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Quantitative Anatomic Analysis and Clinical Application of Lumbar Spinous Process Split Laminotomy

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ABSTRACT

AIM: To investigate the feasibility and safety of lumbar spinous process split laminotomy by quantitative anatomic analysis.

MATERIAL and METHODS: Nine fresh adult human cadaveric specimens (including 45 lumbar segments) were divided into 3 groups randomly. The simulated operations and anatomic measurements were performed to evaluate the visibility angle and surgical corridor at different retraction widths (8 mm, 10 mm, and 12 mm). By measuring the width causing bony fracture in 45 lumbar segments, the safety margin of retraction width was determined. The findings of lumbar spinous process split laminotomy in one typical case were presented.

RESULTS: At 8 mm retraction width, there was not enough surgical corridor for the operation procedures. At 10 mm and 12 mm retraction width, all operation procedures could be conducted smoothly. The 12 mm group presented a larger surgical corridor and shorter operative time compared with the 10 mm group. The imaging examination confirmed no bony fracture and articular capsule impairment. The visibility angle and exposure extent increased in proportion to the retraction width. The retraction width that resulted in the bony fracture ranged from 12.34 mm to 16.82 mm, with an average of (14.56 ± 1.73) mm. The positions of fracture were in the pedicle of the vertebral arch (68.9%), the lamina (26.7%), and the vertebral body (4.4%).

CONCLUSION: The retraction width of 10 mm-12 mm is safe and effective. The micromanipulations such as tumor resection, nervous exploration, dural suture, etc. can be conducted smoothly via the surgical corridor. In addition, the retraction width of 12.34~16.82 mm could serve as a safety margin for surgical planning. Our findings may provide a quantitative reference for clinical application of lumbar spinous process split laminotomy.

KEYWORDS: Split laminotomy, Anatomic research, Simulated operation, Spinous Process

ABBREVIATIONS: SPSL: Spinous Process Split Laminotomy

INTRODUCTION

Surgical treatment of lesions in the spinal canal is challenging because of the surrounding bony structures. Sufficient exposure is a prerequisite for effective surgical operation. The lumbar vertebrae bear great pressure from the upper trunk and transmit gravity force to the pelvis (20). Therefore, the balance between surgical exposure and vertebral stability is an inevitable challenge during the classical surgical approaches, such as laminectomy, semi-laminectomy, laminotomy, etc. (7,10-13). Considering the postoperative recovery period and complications, a novel minimally invasive

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approach is necessary. The spinous process split laminotomy (SPSL) causes less damage to the muscle attachments and bony structures (3,5). Our team has performed SPSL in several cases to remove intracanal lesions; however, the reliable criteria of split width are still unknown (16,17,21). The quantified study on the surgical corridor and the retraction safety margin of SPSL has been rarely reported. Herein, we addressed this issue by using human cadaveric specimens. Our finding may provide anatomical measurement data for clinical application of SPSL.

MATERIAL and METHODS

The review committee agreed to this research project on May 30, 2022 (Jiangsu Hospital).

Surgical Tools

The simulated operation and measurements were carried out using a digital camera (Nikon Coolpix S570, Japan), lamina retractors (Medicon eG, Germany, Figure 1), spine-surgery instruments (provided by Department of Human Anatomy, Fudan University, China), high speed drill system (Midas Rex Legend, Medtronic, US), surgical microscope (Carl Zeiss, Germany), C-Arm (GE OEC, US), CT Scanner (GE, US), and measuring tools.

Characteristics of Human Cadaveric Specimens

Nine fresh adult human cadaveric specimens from the Department of Human Anatomy, Fudan University were used in this study. There were no medical histories regarding pathological changes or surgical operations to the spine and nearby structures, according to the medical records and X-ray scan before dissection.

Simulated Operation

The 9 specimens were randomly divided into 3 groups based on the retraction widths of 8, 10, and 12 mm, which was determined according to our previous studies (16,17,21). The operation procedures were the same in 3 groups, except for the retraction width of the spinous process. In detail, the specimens were positioned prone and incised longitudinally along the posterior midline layer by layer. After dissecting the skin, fascia, muscle, and ligament, the spinous processes were exposed, while the muscle attachments on the vertebrae were preserved. Then, the spinous process was split with a craniotome, leaving a 3 mm fissure between the two separated parts. Two retractors were set in position to separate the laminae and processes. The retractors were opened gently until the preset retraction width was reached. The ligamentum flavum covering the target region was removed to expose the dura mater. The dura mater was incised along the midline and then dural tenting sutures were made to maintain exposure. The border of the cauda equina was explored in every direction. The surgical corridor and exposure extent were measured. The dura mater was sutured in a watertight manner. The operation time of each step was recorded (Figure 2). CT scan was performed in one specimen of each group randomly. The 3D models were reconstructed at four time points: before the operation, after splitting of the spinous processes, after placing the retractors, and after operation, to exclude bony fracture of laminae and vertebral arch (Figure 3).

Figure 1: The retractors used in this study.

Anatomical Measurements

Totally, 45 lumbar vertebrae of 9 specimens were measured. Two Kirschner wires (Wire 1 and Wire 2) were used to define the visibility angle. The sharp tip of the Kirschner wire penetrated connective tissue and reached the anterior wall of spinal canal along the visibility angle of bilateral borders. The visibility angle was limited by the splitting of the spinous processes. The contact points of the Kirschner wire on bony structures were defined as C, F, A (Wire 1) and D, E, B (Wire 2) in order of sharp to blunt. The intersection of two wires was named as Point O. According to the direct measurement values of AC, BD, AB, OC, and OD, the length of AO, BO, CD and the angle degree of $\angle COD$ could be determined. $\angle COD$ was used to describe the visibility angle, while the length of CD was used to measure the exposure extent of the anterior canal wall (Figure 4).

Safety Margin of Retraction Width

To define the safety margin of retraction width, the retractor width was increased gently until fracturing. The fracture width and positions were recorded.

Statistical Methods

The data was recorded and processed initially using Microsoft Excel 2010. Statistical analysis was performed by using SPSS 24.0. The measurement data were presented as means ± standard deviations. Comparisons among groups were performed using variance analysis. The SNK-q test was used to perform pairwise comparisons between groups. A p-value<0.05 was considered as statistically significant.

RESULTS

In surgical simulation, it was difficult to perform the nervous exploration and dural suture in the surgical corridor with a retraction width of 8 mm. When the retraction width was

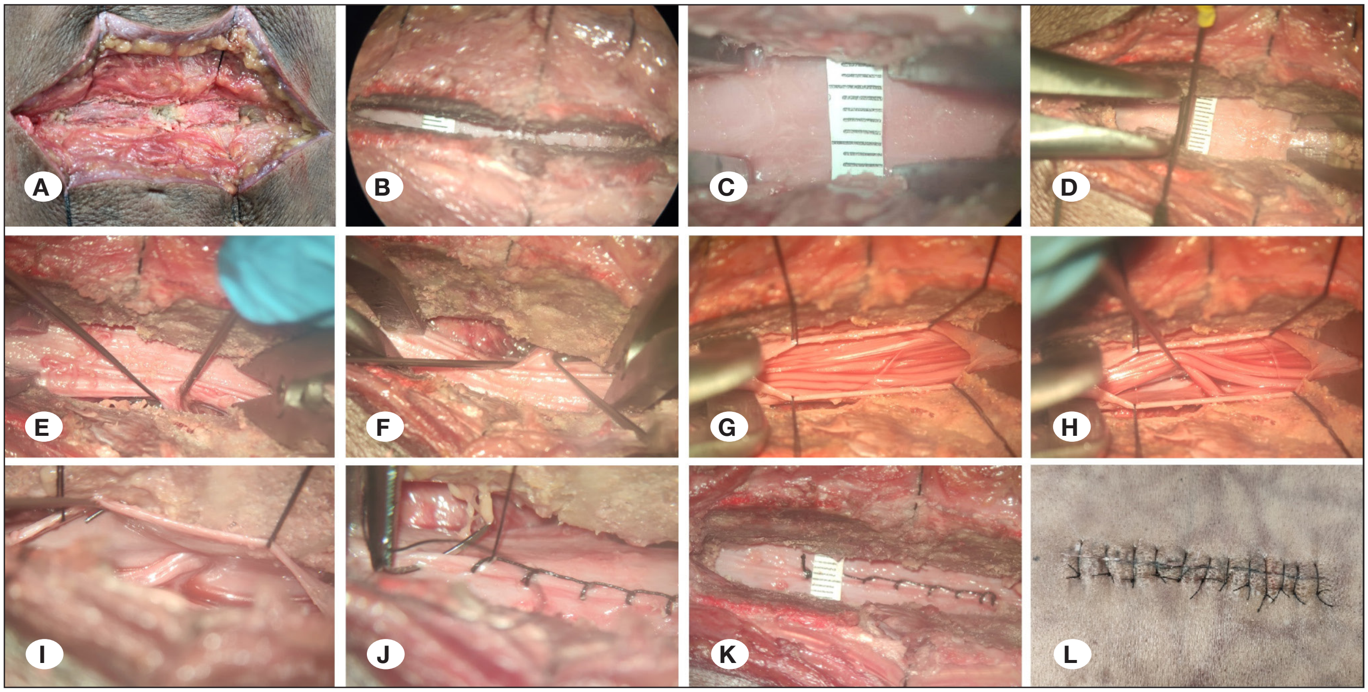
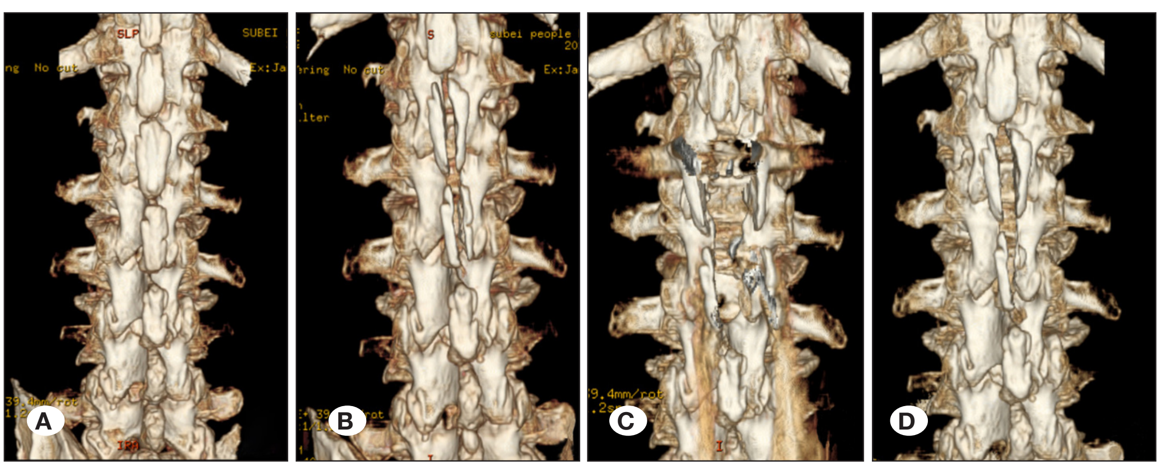


Figure 2: The procedures of simulated operation. **A)** The 2nd`3rd lumbar segment was located and the spinous process was exposed. **B)** The spinous processes were split with craniotome. **C)** The retractors were set in position and the fissure was expanded to preset width. **D)** Measurement of visual angle and exposure extent. **E)** Exploration of the spinal nerve sheath on the left side. **F)** Exploration of the spinal nerve sheath on the right side. **G)** Dural tenting suture. **H)** Exploration of the cauda equina and left intervertebral foramen. **I)** Exploration of the right intervertebral foramen. **J)** Dural suture in water-tight manner. **K)** Removal of retractors and elastic restoration of spinous process. **L)** The layer was closed.



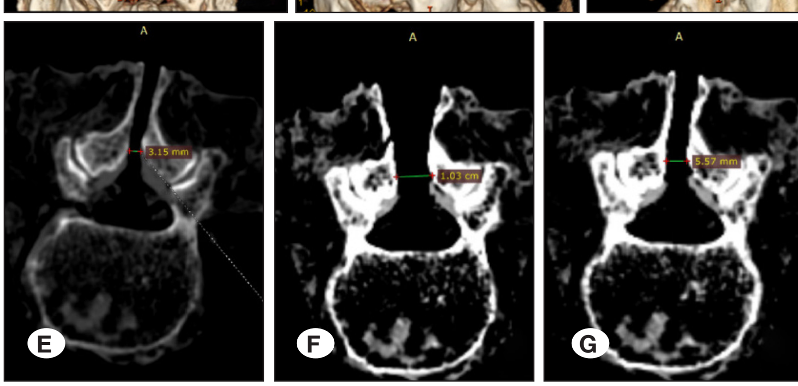


Figure 3: CT and 3D reconstruction at different time points. **A)** Before operation. **B and E)** After spinous processes splitting. **C and F)** Retractors in position. **D and G)** After operation.

Table I: Maximum Visibility Angle (∠COD) of 3 Retraction Levels ($\bar{x}$ ±s,°,n=3)

Group	L1	L2	L3	L4	L5	L1~5
8 mm	50.06 ± 1.91	49.27 ± 2.83	46.30 ± 2.10	48.03 ± 1.91	52.21 ± 2.83	49.93 ± 2.61
10 mm	57.95 ± 3.00	54.82 ± 2.13	53.30 ± 2.06	54.85 ± 1.85	56.89 ± 2.15	55.56 ± 2.74
12 mm	63.64 ± 2.40	62.67 ± 2.44	61.07 ± 1.93	62.36 ± 2.17	64.63 ± 1.25	62.87 ± 2.33

Table II: Maximum Exposure Extent (CD) of 3 Retraction Levels ($\bar{x}$ ±s,mm,n=3)

Group	L1	L2	L3	L4	L5	L1~5
8 mm	18.37 ± 1.02	17.83 ± 1.63	16.02 ± 1.22	17.19 ± 1.36	19.38 ± 1.46	18.23 ± 1.45
10 mm	22.99 ± 1.71	21.49 ± 1.50	20.14 ± 0.86	21.29 ± 0.86	23.65 ± 1.06	22.04 ± 1.71
12 mm	26.67 ± 1.93	25.84 ± 2.09	25.22 ± 1.79	25.98 ± 1.26	27.35 ± 0.73	26.21 ± 1.73

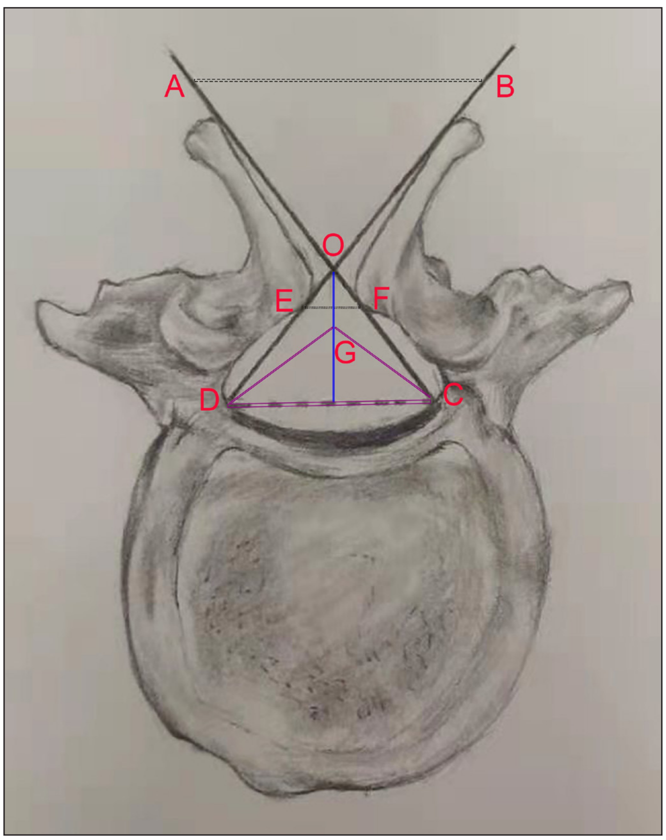


Figure 4: Anatomic measurement methods. AC and BD represent the surgical corridor. ∠COD defines the visibility angle. CD defines the exposure extent.

set at 10 mm and 12 mm, all intra-canal surgical procedures were conducted smoothly. Statistically, the group with 12 mm retraction width presented larger surgical corridor and shorter operative time ((11.22 ± 2.25) min vs (13.58 ± 3.40) min, t=4.240, p=0.036) comparing with the group with 10 mm retraction width. The 3D reconstruction was performed using CT scan data of one random specimen of each group. The pre-operative, intra-operative and post-operative CT imaging presented no bony fracture and articular capsule impairment.

Comparison of Visibility Angle

The maximum visibility angle was measured by ∠COD. The angles of ∠COD of each lumbar segment in the 8 mm, 10 mm, and 12 mm groups are listed in Table I. The maximum visibility angle increases proportionally to the retraction width. There were significant differences among three groups (p<0.05~0.001).

Comparison of Exposure Extent

The length of CD was used to evaluate the exposure extent. In three groups, the length of CD increased with the retraction width (Table II). Significant difference was found in three groups (p<0.01~0.001).

Safety Margin of Retraction

The retraction width that could result in bony fracture ranged from 12.34 mm to 16.82 mm, with an average width of (14.56±1.73) mm. The positions of fracture were different in these 45 lumbar segments, including 31 in the pedicle of vertebral arch (68.9%), 12 in the lamina (26.7%), and 2 in the vertebral body (4.4%).

Findings From a Typical Case

A 53-year-old female patient present sudden paralysis in the lower limbs. She had no history of trauma. Physical examination revealed level 0 muscle strength in bilateral lower limbs and the Babinski reflex was present bilaterally. The light tactile sense and position sense of the lower limbs almost disappeared. Imaging examination showed that at the level of the 12th thoracic and the 1st lumbar vertebral body, the spinal cord swelled and there was an intramedullary space-occupying lesion and hematoma (Figure 5). She received SPSL. Intra-operatively, the 12th thoracic and the 1st lumbar spinous processes were split and expanded to 10 mm in width. Once the swollen spinal cord was exposed, an incision was made along the posterior median sulcus. The hematoma and the lesion were shown as a black grape-like mass measuring 1×1×1 cm in size (Figure 6). The lesion was completely

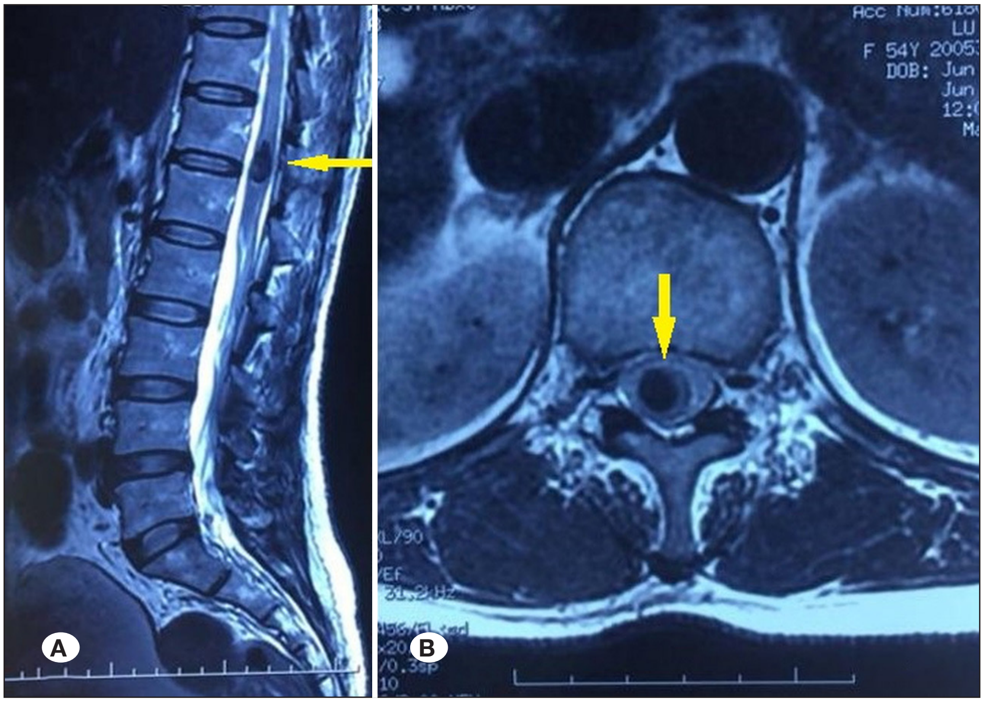


Figure 5: Preoperative MRI.
A) Sagittal slice.
B) Axial slice. An intramedullary space occupying lesion and hematoma were observed (Marked by yellow arrow).

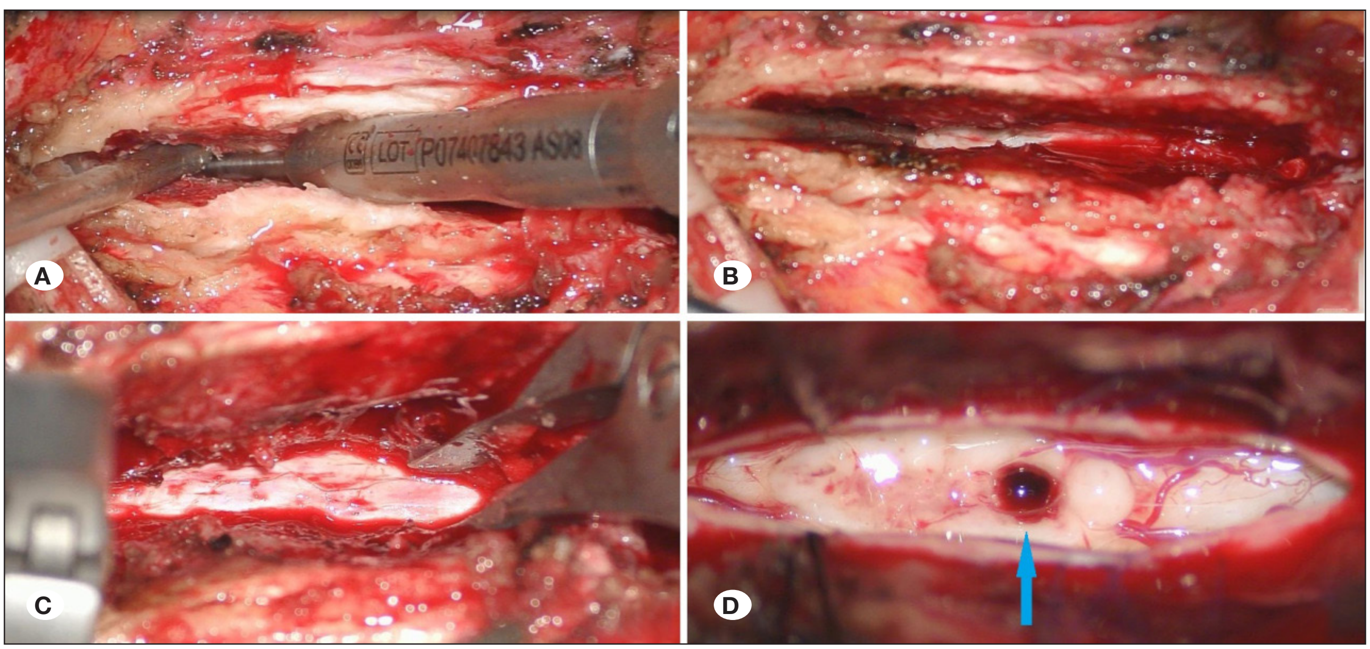


Figure 6: Lesion exposure. **A)** Splitting of the spinous processes with a craniotome. **B)** The split fissure before retraction. **C)** Opening of the retractors. **D)** Incision of the spinal cord and exposure of the hematoma (Marked by blue arrow).

resected. After resection, there was no active hemorrhage. Then, a watertight dural suture was made. With the removal of retractors, the splitting between the spinous processes recovered partly depending on elasticity. The supraspinous ligament was sutured and the incision was closed layer by layer (Figure 7). No operation-related complications were observed during hospitalization and the patient was discharged 9 days after the operation. The pathology type of the lesion was cavernous hemangioma. The lumbar CT scan 3D reconstruction demonstrated no bony fracture in the surgical region. At 3 days after the operation, the lumbar MR imaging confirmed that the lesion was completely resected (Figure 8). On regular follow-up, the patient reported no sign of spinal instability. The muscle strength of the lower limbs recovered to level III-IV and the sensation function recovered partly after two months of rehabilitation training.

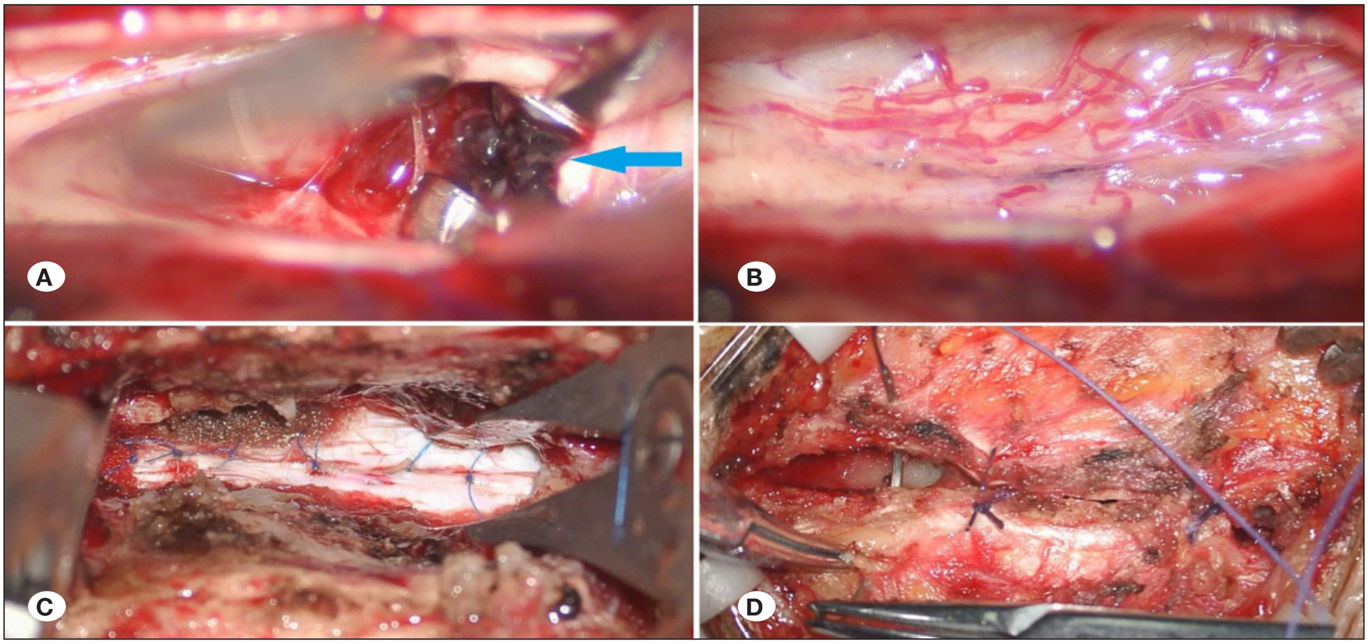


Figure 7: Lesion resection and surgical corridor closure. **A)** Lesion resection (Marked by blue arrow). **B)** The spinal cord after lesion removal. **C)** Watertight dural suture. **D)** Suture of the supraspinous ligament.

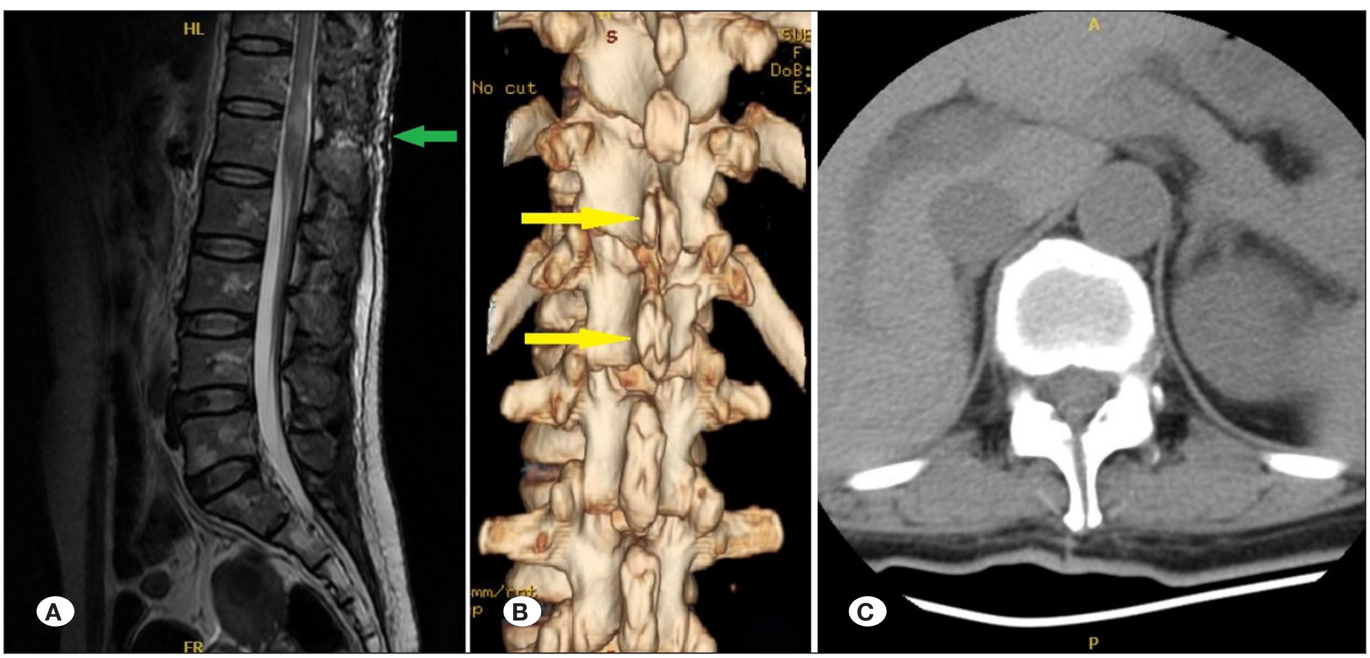


Figure 8: Postoperative imaging. **A)** MRI revealed complete resection (Operative segments marked by green arrow). **B)** 3D reconstruction revealed no bony fracture (Split segments marked by yellow arrows). **C)** The restoration of split spinous process.

DISCUSSION

A surgical approach that balances between feasibility and minimal invasion is the eternal pursuit of surgeons. The bony structures, muscles and ligaments affect the stability and stress distribution of the spine remarkably (15,18,22). The SPSL was firstly introduced in 2004 by Vajda et al. SPSL can be used for the surgical treatment of multi-segment intracanal lesions in pediatric patients. There are shorter postoperative recovery time and better outcomes of incision healing after SPSL. During the 15-month follow-up, the average complete healing period of split laminae was 8.6 months (5). SPSL was modified and applied to 19 adult patients with different pathology types by Banczerowski et al. These adult patients had good prognosis and the lesions were resected totally or sub-totally, as confirmed by MR imaging. Pathology examination and lumbar

CT 3D reconstruction during follow-up did not observe any adverse reactions or severe complications related to SPSL (3). Although SPSL provides a relatively narrow surgical corridor, its feasibility in lesion resection has been reported in many cases (2,3,8,19). However, the safety margin of retraction width and the quantitative surgical corridor have not been reported. In this study, we performed simulated SPSL in fresh cadaveric specimens. We found that the lesion exposure, dural tenting suture, and dural incision were conducted smoothly at 10 mm and 12 mm of retraction width, and the effect was better under the retraction width of 12 mm. Correspondingly, the visibility angle and surgical corridor improvement were in proportion to the retraction width. We conclude that the 10~12 mm retraction width can achieve the balance between safety and surgical feasibility for SPSL.

Secondary bony fracture is one of the potential complications related to SPSL (3,14). Elastic deformation of bilateral laminae and the vertebral arch is the essential factor of SPSL and also the cause of secondary bony fracture. As confirmed by CT scan 3D reconstruction, bony structures and articular capsules of specimens from 3 groups were intact after the simulated SPSL. The retraction safety margin was measured in a total of 45 lumbar vertebral segments from 9 specimens. The retraction width causing fracture ranged from 12.34 mm to 16.82 mm, with an average width of 14.56 ± 1.73 mm. In 2018, Arocho-Quinones et al. reported that no vertebral fracture was observed at 10 mm of retraction width, while the vertebral body and laminae impairments were found when the retraction width was expanded to 15 mm (1). Therefore, pre-operative examination of bony substance is necessary to lower the rate of secondary bony fracture. Aging, osteoporosis, abnormal bony structure, and local trauma history are risk factors for complications in the stage of surgery preparation. One study reported that no complications related to laminal process fracture were revealed during hospitalization and follow-up in patients who underwent SPSL (3). This may be attributed to the intact muscle and ligament structures that keep the stability of the fractured laminal process. This assumption could be supported by a study by Banczerowski et al., which pointed out that the fracture of the laminal processes without damaging the vertebral body would not affect the stability of the spine (2).

Some studies have compared SPSL with the other surgical approaches. For example, Cho et al applied different techniques to treat lumbar spinal stenosis (6). They found that patients underwent SPSL had early mobilization, shorter hospitalization, and lighter postoperative pain. The rate of satisfactory decompression in SPSL group reached 93% (6).

The postoperative pain of posterior spinal approaches is highly related to paravertebral muscle damage. The SPSL causes less damage to the paravertebral muscle, as evidenced by reduced creatine phosphokinase and C-reactive protein (9).

One surgical approach may not be applicable to all lesion types. In this study, the visibility angle and exposure extent may guide surgeons in preoperative design. Whether SPSL is applicable can be determined based on the location, size, and mobility of the lesion.

CONCLUSION

The SPSL is applicable to intra-canal surgery, especially in the posterior midline. Our results revealed that 10~12 mm of retraction width was safe and effective. Via the surgical corridor, micromanipulations such as tumor resection, nervous exploration, dural suture, etc. can be smoothly performed. Additionally, the retraction width in the range of 12.34~16.82 mm could be a safety margin for surgical planning.

AUTHORSHIP CONTRIBUTION

Study conception and design: ZY
Data collection: MW, RW
Analysis and interpretation of results: XW, JX
Draft manuscript preparation: JX, RW
Critical revision of the article: XW
Other (study supervision, fundings, materials, etc...): HZ, YL
All authors (JX, RW, XW, ZY, XW, MW, YL, HZ) reviewed the results and approved the final version of the manuscript.

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