

Percutaneous Endoscopic Unilateral Laminotomy and Bilateral Decompression under 3D Real-Time Image-Guided Navigation for Spinal Stenosis in Degenerative Lumbar Kyphoscoliosis Patients: An Innovative Preliminary Study

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Abstract

Background

The aim of this study is to introduce a new method of percutaneous endoscopic decompression under 3D real-time image-guided navigation for spinal stenosis in degenerative kyphoscoliosis patients without instability or those who could not endure major surgery due to multiple comorbidities. Decompression along using endoscope for kyphoscoliosis patient is technical demanding and may result in unnecessary bone destruction leading to further instability. The O-arm/StealthStation system, a 3D real-time image-guided navigation system, is popular for its ability to provide automated registration with intraoperative, postpositioning computed tomography (CT) with no radiation exposure to operative staffs. With 3D real-time image-guided navigation, we could improve the accuracy of surgery and maintain the spinal stability as preoperative condition.

Methods

In this study, we presented four cases. All patients were over seventy years old female with variable degrees of kyphoscoliosis and multiple comorbidity who could not endure major spine fusion surgery. Percutaneous endoscopic unilateral laminotomy and bilateral decompression under 3D real-time image-guided navigation were successfully performed with following steps. First, the reference pin was introduced over iliac crest. Second, all navigational instruments were registered to the O-arm Stealth Station. Third. With the interlaminar approach, a 8.0 mm dilator followed by operative sleeve was introduced toward the ligamentum flavum. Then the endoscope attached with universal tracker was inserted, and the boundaries of lamina and facet joint were well-identified through the monitor. Finally, unilateral laminotomy and resection of ligamentum flavum with joy-stick technique for bilateral decompression were performed under the navigation system. Patients' demographics, image study parameters, and outcome measurements including pre- and post-operative serial visual analog scale (VAS), and Oswestry Disability Index (ODI) were well documented. The follow-up time was one year.

Results

All patients were successfully treated with this technique. Pre- and post-operative MRI showed average dural sac cross sectional area (DSCSA) improved from 81.62 (range 67.34–89.07) to 153.27 (range 127.96–189.73). All preoperative neurological symptoms including radicular leg pain and sciatica improved postoperatively. The mean ODI (%) were 85 (range 82.5–90) at initial visit, 35.875 (range 25–51) at 1 month post-operatively, 26.875 (range 22.5–35) at 6 months post-operatively and 22.5 (range 17.5–30) at 12 months post-operatively ($p < 0.05$). The mean VAS score were 9 (range 8–10) at initial visit, 2.25 (range 2–3) at 1 month post-operatively, 1.75 (range 1–2) at 6 months post-operatively and 0.25 (range 0–1) at 12 months post-operatively ($p < 0.05$). There was no surgery-related complication

such as inadequate decompression, dural tear, iatrogenic neurological injury, uncontrolled epidural hemorrhage, unnecessary bone destruction with further instability.

Conclusions

To the best of our knowledge, this is the first preliminary study of percutaneous endoscopic laminotomy under O-arm navigation with successful outcomes. The innovative technique may serve as a promising solution in treating spinal stenosis patients with lumbar kyphoscoliosis and multiple comorbidities.

Background

With aging of the population, spinal stenosis with degenerative kyphoscoliosis has become an increasingly common condition. Lumbar spinal stenosis with or without degenerative spondylolisthesis is a pathologic condition that is often observed in the geriatric population, which is the spinal canal narrowing caused by redundant ligamentum flavum and hypertrophic facet joints and osteophytes, and may present with clinical symptoms such as radicular leg pain or neurogenic claudication.[1, 2]

Recent studies have suggested that nonsurgical treatment may not be as effective.[3, 4] The current medical evidence continues to support the role of surgery over non-operative therapies for symptomatic stenosis patients associated with spondylolisthesis.[5] The prospective, randomized, multicenter Spine Patient Outcomes Research Trial (SPORT) also suggests that patients who are treated surgically present with a significantly greater improvement in pain, function, satisfaction, and self-rated progress over eight years compared to patients treated non-operatively.[6–8]

Various studies have evaluated the efficacy of decompression alone versus decompression with fusion for this condition, but the results are still controversial.[9–13] Decompression alone have shown similar results in clinical outcomes compared to decompression with fusion.[9, 11, 13] Open discectomy with laminotomy or laminectomy alone has been considered as standard treatment for lumbar spinal stenosis without instability during the last decades.[14] Percutaneous endoscopic decompression which features less tissue disruption and small incisions serves as a solution to patients with multiple comorbidities. However, decompression alone using endoscope for kyphoscoliosis patient is technically demanding and may result in unnecessary bone destruction leading to iatrogenic instability.[15, 16]

Considerable advances in 3D real-time image navigation have changed the nature of spine surgery.[17, 18] With the assistance of 3D real-time image navigation, the depth and location of endoscope trocar, high speed burr and relevant anatomy could be instantly demonstrated on the monitor during the procedure. The amount of bony structure removed could be well-visualized on the monitor. Thus, the risk of inadequate decompression, dural tear, iatrogenic neurological injury, uncontrolled epidural hemorrhage, unnecessary bone destruction with iatrogenic instability could be thus limited. This is the first study reporting endoscopic decompression surgery under 3D real-time image navigation to treat degenerative kyphoscoliosis patients.

The purpose of this study is to describe a novel method which combined percutaneous endoscopic surgery and 3D real-time image navigation. The preliminary result showed adequate and precise decompression without leading to iatrogenic instability when treating spinal stenosis in degenerative kyphoscoliosis patients.

Methods

1. Patient enrollment

Four kyphoscoliosis patients diagnosed with lumbar spinal stenosis between March 2017 and January 2018 were enrolled in this study. (Fig. 1) Our inclusion criteria were as follows: lumbar spinal stenosis with kyphoscoliosis, radicular leg pain or sciatica refractory to conservative treatment for at least 6 months, absence of spinal instability such as fracture or spondylolisthesis. We excluded patients with spinal instability, compression or burst fracture, infection, tumor, previous lumbar surgery. The participants included four women with an average age of 80.25 years (range, 73-86 years). The average Body Mass Index (BMI) was 24.58 (range, 19.94-28.36). The affected levels ranged from L2-S1. As for the degree of spinal deformity, data were summarized in Table 1 According to Schwab Classification.[19]

2. Outcome Evaluation

Radiology outcome measurement including serial radiographs (Fig. 1) and dural sac cross sectional area (DSCSA) on MRI were well documented. (Fig. 2) (Table 2) As for the clinical outcome evaluation, the Oswestry Disability index (%) (ODI), Visual analogue scale (VAS) were collected at the initial visit and at 1 month, 6 months and 12 months post-operatively. (Table 3)

3. Statistical Analyses

Statistical Analyses were performed using SPSS for Windows, version 24 (SPSS Inc, Armonk, NY). The Friedman two-way analysis of variance (ANOVA) by ranks test was used as a non-parametric test. A $p < 0.05$ was considered statistically significant.

4. Navigation system and Instruments

The O-arm/StealthStation system (Medtronic Inc., Minneapolis, MN, USA), a 3D real-time image-guided navigation system, is popular for its ability to provide automated registration with intraoperative, postpositioning computed tomography (CT). With SureTrak® II Universal Tracker (Medtronic Inc., Minneapolis, MN, USA) attached to the endoscope instrument, the depth and position of the endoscopic working channel could be observed in real-time fashion on the O-arm/StealthStation monitor.

The Vertebris® Spine Endoscope system (Richard and Wolf, Knittlingen, Germany) features high-resolution endoscope with a 6.9 x 5.6 mm diameter and a 4.1 mm intra-endoscopic working channel. The angle of vision is 25°. The working sleeve has an 8.0 mm outer diameter and a beveled opening, which enable visual and working fields creation in an area with a clear, anatomically preformed cavity.

Surgitron, a high-voltage bipolar probe (Ellman Innovations, New York, USA), is well-known for pinpoint coagulation in a wet field with simultaneously minimal burning or charring of soft tissue. The thermocoagulation device aims to maximize hemorrhage control and thus improves the visibility of the operative field.

5. Surgical Technique

5.1 Patient Preparation

The surgery was conducted under general anesthesia. The patient was positioned prone on a well cushioned and supportive radiolucent table with the abdomen hanging free. Bilateral knees were flexed to over 90 degrees as possible for the opening of interlaminar space. Back skin was then well prepared and draped.

5.2 Reference Pin Insertion and Image Acquisition

First, we made a small incision over the iliac crest. We inserted the reference pin through the cannula, and used an impactor to nail the pin into the bone until the tap cap bottoms out on the cannula. Then we removed the tap cap and cannula from the pin, placed the spine reference on the pin and rotated the assembly to lock the frame in place.

The spinal segment of interest was scanned using the O-arm navigation and the images were automatically registered to the Stealth Station. All the navigational instruments were registered.

5.3 3D Real-Time Image-Navigated Percutaneous Endoscopic Decompression

Interlaminar approach was chosen. The skin incision was made under O-arm navigation, which was under the spinal laminal junction. A dilator, 8.0 mm in outer diameter, was bluntly inserted to the edge of the interlaminar window. Then, an operative sleeve with a beveled opening was directed towards the ligamentum flavum. After attaching the SureTrak® II Universal Tracker to the VertebriS® Spine Endoscope (Fig. 3), the endoscope was inserted into the working channel (Fig. 3).

After introduction of the endoscope, the bony boundaries of superior lamina, inferior lamina and facet joint were identified and the soft tissues were removed with bipolar probe, punch and forceps. To broaden the working space, 3-4mm of bone around superior and inferior lamina was removed with a diamond burr. The depth and location of the bony landmark could be well visualized through the O-arm navigation system. (Fig. 4) The facet joint was carefully protected from damage with the aid of O-arm navigation system, which prevented the spinal column from instability. Not until the cranial, caudal, medial, and lateral border of the operative field were well prepared should the ligamentum flavum being opened. A lateral window of approximately 4-6 mm was made on the ligamentum flavum. The neural structures and epidural fat tissues were exposed. The perineural membrane was dissected from the neural structure carefully under direct endoscopic visualization. The operating sleeve with beveled opening could be turned and used as a nerve hook. With the joystick technique, the hypertrophic

ligamentum flavum could be removed by controlling endoscope in either direction. Finally, epidural bleeding was checked and well-controlled by Surgitron bipolar probe. The whole procedure was done safely and effectively under precise O-arm navigation (Fig. 5).

Results

Without unnecessary bone destruction, the spinal stenosis was successfully decompressed through endoscopic surgery. Both the endoscopic insertion wound and the reference pin insertion wound were about 1 cm (Fig. 6). All patients could stand and walk freely on a walker on postoperative day 1. The hospital stay was within 3 days. The efficacy of decompression was confirmed by MRI at 12 months follow-up post-operatively. Average dural sac cross sectional area (DSCSA) improved from 81.62 (range 67.34–89.07) to 153.27 (range 127.96-189.73) (Fig. 2) (Table 2). The follow-up X-ray performed at 12 months post-operatively showed no progress of the scoliosis (Fig. 1). As shown in Table 3, the mean ODI (%) were 85 (range 82.5–90) at initial visit, 35.875 (range 25–51) at 1 month post-operatively, 26.875 (range 22.5–35) at 6 months post-operatively and 22.5 (range 17.5–30) at 12 months post-operatively ($p < 0.05$). The mean VAS score were 9 (range 8–10) at initial visit, 2.25 (range 2–3) at 1 month post-operatively, 1.75 (range 1–2) at 6 months post-operatively and 0.25 (range 0–1) at 12 months post-operatively ($p < 0.05$). There was no surgery-related complication such as inadequate decompression, dural tear, iatrogenic neurological injury, uncontrolled epidural hemorrhage, unnecessary bone destruction with iatrogenic instability.

Discussion

To the best of our knowledge, this is the first clinical study utilizing the technique of percutaneous endoscope with O-arm navigation to treat spinal stenosis for kyphoscoliosis patients. The advantages of this combined technique are high precision with promising decompression effect, minimal invasive surgery with little soft tissue damage, and preservation of original spinal stability.

A recent systematic review and meta-analysis has demonstrated that in patients whose primary complain are radiculopathy with an underlying biomechanically stable spine, decompression surgery alone with a less invasive technique may be sufficient. Decompression with fusion does not appear to be more effective than decompression alone when considering pain relief, walking ability, or disability status.[20]

The gold standard method of the decompression of lumbar spinal stenosis is laminectomy with or without lateral recess and foraminal decompression. A laminectomy removes the entire lamina and the underlying ligamentum flavum, while a laminotomy removes only a small bone window from the lamina, unilaterally or bilaterally, which could be accomplished through minimally invasive surgery, such as percutaneous endoscope technique.[21, 22] Minimally invasive decompression plays an important role for elderly patients. For elderly patients with focal lumbar spinal stenosis, outcomes and surgical morbidity have been shown to be similar to those in the younger demographics.[23]

Several studies have focused on the efficacy of percutaneous endoscopic surgery for spinal stenosis. Ito et al. demonstrated improved VAS, ODI and Japanese Orthopedic Association (JOA) score after conducting endoscopic decompression with sublaminar approach.[24] Kang et al. compared biportal endoscopic surgery with microscopic surgery and found that there was shorter hospital stay, shorter operation time, less hemovac drainage and less opioid use in endoscopic surgery group.[25] Kim and Choi found satisfactory results at minimum 2-year follow-up with no wound infection or segmental spinal instability after conducting endoscopic decompression for lumbar spinal stenosis.[26] Comparative analysis between microscopic, tubular and endoscopic decompression also discovered that tubular and endoscopic surgery group showed less invasiveness with less increase of serum CPK enzyme level, shorter hospital stay, and less immediate postoperative back pain.[27] The efficacy and safety of endoscopic decompression have been thoroughly investigated.

The original treatment plan for our patients was open surgery and correction of scoliosis with long fusion to sacrum (in order to avoid fusion above the apex of curve) with laminectomy and foraminal decompression. However, the adverse effect of long fusion brings certain early perioperative complications in old age patients with multiple comorbidities.[28] Therefore, decompression alone using percutaneous endoscope seemed to be a reasonable alternative. Decompression alone with laminectomy may lead to iatrogenic instability. However, with accurate O-arm guided navigated decompression, excessive bone removal could be successfully avoided. With this combined technique, it was possible to overcome abnormal anatomical challenges and broaden the available stabilization options in the spinal surgery.[29, 30] Decompression alone in old patients with multiple comorbidities was difficult to achieve adequate decompression without unnecessary bony destruction. O-arm navigation provided a new option for this kind of patients, along with a reduction in radiation exposure for operating room staff. With O-arm navigation, this technique could be applied in even more complicated cases, particularly in the elderly or immunocompromised patients, as well as in patients with multiple comorbidities.[31]

The study has some limitations. First, there was a limited number of patients and no control group. Second, the follow-up was short, lacking long-term follow-up data. However, the purpose of this study is to describe the combined technique and assess its clinical and radiological results. Decompression alone using endoscope under O-arm navigation could be considered in patients with multiple comorbidities who could not endure major surgery and surgery-related hazardous complication.

Conclusions

To the best of our knowledge, this is the first preliminary study of percutaneous endoscopic laminotomy under O-arm navigation with successful outcomes. Percutaneous endoscopic laminotomy under O-arm navigation is a minimal invasive procedure compared to open posterior surgery, such as decompression surgery plus fusion surgery, with no excessive bone and soft tissue destruction, smaller cosmetic wound, shorter hospitalized duration, but similar treatment effects. We believe this novel technique is promising for spinal stenosis patients with lumbar kyphoscoliosis and multiple comorbidities. Further studies on larger sample are required to support these preliminary results

Abbreviations

BMI: Body Mass Index; 3D:Three-Dimensional; AP:Anteroposterior; CT:Computed Tomography; MRI:Magnetic Resonance Imaging; T2WI:T2-Weighted Image; ODI:Oswestry Disability Index (%); VAS:Visual Analogue Scale; JOA:Japanese Orthopedic Association

Declarations

Ethics approval and consent to participate

This research did not increase the risk and economic burden of patients, the patients' rights were fully protected, and the project design was conducted in line with scientific and ethical principles. This study was approved by China Medical University & Hospital Research Ethics Committee (reference number: 1673) (CMUH107-REC2-173). All participants in this study have provided informed written consent prior to enrollment.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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The authors received no specific funding for this work.

Authors' contributions

HTC, YJC and CCC participated in the design of the study. CCC was responsible for performing the clinical procedures. TYH and CWL contributed to manuscript drafting. CWL, YSL and PHH contributed to data collection. CWL, CSL, PCC and HKT contributed to manuscript editing. All

authors read and approved the final manuscript.

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Tables

Table 1. Profiles of Patient with Kyphoscoliosis

	Case 1	Case 2	Case 3	Case 4
Age (years)	73	86	82	80
BMI (kg/m ²)	28.36	23.37	19.94	26.63
Comorbidities	Diabetes Mellitus Chronic Kidney Disease Stagelll Chronic Obstructive Pulmonary Disease	Paroxysmal atrial fibrillation Hypertension Diabetes Mellitus Chronic Kidney Disease Stagell	Chronic Kidney Disease Stagelll Dementia	Hypertension Diabetes Mellitus Congestive Heart Failure
Schwab Classification for Adult Spinal Deformity				
Type and Location of Deformity	TypeV Lumbar Major Curve	TypeV Lumbar Major Curve	TypeV Lumbar Major Curve	TypeV Lumbar Major Curve
Lordosis Modifier: Sagittal Cobb angle from T12 to S1	20.36 degrees	20.31 degrees	21.14 degrees	21.6 degrees
Subluxation Modifier: Frontal or Sagittal Plane (Anterior or Posterior), Maximum Value	++ Frontal subluxation 16mm (>7mm)	+Frontal subluxation 6mm (1-6mm)	++ Frontal subluxation 9.4mm (>7mm)	+ Frontal subluxation 5.53mm (1-6mm)
Global Balance Modifier: Sagittal Offset from Posterior Superior Corner S1	Positive: 7.98cm	Positive: 7.13cm	Positive: 7.01cm	Positive: 4.63cm

Table 2. Patient Radiology Results

	Operation Level	Pre-OP DSCSA (mm ²)	Post-OP DSCSA (mm ²)
Case 1	L3/L4	89.07	189.73
Case 2	L4/L5	84.39	143.05
Case 3	L2/L3	85.68	152.34
Case 4	L3/L4	67.34	127.96

DSCSA Dural Sac Cross Sectional Area, *Pre-OP* Preoperative, *Post-OP* Postoperative

Table 3. Patient Clinical Results

Diagnosis	Pre-OP		Post-OP					
	ODI	VAS	ODI	VAS	ODI	VAS	ODI	VAS
			1 Month	1 Month	6 Month	6 Month	12 Month	12 Month
Case 1 Kyphoscoliosis with Spinal Stenosis L3-L4	87.5	9	25	3	22.5	1	17.5	1
Case 2 Kyphoscoliosis with Spinal Stenosis L3/L4/L5	82.5	10	35	2	25	2	20	0
Case 3 Kyphoscoliosis with Spinal Stenosis L2/L3/L4	90	9	51	2	25	2	22.5	0
Case 4 Kyphoscoliosis with Spinal Stenosis L3/L4	80	8	32.5	2	35	2	30	0

VAS Visual Analogue Scale, ODI Oswestry Disability index, Pre-OP Preoperative, Post-OP Postoperative

Figures

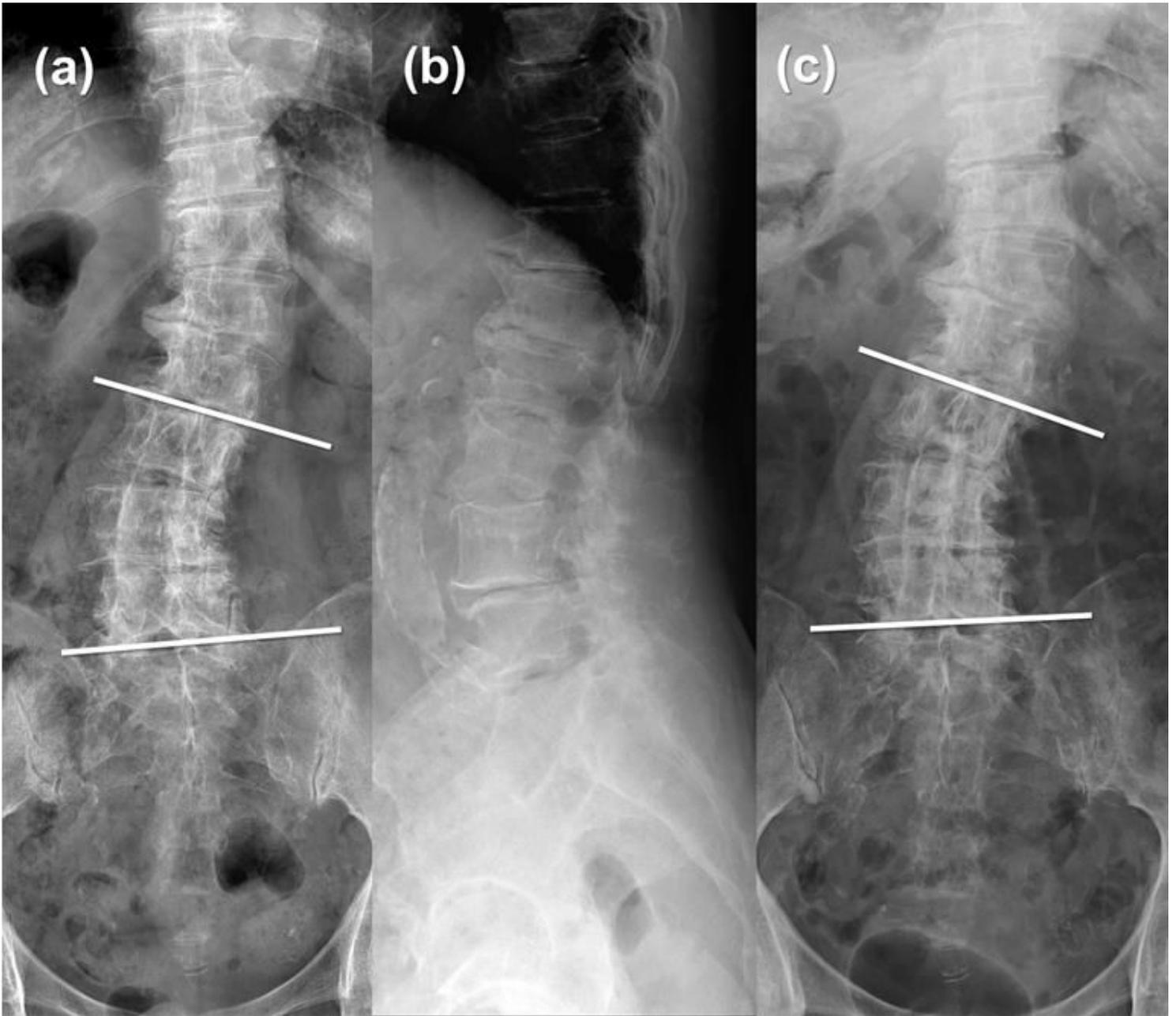


Figure 1

(a) Preoperative AP X-ray shows 21.85° Cobb angle scoliosis from L3-L5. (b) Preoperative lateral X-ray reveals mild spondylolisthesis over L4-L5. (c) Postoperative AP X-ray shows 21.84° Cobb angle scoliosis from L3-L5. (a)(c) Serial images demonstrate no progression of the scoliosis.

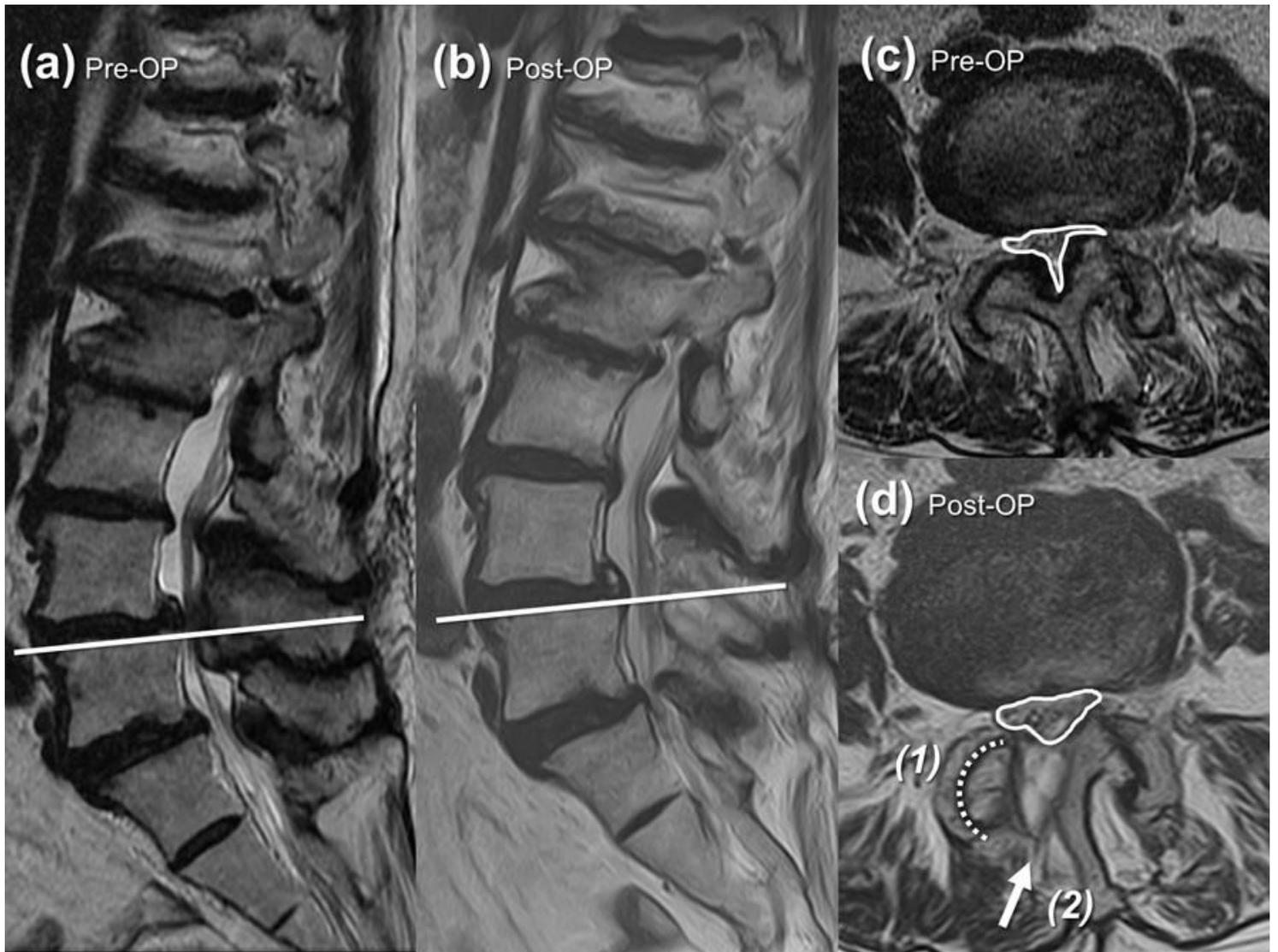


Figure 2

(a) Preoperative sagittal section of T2WI MRI shows severe stenosis over L4-L5. (b) Postoperative sagittal section of T2WI MRI shows stenosis being relieved with intact posterior elements. The decompression level (White line) on axial section of T2WI MRI is shown in (c) and (d). Comparing (c) preoperative and (d) postoperative T2WI axial section MRI, dura sac cross-sectional area (DSCSA) increases significantly after endoscopic laminotomy at L4-5 under O-arm navigation (1) without any facet joints damage, via (2) interlaminar approach.

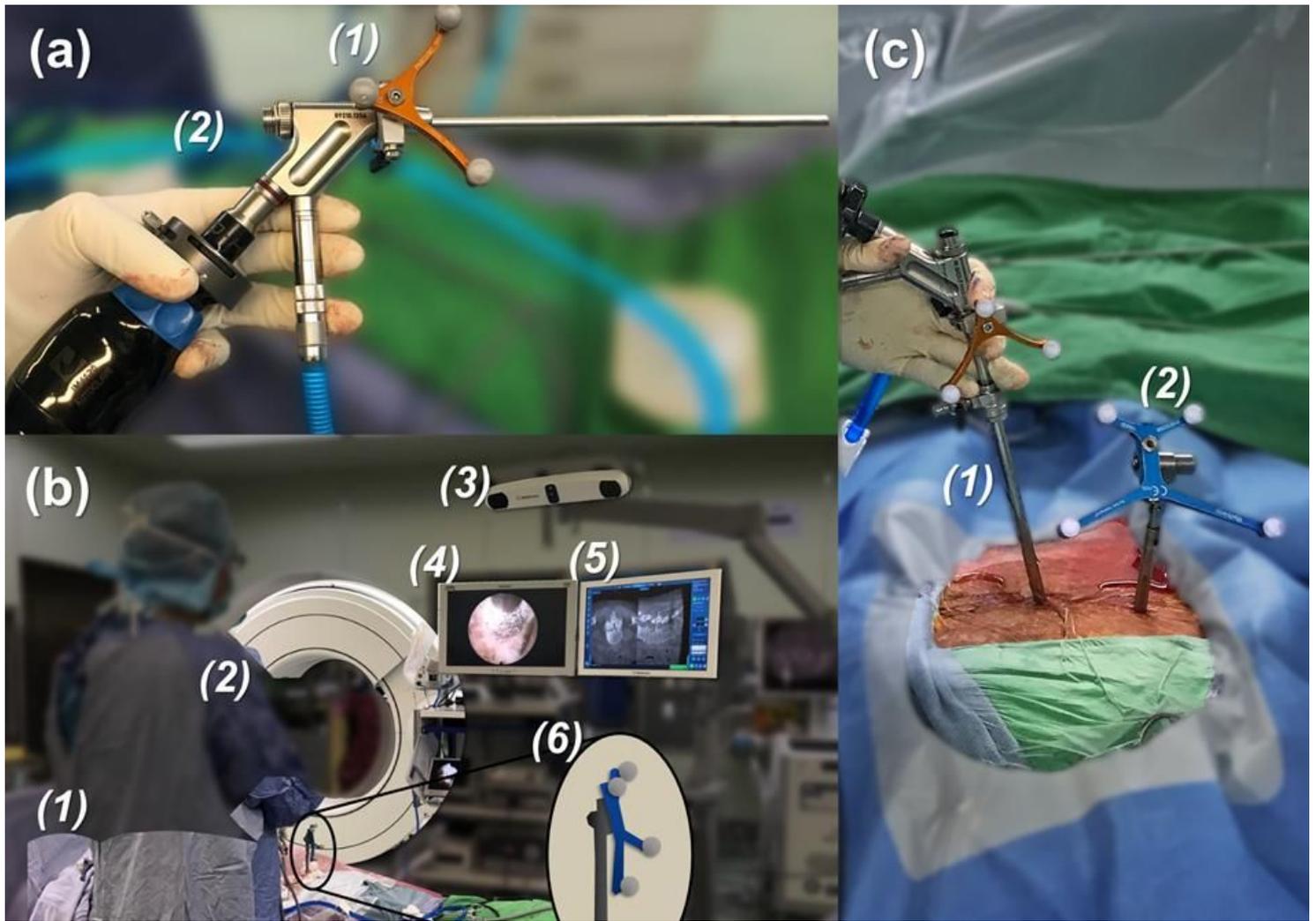


Figure 3

(a) Intraoperative photo shows the attachment of (1) SureTrak® II Universal Tracker, Small Passive Fighter to the (2) VertebriS® Spine Endoscope. (b) Photos reveals the setting of surgery, including (1) patient positioning, (2)(3) O-arm setting, (4) endoscope monitoring, (5) navigation monitoring and (6) reference pin position. (c) Photo shows the relative position of (1) the endoscope in the sleeve, and (2) the percutaneous reference pin (in the area over the iliac crest).

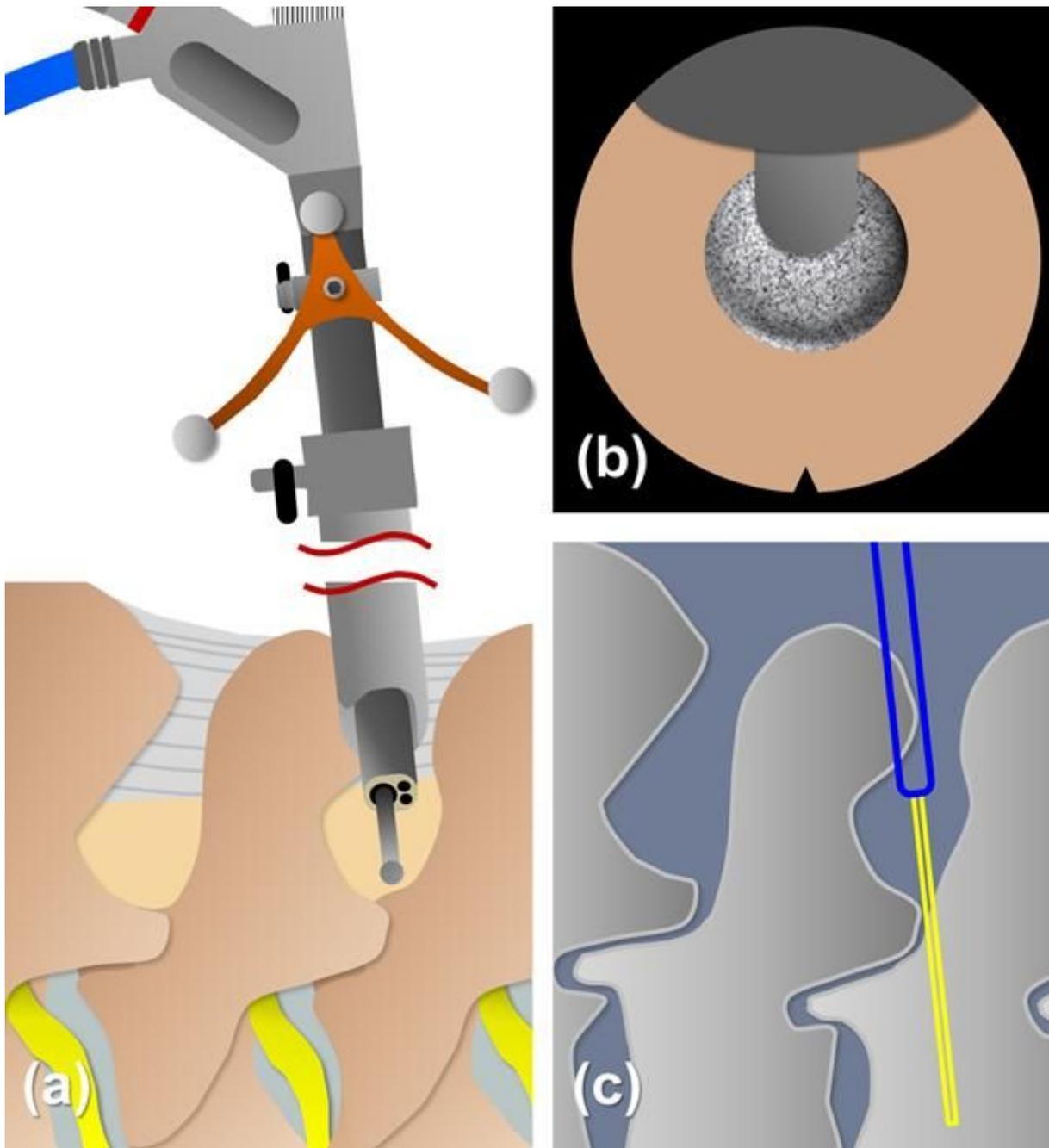


Figure 4

Pattern diagram shows (a) the navigational instrument set-up with universal tracker attached to the endoscope. The burr tip docks on the lamina. (b)(c) The depth of the endoscope in the working field can be simultaneously seen on the navigation monitor. The blue bar indicates the tip of endoscope and the yellow bar points out the trajectory of burr.

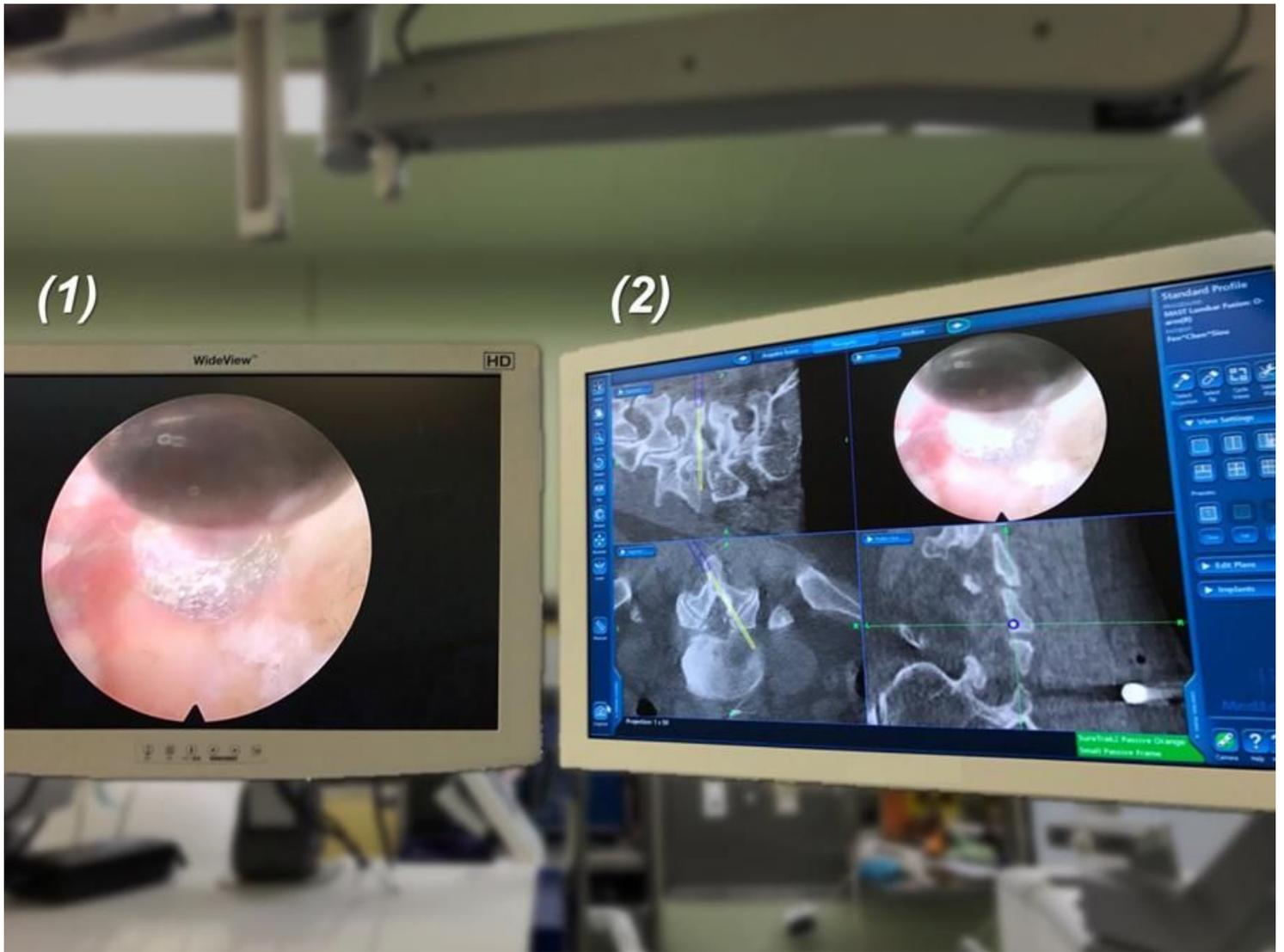


Figure 5

Combining (1) Endoscopic images and (2) O-arm navigation images, the trajectory of the burr is navigated. The depth of burr could be adjusted precisely during laminotomy under 3D real-time O-arm navigation.

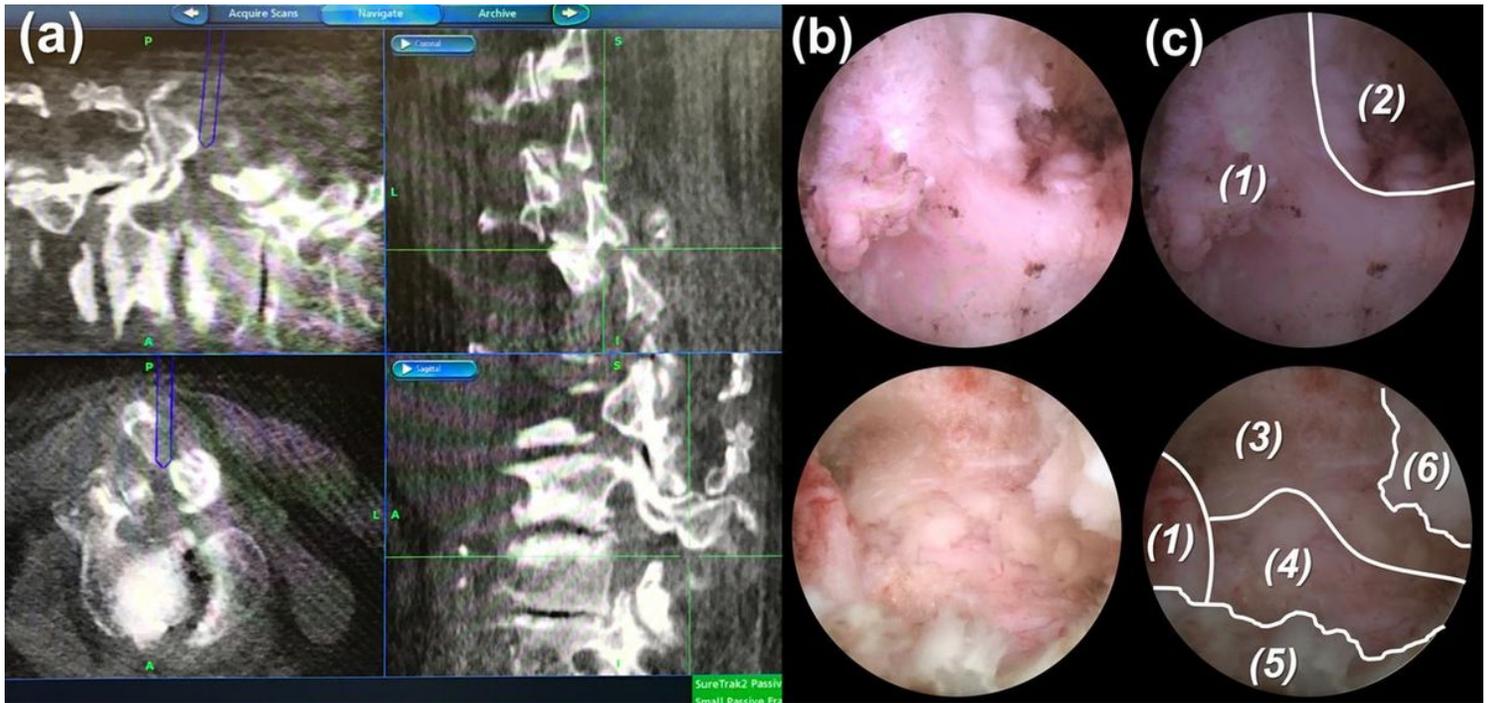


Figure 6

Surgeon performs endoscopic laminotomy under precise O-arm navigation. Intraoperative photos show (a) O-arm navigation images (b) Endoscopic images and (c) its introduction: (1) base of spinous process, (2) interlaminar space, (3) right side lateral recess, (4) dura, (5) left side lateral recess, (6) ligamentum flavum.

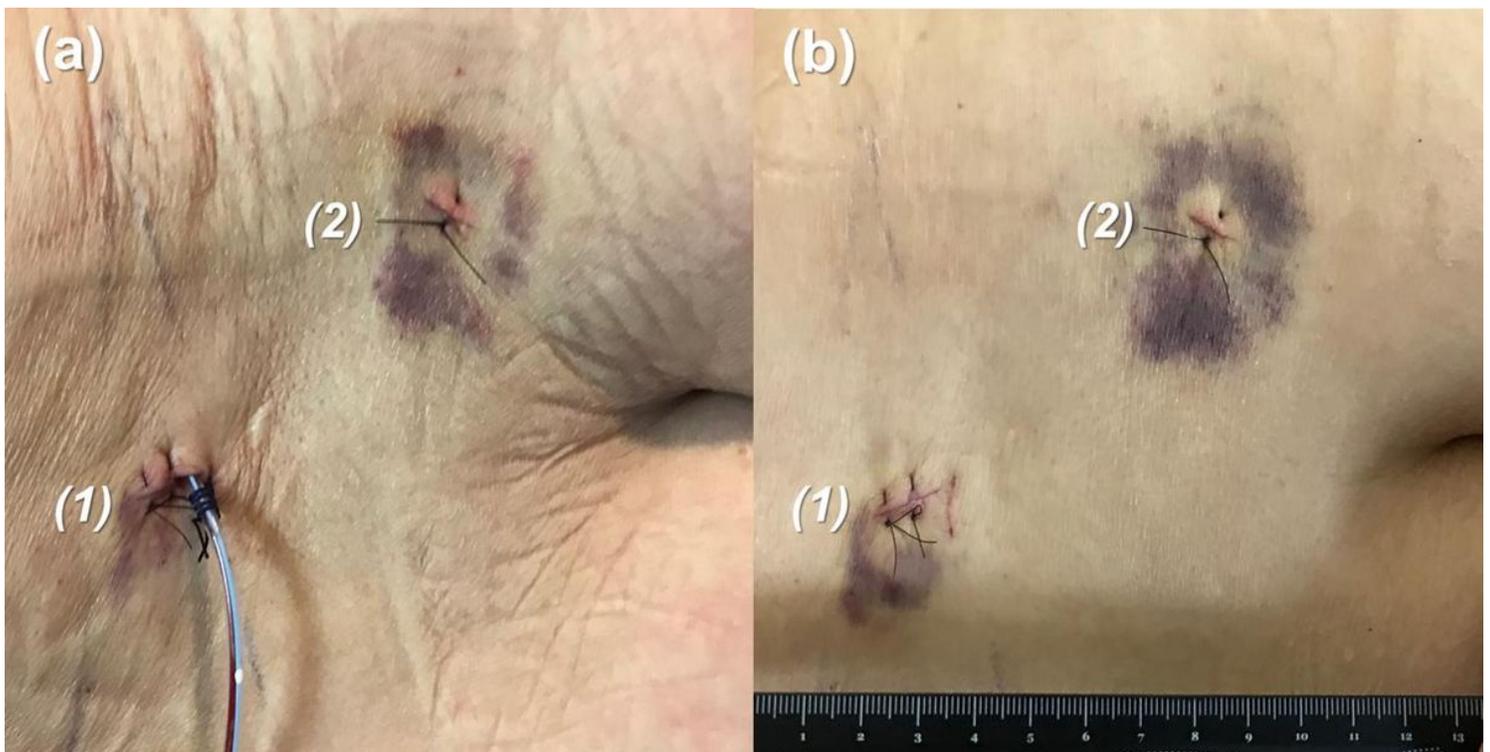


Figure 7

- (a) Surgical wounds on postoperative day 1 with a Hemovac drainage in the endoscope insertion wound;
- (b) Both (1) the endoscope insertion wound and (2) the percutaneous reference pin insertion wound are about 1cm.