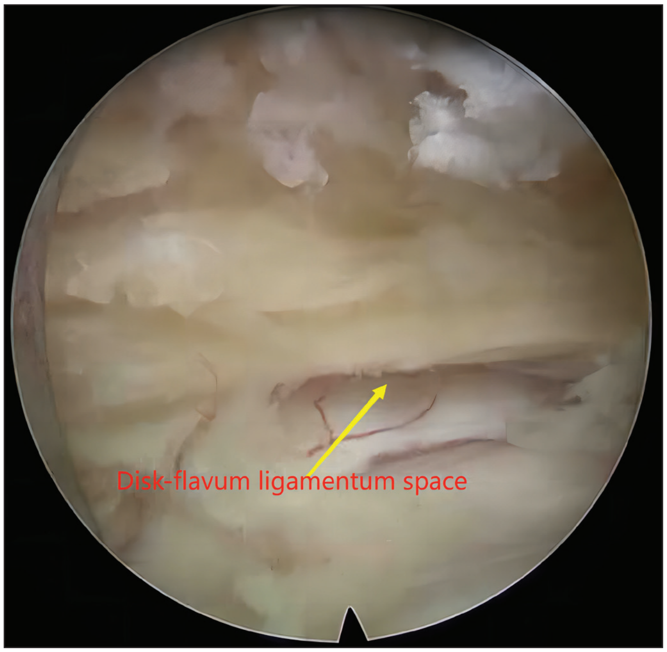

Figure 11: The disk-flavum ligamentum space under the endoscope. By moving the working cannula outward, we can disk-flavum ligamentum space between the lateral edge of the ligamentum flavum and the ventral intervertebral disc, which also helps define the safe operating area.

The eighth marker: Ligamentum flavum (Figure 10)

Following foraminoplasty, the ligamentum flavum becomes visible under the endoscope. Foraminoplasty alone allows for visualizing the ligamentum flavum in approximately 30% to 70% of cases. It's important to note that the color and thickness of the ligamentum flavum vary with age. In younger patients, it appears as a thin, light-yellow structure, whereas in elderly individuals, it tends to be thicker and darker yellow. Accurately discerning this anatomical landmark is crucial for conducting safe operations around nerve roots and serves as a prerequisite for effective nerve decompression.

The ninth marker: disk-flavum ligamentum space(DFLS) (Figure 11)

Once the ligamentum flavum is visualized endoscopically, the working cannula is carefully maneuvered outward to gain a clear view of the lateral boundary of the ligamentum flavum, the ventral disc, and the natural space between them - known as the Dorsal Foraminolateral Space (DFLS). It is imperative to exercise caution to prevent any inadvertent damage to neural structures.

For a secure approach, it is advisable to expose the DFLS from the caudal side of the intervertebral space, which is situated at the base of the safety triangle. The working cannula is then gently rotated to achieve full exposure of the DFLS and the lateral margin of the ligamentum flavum. Subsequently, the ligamentum flavum is methodically excised to completely unveil the neural structures concealed beneath it (Figure 12). These neural structures may encompass either the traversing nerve root or the lateral boundary of the dural sac.

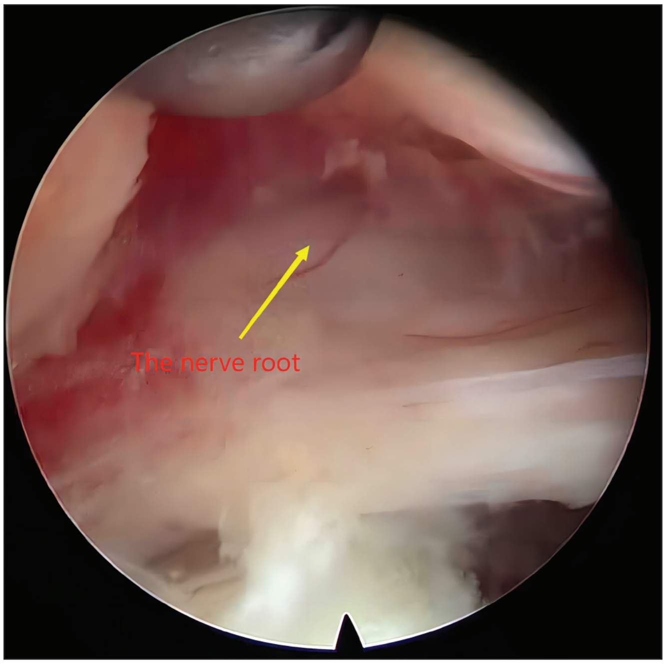

Figure 12: The ligamentum flavum was lifted and the nerve root was seen under the endoscope. The nerve root is covered by the ligamentum flavum. By removing the outer edge of the ligamentum flavum and lifting the covering ligament, the underlying nerve root can be visualized.

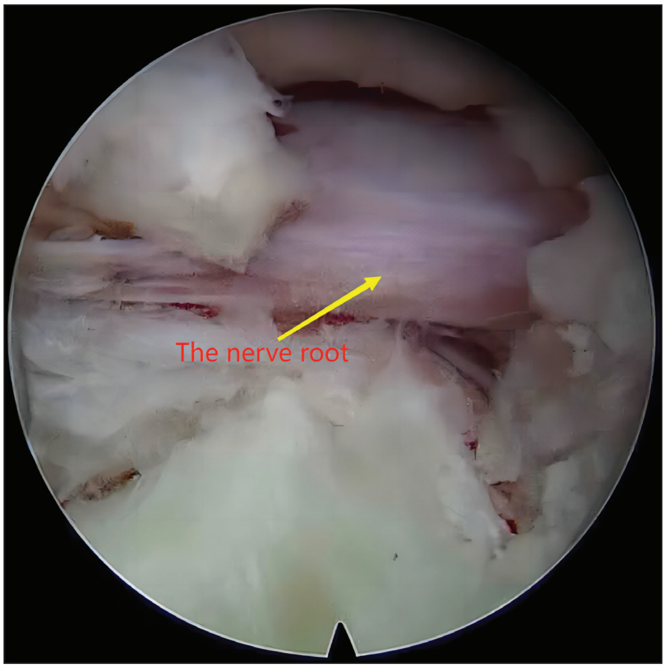

Figure 13: The outer edge of the nerve root under the endoscope. Removing the hypertrophied ligamentum flavum to expose the nerve root allows for safer and more effective surgical procedures. Once the position of the nerve root is clearly identified, it is possible to more thoroughly remove the tissues that are compressing the nerve root.

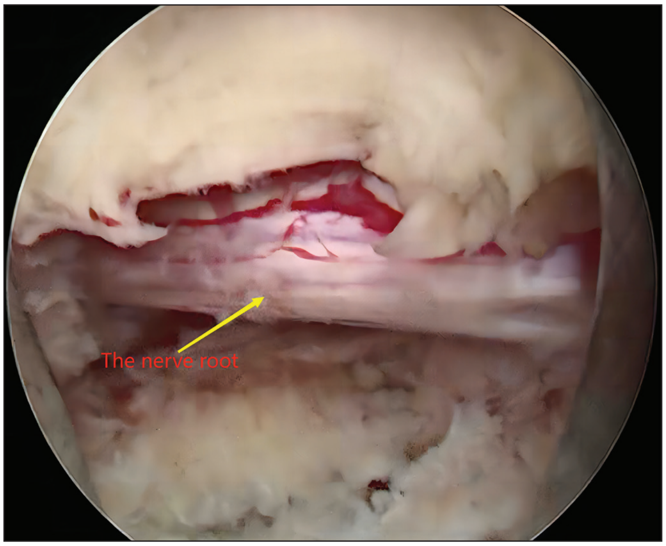

Figure 14: The nerve structure can be seen free from oppression and beating freely under the endoscope. After adequate decompression of the nerve root, it can be seen freely pulsating under the endoscope due to the flow of fluid. If the nerve root is under pressure, it will not pulsate.

The tenth marker: The outer edge of the nerve root (Figure 13)

Following a systematic and gradual resection of the ligamentum flavum, the nerve roots come into clear view under the endoscope. This visual confirmation of the nerve structure helps prevent any potential nerve damage that could occur with blind manipulation.With precision, the ventrally herniated intervertebral disc and proliferative osteophytes are removed, allowing for a focused approach towards the central spinal canal for decompression. The notch of the working cannula is then adjusted dorsally to carefully separate the compressed tissue from the neural structure. Various specialized endoscopic decompression tools, such as the endoscopic bone knife, endoscopic ring saw, punch forceps, and flexible nucleus pulposus forceps, are employed to effectively remove the compressed tissue.This technique permits the removal of migrated discs, calcified discs, or even the application of a comprehensive 270° decompression for severe Lumbar Spinal Stenosis (LSS). In cases involving LSS with degenerative spondylolisthesis, the posterior upper edge of the lower vertebral body can be carefully removed by exerting downward pressure on the working cannula.The decompression process extends across the midline to the contralateral side, achieving thorough decompression in zones 1, 2, 3, and 4, until a satisfactory level of decompression is achieved (18). At this point, the nerve structure is observed to pulsate freely (Figure 14).

Statistical Analysis

T-test was applied to analyze VAS, ODI, age, operation time, and the frequency of X-ray fluoroscopy. And a chi-square test was performed to determine gender. All data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 25 (IBM, USA). When p value is less than 0.05, the results are considered to be significant.

RESULTS

In the navigational group, the male gender accounted for 33 individuals (55.00%), with an average age of 59.03 ± 16.60 years. The Visual Analog Scale (VAS) score during surgery was reported as 7.75 ± 0.95. In the conventional group, there were 25 individuals (45.45%) identified as male, with an average age of 57.45 ± 16.94 years and a VAS score of 7.42 ± 1.01. However, these differences were not statistically significant ($p>0.05$).

The navigational group had a shorter operation time of 56.33 ± 9.90 minutes and a lower average number of fluoroscopic exposures during surgery (4.97 ± 1.53) compared to the conventional group, which had an operation time of 71.73 ± 17.80 minutes and an average of 6.44 ± 1.52 fluoroscopic exposures. These differences were statistically significant ($p<0.001$) , as shown in Table I.

In the navigational group, the VAS scores before surgery, 1 day after surgery, and at 3 months post-surgery were 7.62 (±0.83), 2.08 (±0.67), and 1.27 (±0.48), respectively. In the conventional group, the VAS scores before surgery, 1 day after surgery, and at 3 months post-surgery were 7.51 (±0.98), 2.33 (±1.06), and 1.51 (±1.03), respectively. There was no statistically significant difference between the two groups, but in both groups, the VAS scores at 1 day and 3 months post-surgery were lower than the preoperative values. Additionally, the VAS score at 3 months post-surgery was lower than the score at 1 day post-surgery, and this difference was statistically significant ($p<0.05$).As for the ODI (Oswestry Disability Index) scores, in the navigational group, the scores before surgery, 1 day after surgery, and at 3 months post-surgery were 80.10 (±6.12), 22.43 (±7.84), and

Table I: The Data Compared Between Navigational and Conventional TELD Group

	Male gender	Age(years)	VAS during operation	Operation time (minute)	Frequency of X-ray fluoroscopy
Navigational group (n=60)	33 (55%)	59.03 ± 16.60	7.75 ± 0.95	56.33 ± 9.90	4.97 ± 1.53
Conventional group (n=55)	25 (45%)	57.45 ± 16.94	7.42 ± 1.01	71.73 ± 17.80	6.44 ± 1.52
t/χ^2	1.046	0.504	1.813	5.792	5.156
p-value	>0.05	>0.05	>0.05	**<0.001**	**<0.001**

***TELD:** Transforaminal endoscopic lumbar discectomy. P<0.05, the difference was considered significant.*

Table II: The Segment Compared Between Navigational and Conventional TELD Group

	L2/3	L3/4	L4/5	L5/S1
Navigational group (n=60)	2 (3.33%)	3 (5.00%)	30 (50.00%)	25 (41.67%)
Conventional group (n=55)	1 (1.81%)	4 (7.27%)	26 (47.27%)	24 (43.64%)
χ^2	<0.001	0.014	0.085	0.046
p-value	1.000	0.905	0.770	0.831

***TELD:** Transforaminal endoscopic lumbar discectomy. P<0.05, the difference was considered significant.*

Table III: The VAS and ODI of Navigational and Conventional TELD Group at Preoperative, Postoperative 1 Day and 3 Months

		preoperative	postoperative 1 day	postoperative 3 months	p-value
VAS	navigational group	7.62 (±0.83)	2.08 (±0.67)*	1.27 (±0.48) *#	**<0.05**
	conventional group	7.51 (±0.98)	2.33 (±1.06) *	1.51 (±1.03) *#	**<0.05**
ODI	navigational group	80.10 (±6.12)	22.43 (±7.84) *	19.80 (±6.01) *#	**<0.05**
	conventional group	77.80 (±12.01)	23.78 (±8.43) *	20.47 (±6.62) *#	**<0.05**

***VAS:** Visual analogue scale, **ODI:** Oswestry disability index., **TELD:** Transforaminal endoscopic lumbar discectomy. ***:** The difference was statistically significant compared with preoperative, **#:** The difference was statistically significant compared with postoperative 1 day. P<0.05, the difference was considered significant.*

19.80 (±6.01), respectively. In the conventional group, the scores before surgery, 1 day after surgery, and at 3 months post-surgery were 77.80 (±12.01), 23.78 (±8.43), and 20.47 (±6.62), respectively. There was no statistically significant difference between the two groups, but in both groups, the ODI scores at 1 day and 3 months post-surgery were lower than the preoperative values. Additionally, the ODI score at 3 months post-surgery was lower than the score at 1 day post-surgery, and this difference was statistically significant (p<0.05), as shown in Table II.

DISCUSSION

Transforaminal endoscopic lumbar discectomy (TELD) has emerged as the foremost approach in alleviating pain for patients suffering from lumbar disc herniation or spinal stenosis. This minimally invasive procedure offers distinct advantages over traditional surgery, such as swifter recovery and reduced invasiveness (8,17). Based on the patients' VAS and ODI data in Table III, it can be observed that the patients achieved a satisfactory surgical outcome postoperatively. Inexperienced practitioners often encounter challenges in swiftly mastering the operational protocols. This predicament primarily stems from their limited familiarity with identifying tissues under the endoscope, leading to uncertainties in localizing target areas. Consequently, this lack of proficiency contributes to prolonged surgical durations and heightened fluoroscopic exposures during the procedure. Drawing from our experience, integrating discernible landmarks at each phase of the procedure facilitates smoother execution, resulting in a significant reduction in both surgical time and fluoroscopic exposures, as demonstrated in Table I. The adoption of a local anesthesia approach for our surgical cases effectively trims down the surgical duration, thereby minimizing patient discomfort and post-operative pain, ultimately enhancing overall satisfaction with the procedure. Furthermore, the reduction in fluoroscopic exposures translates to diminished radiation exposure for both patients and the surgical team, fostering a safer surgical environment and yielding additional time efficiencies.In addition to the reduction in surgical time, precise identification of anatomical structures under the endoscope is imperative to prevent inadvertent damage to nerves and blood vessels. While neither of the surgical procedures in this study resulted in nerve or vascular injuries, it is noteworthy that the surgeons were already adept in traditional surgical techniques. However, with the implementation of enhanced navigational guidance through landmark selection, further reductions in surgical time and fluoroscopic exposures were observed.It is essential to note that our reported surgical time encompasses the entire process, including patient disinfection, local anesthesia administration, confirmation of the surgical field under X-ray, and assembly of various equipment for the transforaminal endoscope. Consequently, our reported surgical time may be slightly longer compared to studies that exclude these initial preparation steps

CONCLUSION

In summary, the systematic use of the ten identified landmarks offers a structured and simplified approach for performing exposure, shaping, and decompression in TELD procedures. This method not only reduces surgical duration, minimizes fluoroscopy use, and enhances surgical safety, but also ensures favorable clinical outcomes. Furthermore, it streamlines the application of TELD technology and accelerates the learning process for novice surgeons.

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Declarations

Funding: None.

Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: JYL, LQ

Data collection: QH

Analysis and interpretation of results: QH, ML, LQ

Draft manuscript preparation: JYL, XT, HL

Critical revision of the article: QH, ML

All authors (JYL, QH, ML, XT, HL, LQ) reviewed the results and approved the final version of the manuscript.

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