Totally endoscopic trans-superior articular process lumbar interbody fusion: A case series on the development and preliminary evaluation of an innovative minimally invasive lumbar spine surgical technique

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Abstract. The present study is a retrospective analysis aimed at evaluating the early clinical efficacy and preliminary safety of full-endoscopic transforaminal upper facet joint lumbar interbody fusion (TSAP-LIF) in patients with lumbar degenerative diseases treated at the Department of Orthopaedics at Changzhi Yunfeng Hospital (Changzhi, China). The present study collected clinical follow-up data and radiological images, which were accessed and collected between January 1, 2021 and December 31, 2022. All surgeries were performed by the same group of experienced surgeons to ensure consistency in surgical technique and its impact on patient outcomes. The study included patients' preoperative baseline characteristics, operative time, intraoperative blood loss, postoperative complications and follow-up results (with a follow-up period of 6 months). Clinical outcomes were assessed using the Oswestry Disability Index (ODI) and Visual Analog Scale (VAS), and radiological evaluations were conducted using postoperative X-rays and computed tomography scans to determine the intervertebral fusion rate. Among the 9 patients, there were 4 men and 5 women, with an average age of 47.3±13.1 years (range, 23-67 years). The average operation time was 113.3±13.9 min, and the average intraoperative blood loss was 101.6±13.8 ml. The postoperative complication rate was 0%. The average hospital stay was 12.7±3.2 days. The average VAS score improved from 7.7±1.4 preoperatively to 2.6±1.2 at 3 months postoperatively and to 1.2±1.1 at 6 months postoperatively. The average ODI score improved from 56.7±8.2 preoperatively to 22.7±5.6 at 1 month postoperatively and to 10.2±4.2 at 6 months postoperatively. Radiological examinations showed an intervertebral fusion rate of 88% at 6 months postoperatively. Retrospective analysis indicates that TSAP-LIF is a safe and effective method for treating lumbar degenerative diseases. The clinical outcomes are significant, with reduced operation time, marked improvement in patient pain and function and a high intervertebral fusion rate. To further evaluate the clinical efficacy of this procedure, larger sample sizes and longer follow-up periods are required.

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Abbreviations: TSAP-LIF, trans-superior articular process lumbar interbody fusion; CT, computed tomography; VAS, visual analog scale; ODI, Oswestry Disability Index; LSS, lumbar spinal stenosis

Key words: full endoscopy, trans-superior articular process, lumbar degenerative disease, lumbar fusion surgery, retrospective study

Introduction

Lumbar interbody fusion (LIF) surgery is widely employed in orthopaedic procedures to treat various spine-related diseases, such as degenerative diseases, spondylolisthesis, lumbar spinal stenosis (LSS) and spinal instability (1). The primary aim of this surgery is to alleviate pain and increase spinal stability by fusing two or more vertebrae (2). This is achieved by implanting bone fusion materials (such as autologous bone, polyether ether ketone or metal) and reinforcing the spinal structure with metal devices (such as screws and rods) (3).

Full endoscopic spinal surgery represents an innovation in the surgical field, allowing physicians to perform spinal operations using an endoscope through smaller incisions (4). This technique provides clearer and broader visual fields, finer neural decompression and improved intervertebral

space handling. Using the trans-superior articular process approach under endoscopy allows direct decompression of the affected foramina, lateral recess stenosis and central canal (5). Under endoscopic observation, the cartilage endplate can be scraped without excessive treatment of the bony endplate. This improvement in surgical anatomy can minimize surgical trauma, reduce recovery time and decrease the incidence of complications (6). This technique has been widely applied in various spinal surgeries, such as decompression, spinal fixation and spinal fusion surgeries. Despite its numerous advantages, it faces some challenges. First, full endoscopic surgical techniques require highly skilled surgeons, which can only be achieved through specialized training. Second, for some complex conditions, such as severe spinal scoliosis (7) or severe spinal stenosis, this technique may not provide a sufficient surgical view or operating space. Additionally, the long-term efficacy and success rate of full endoscopic techniques in spinal surgery require further research for confirmation.

Trans-superior articular process LIF surgery under full endoscopy is an innovative surgical method designed to overcome the limitations of traditional spinal surgical techniques. Traditional spinal surgical methods, especially LIF surgery, typically require large surgical incisions, extensive tissue dissection and wide exposure of spinal structures (8). Furthermore, uncertainties in the bone fusion process and potential failures of fixation devices could affect the long-term success rate post-surgery (9). These factors may lead to significant surgical trauma, prolonged recovery time and a high risk of complications. Current studies almost unanimously agree that endoscopic lumbar fusion surgery has advantages over traditional surgical methods, such as smaller surgical incisions, reduced muscle and soft tissue dissection, less bleeding and faster postoperative recovery (10-16). Therefore, developing a new surgical method is crucial to reduce surgical trauma, shorten surgery and recovery times and lower the risk of complications. In the present study, the primary goal of transforaminal upper facet joint LIF (TSAP-LIF) under full endoscopy was to use endoscopes and specialized surgical tools through smaller incisions and with less tissue dissection. Unlike the currently popular approaches, this technique enables LIF surgery to be performed by only removing the superior articular process, without removing the inferior articular process, resulting in fewer steps and a reduced surgical duration for patients.

Materials and methods

Study design. TSAP-LIF under full endoscopy has similar indications to traditional spinal fusion techniques for the treatment of Grade 1-2 symptomatic spondylolisthesis and spinal stenosis (Table I, classified by the Meyerding system) (17). The present study is a retrospective analysis aimed at evaluating the early clinical efficacy and preliminary safety of TSAP-LIF performed under full endoscopy in patients treated at Changzhi Yunfeng Hospital (Changzhi, China). All surgeries were conducted by the same experienced surgeon to ensure consistency in surgical technique and its impact on patient outcomes. Follow-up data and imaging studies from January 1, 2021, to December 31, 2022, were retrospectively analyzed. The study data obtained from the hospital's electronic medical records included patients' preoperative baseline characteristics, operative time, intraoperative blood loss, postoperative complications and follow-up outcomes (with a follow-up period of 6 months). Clinical outcomes were assessed using the Oswestry Disability Index (ODI) (Table II) (18) and Visual Analog Scale (VAS) (Table III) (19), while radiographic evaluations were performed using postoperative X-rays and computed tomography (CT) scans to determine the interbody fusion rate. Identifiable information about individual participants (Table IV), such as name, sex, age, address, identification number and facial image data, was obtained during or after data collection.

Preoperative planning. Preoperatively, the surgical approach trajectory was planned using axial T2-weighted magnetic resonance imaging, with the approach marked by continuous red lines reaching the lateral recess through the SAP (Fig. 1A and B).

Intraoperative procedures. Patients were positioned prone on an X-ray translucent surgical table under general anesthesia with sedation monitoring. The endoscopic video monitor and C-arm X-ray machine were placed opposite the affected side of the patient, and the surgeon operated from the affected side. By suspending a saline bag 1-1.5 meters above the patient's plane, sufficient flow was ensured to maintain a clear endoscopic view. Saline irrigation was performed without a pump to avoid increasing intracranial pressure in the event of an iatrogenic dural tear. Active communication with the anesthesia team maintained systolic pressure below 110 mmHg, effectively controlling intraoperative bleeding.

Approach and exposure. During surgery, the endoscope was inserted from the side with radiculopathy symptoms. Using the C-arm X-ray machine for positioning, the skin entry point of the L4/L5 pedicle was marked, and a 1- to 1.5-cm incision was made 6 cm lateral to the interlaminar space (Fig. 1C) as a puncture point for inserting the working cannula and interbody cage. Following skin disinfection and draping, a puncture was made at the marked point, and a guide wire was percutaneously introduced into the dorsolateral part of the L5 superior articular process, guiding the insertion of the working cannula (Fig. 2A-C). Local anesthesia was administered with 5% lidocaine (5 ml) layer by layer to the shoulder of the L5 superior articular process.

Bone resection and decompression. During the resection of the L5 superior articular process, the target area was adequately exposed by gradual dilation through the cannula, and an osteotome was used to progressively resect the left superior articular process of L5 under endoscopic view (Fig. 3A), safely exposing the nerve root. The osteotome was operated slowly and steadily to avoid damaging the spinal canal or nerves. Before performing the discectomy and contralateral lateral recess decompression, the ligamentum flavum (Fig. 3B) was removed to expand the surgical field and expose the intervertebral disc.

Interbody fusion. Upon completing bilateral lateral recess decompression, a large working cannula was inserted, and under direct endoscopic visualization, a discectomy was

Table I. Meyerding classification of spondylolisthesis.

Meyerding grade	Percentage of slip (%)	Clinical description
Grade I	0-25	Mild spondylolisthesis
Grade II	25-50	Moderate spondylolisthesis
Grade III	50-75	Severe spondylolisthesis
Grade IV	75-100	Very severe spondylolisthesis
Grade V	>100	Spondyloptosis

performed at L4-5, relieving the compressed nerve root. After adequate decompression, an endoscopic dilator was used to expand the intervertebral space, and the endoscope sheath was rotated to protect the endplates. Disc material and cartilage endplates were cleaned using rongeurs and curettes (Fig. 3C and D), preparing the upper and lower endplates for the cage insertion.

Grafting and instrumentation. For grafting and cage insertion, the intervertebral space was progressively expanded using a spreader, and a trial cage was used to determine the appropriate height of the interbody cage. Based on the trial's tightness, a polyetheretherketone (PEEK) interbody cage of suitable height was selected. The resected articular process was trimmed into suitable bone graft blocks, and a funnel-shaped graft inserter was used to initially place part of the graft block anteriorly into the L4-5 intervertebral space, followed by graft granules. Before inserting the cage, the position of the exiting nerve root was rechecked under endoscopy, and the cage was placed under X-ray fluoroscopy to confirm its satisfactory position. Pedicle screws were inserted using a percutaneous technique, and titanium rods were placed and secured with compression fixation after confirming the fluoroscopic position. A drain was placed on the rod side to avoid nerve irritation.

Postoperative management. Postoperatively, decompression work and interbody graft size were assessed using plain films (Fig. 4) and CT (Fig. 5). Patients were discharged in good condition, with proper wound care, effective pain control and satisfactory mobility. Patients were required to wear a tight thoracolumbar brace for 1.5 months. Short-term radiographic outcomes were assessed, including a 6-month postoperative follow-up and CT images beyond 6 months. Clinical outcomes were evaluated using the ODI and VAS for back pain, as well as operative time, intraoperative blood loss, hospitalization time and surgery-related complications.

Outcome measures. Pain intensity was quantified using the Visual Analogue Scale (VAS), a validated 10-cm horizontal line anchored by 'no pain' (0) and 'worst imaginable pain' (10). Patients marked their perceived pain level, which was measured to the nearest millimeter (0-100 mm scale). Pain severity was categorized as: 0 (no pain), 1-3 (mild pain, no sleep disturbance), 4-6 (moderate pain, mild sleep interference) and 7-10 (severe pain, sleep disruption). The Oswestry Disability Index (ODI) assessed lumbar dysfunction through 10 domains: Pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual function, social life and traveling. Each item contains six statements graded 0 (no disability) to 5 (maximum disability). If all items were answered (maximum 50 points), the denominator was 50; if any item was omitted (e.g., sexual function), the denominator adjusted to 45. Higher scores indicate greater disability. Assessments were conducted preoperatively and postoperatively at 1, 3 and 6 months and at the final follow-up.

Statistical analysis. Statistical analyses were conducted using IBM SPSS Statistics v27.0 (IBM Corp). Continuous variables are expressed as the mean ± standard deviation following confirmation of normality via Shapiro-Wilk tests. Between-group comparisons utilized repeated-measures ANOVA with Greenhouse-Geisser epsilon correction for sphericity violations. Post-hoc pairwise comparisons applied Bonferroni-adjusted α levels (0.05/3=0.0167 for three-group comparisons). All tests were two-tailed, with $P<0.05$ considered to indicate a statistically significant difference. Data were presented as mean ± SD.

Results

The present retrospective study aimed to evaluate the early clinical efficacy and preliminary safety of endoscopic TSAP-LIF in patients with LSS. The study included 9 patients with LSS, as detailed in Table I, which presents their baseline characteristics. The average age of the patients (5 women and 4 men) was 47.3±13.1 (range: 23-67) years. All patients underwent single-segment fusion, with 8 receiving L4/5 segment fusion and 1 receiving L5/S1 segment fusion. Results showed significant improvement in ODI and VAS scores at 1 and 6 months post-operation compared with preoperative scores, with an intervertebral fusion rate of 88% at 6 months (based on postoperative CT imaging, which revealed 1 case of non-fusion) and no postoperative complications (Table V). CT scans 6 months post-operation (Figs. 4B and D and 5) showed adequate decompression of the affected side and central spinal canal. Additionally, imaging revealed a larger graft contact area compared with that of the entire intervertebral disc region. X-rays (Fig. 4B and D) taken within 1 week post-operation indicated well-prepared cartilage endplates with no gaps between the intervertebral graft and vertebrae. Furthermore, CT scans at 6 months post-operation (Fig. 5) showed continuous growth and remodeling of trabecular bone, with no significant gaps observed between the graft, cage and endplates. The average surgical time was 113.3±13.9 min, and the average intraoperative blood loss was 101.6±13.8 ml (Table V). The average hospital stay was 12.7±3.2 days. No surgery-related complications occurred in the present study (Table V). The average VAS score improved from 7.7±1.6 preoperatively to 2.6±1.4 ($P<0.0001$) at 3 months post-operation and to 1.2±1.1 ($P=0.1283$) at 6 months post-operation. The average ODI score improved from 56.7±8.2 preoperatively to 22.7±5.6 ($P<0.0001$) at 1-month post-operation and to 10.2±4.2 ($P<0.001$) at 6 months post-operation (Fig. 6).

Table II. Oswestry disability Index assessment form.

Item	Scoring options (0-5 points)
Pain intensity	No pain (0)-worst imaginable pain (5)
Personal care	Normal self-care (0)-bedridden requiring assistance (5)
Lifting ability	Can lift heavy weights without pain (0)-unable to lift anything (5)
Walking ability	Unlimited walking (0)-can only crawl (5)
Sitting tolerance	Can sit comfortably for any duration (0)-unable to sit at all (5)
Standing ability	Can stand as needed (0)-unable to stand (5)
Sleep quality	Uninterrupted sleep (0)-complete insomnia due to pain (5)
Sex life	Normal sexual activity (0)-unable to engage (5)
Social life	Unrestricted social activities (0)-complete loss of social life (5)
Travel ability	Can travel long distances (0)-only able to travel for medical care (5)

ODI percentage=(Total score/50) x100. If an item is skipped, the denominator is adjusted (e.g., 45 if one item is omitted).

Table III. Visual analogue scale.

Pain level	Analogue scale (cm)	Pain intensity	Symptom description
0	0	No pain	Not applicable
1	1-2	Mild pain	Tolerable pain with normal daily activities and sleep unaffected
2	3-4	Moderate pain	Pain moderately affects sleep and requires analgesics
3	5-6	Severe pain	Severe pain disrupting sleep, requiring narcotic analgesics
4	7-8	Intense pain	Significant sleep disturbance with associated symptoms (e.g. Sweating, tachycardia)
5	9-10	Unbearable pain	Profound sleep impairment with comorbidities or passive positioning

Discussion

Lumbar degenerative disease is a common condition in spinal orthopaedics, often causing back and leg pain with restricted movement. Lumbar fusion surgery has become the standard procedure for treating such diseases. The origin of spinal endoscopy dates back to the early 1930s when Burman used arthroscopic instruments to perform the first 'spinal endoscopy' on a cadaver, successfully displaying the spinal cord and nerve roots (20). Soon after, Pool (21) began performing spinal endoscopy through incisions ≤2.5 mm long, providing detailed observation of the nerve roots. With the advancement of optical lens systems and fiber optic technology, and the continuous development and expansion of surgical techniques, Cloward (22) first proposed posterior LIF (PLIF) in 1953. This technique offered clear surgical field exposure, high neural decompression and a stable three-dimensional spine structure, restoring the normal lumbar curvature. However, PLIF also had significant drawbacks, such as damaging posterior spinal structures (e.g. spinous processes, lamina and bilateral facet joints) and causing nerve root traction injuries (22). In 1983, Kambin and Zhou (23) performed the first percutaneous arthroscopic discectomy, and in 1991, Kambin (24) introduced the concept of a triangular safety zone, a triangular area formed by the upper edge of the lower vertebra, the outer edge of the dural sac or traversing nerve root and the inner edge of the exiting nerve root. This area is relatively safe for surgical operations and is the pathway for endoscopic transforaminal neural decompression and interbody fusion. To reduce iatrogenic injuries, Leu and Hauser (25) first reported the use of percutaneous endoscopic lumbar fusion in 1996, although this surgery had a high overall complication rate, including postoperative nerve root pain with dysesthesia, symptomatic interbody cage displacement and the need for salvage surgery. Since then, surgical methods and tools have gradually improved, allowing for adequate discectomy, endplate preparation and the use of appropriate lumbar interbody cages to avoid nerve injuries.

The indications for TSAP-LIF under full endoscopy are similar to those for conventional spinal fusion surgery, especially when spinal instability causes neural compression (26). With regard to approach selection, the SAP reshaping should ensure the safety of the exiting nerve root, typically by gradually reshaping the dorsal side of the SAP to create sufficient safe space and reduce the probability of nerve root injury. The rational use of foraminoplasty tools, such as power systems,

Table IV. Summary of patient statistics and diagnostic data.

Patient no.	Sex	Age, years	Diagnosis	Level
1	F	45	L4-5 disc herniation and degeneration (left-of-center type) combined with mild posterior slippage of the L4 vertebral body.	L4/5
2	F	52	L4-5 intervertebral disc prolapse, degeneration leading to spinal canal stenosis (right-of-center type), combined with degenerative changes of the endplates.	L4/5
3	F	55	L4-5 intervertebral disc prolapse, degeneration leading to spinal canal stenosis.	L4/5
4	M	67	L5-S1 intervertebral disc herniation combination of L5 isthmic fracture of the arch with forward slip (first degree).	L5/S1
5	F	46	L4-5 intervertebral disc herniation, degeneration combined with mild forward slippage of L4 vertebrae, bilateral vertebral tuberosity and hyperplasia leading to spinal canal stenosis.	L4/5
6	F	54	L4-5 disc herniation, degeneration (right intervertebral foramina type) leading to spinal stenosis combined with mild forward slip of the L4 vertebrae, and spinal stenosis due to bilateral hypertrophy and hyperplasia of the vertebral tuberculum.	L4/5
7	M	52	L4-5 intervertebral disc herniation, degeneration leading to spinal stenosis, combined with vertebral body endplate inflammation.	L4/5
8	M	23	L4-5 disc herniation causing spinal stenosis.	L4/5
9	M	32	L4-5 disc herniation causing spinal stenosis (left radicular type).	L4/5

F, female; M, male.

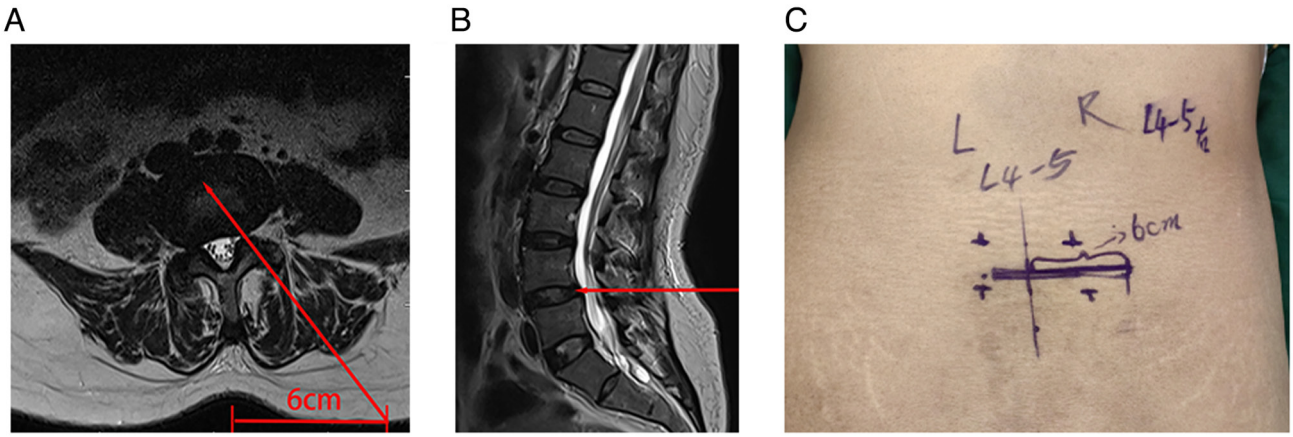

Figure 1. Preoperative planning and incision marking. (A) Preoperative axial magnetic resonance imaging (MRI) for surgical planning, highlighting the 6 cm measurement (red arrow) along the spinal axis. (B) Preoperative sagittal MRI for trajectory mapping, with the region of interest demarcated by red lines. (C) Preoperative skin marking of incision sites (blue ink), indicating the L4-5 right interlaminar window and 6 cm incision length.

trephine systems and protective sleeves under full endoscopy, can effectively prevent injury to the exiting nerve root and dural sac (27).

According to the location and characteristics of stenosis, a reasonable decompression method should be selected. The TSAP approach can cover most of the intervertebral foramen's internal and external ranges and the affected-side lateral recess. It is also suitable for severe central canal stenosis dorsal decompression and L5/S1 segment decompression (28), but cannot perform bilateral decompression through a unilateral approach, which is a limitation of this technique (29). Therefore, the indications of the patient should be clarified preoperatively.

Proper graft bed preparation is a prerequisite for achieving bony fusion, which can be performed under direct vision or endoscopic vision. The former is similar to traditional methods, using endplate chisels and curettes to scrape the cartilage endplate, but it is prone to damaging the bony endplate. High-quality endoscopic treatment of the cartilage endplate can avoid excessive damage to the bony endplate, although it is less efficient. Previous reports (30-32) used modified instruments, such as specially designed endplate chisels

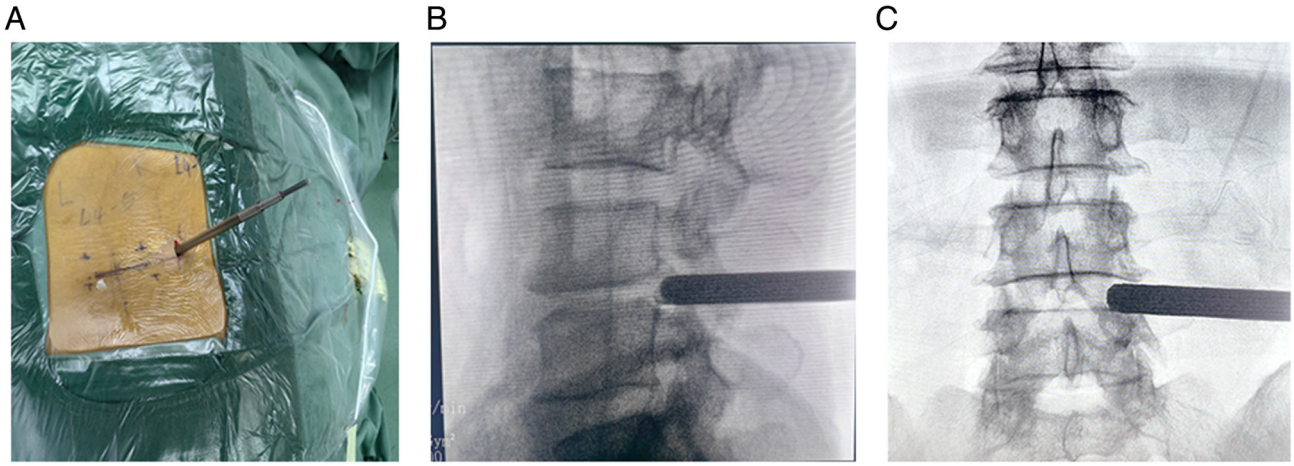

Figure 2. Intraoperative channel placement verification. (A) Intraoperative photograph of the working channel insertion under sterile draping, showing the dilator cannula positioned within the soft tissue. (B) Intraoperative anteroposterior fluoroscopic image confirming guidewire placement through the dilator channel at the L4-5 interlaminar window. (C) Lateral fluoroscopic view demonstrating dilator cannula trajectory aligned with the intervertebral disc space.

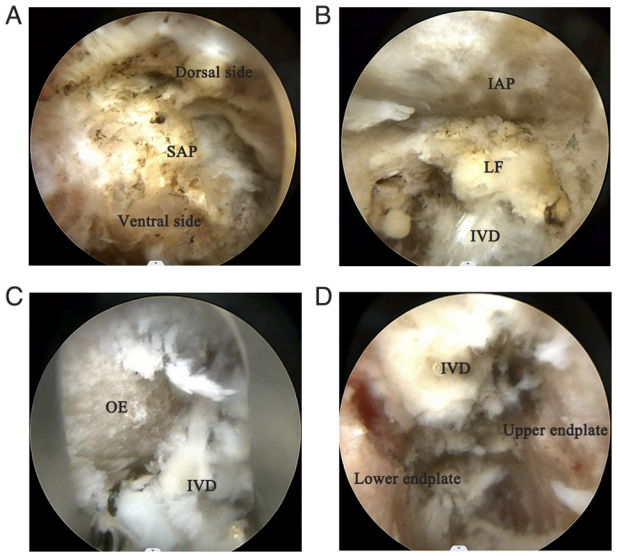

Figure 3. Key surgical steps in lumbar decompression. (A) L5 SAP resection, (B) removal of the ligamentum flavum and intervertebral discs, (C) decortication of the OE, (D) Processed endplate and remaining intervertebral discs. SAP, superior articular process; IAP, inferior articular process; LF, ligamentum flavum; IVD, intervertebral disk; OE, osseous endplate.

and L-shaped reverse curettes, to handle the intervertebral space safely and efficiently, preparing the graft bed through a combination of direct and endoscopic vision (33).

After years of clinical screening and verification, PEEK cages are the most widely used clinically (34). Although smaller cages can safely pass through the working path, they may not effectively restore intervertebral height, and PEEK is an inert bone-inducing material, unfavorable for LIF. Clinical refinements to the shape and size of the cages have been made to address this problem, and their hollow centers have been designed to accommodate osteoinductive material implants to promote inward growth of bone to induce fusion where rigid stabilization is required. Graft material selection includes autogenous bone from decompression, autogenous iliac bone, allograft bone and BMP-2. In theory, autogenous bone from decompression is the best choice. If affected by bone quantity, composite grafting with autogenous bone from local decompression and other graft materials can be used (35).

Bilateral pedicle screw fixation is currently advocated, providing a more stable biomechanical environment than unilateral fixation, bilateral lamina facet screws or facet screws, reducing complications such as cage displacement, graft non-union and internal fixation failure (36).

TSAP-LIF has significant advantages in terms of a shorter operation time compared with other minimally invasive LIF surgeries. Zhang *et al* (37) conducted a retrospective study of 62 patients, where the operation time for endoscopic transforaminal LIF (Endo-TLIF) was 202.6±31.4 min, and that for minimally invasive transforaminal LIF was 192.1±18.9 min. In the present study, the operation time was 113.3±13.9 min. Unlike Endo-TLIF, which requires the removal of both superior and inferior articular processes, TSAP-LIF only involves the removal of the superior articular process. The use of ring saw tools allows for rapid excision of the superior articular process, thus shortening the operation time. Fan *et al* (38) retrospectively analyzed the data of 69 patients with LSS, finding that the operation time for unilateral lateral interbody fusion was 112.78±19.29 min and that for Endo-TLIF was 174.58±18.41 min. According to a recent meta-analysis, percutaneous endoscopic lumbar interbody fusion (PE-LIF) compared with unilateral biportal endoscopic transforaminal lumbar interbody fusion (UBE-TLIF), the TSAP-LIF procedure showed similar operative time; however, TSAP-LIF exhibited advantages in reduced tissue trauma (supported by lower intraoperative blood loss and postoperative CRP levels), which accelerated wound healing (39). Nevertheless, due to limitations in instrument maneuverability, the working and viewing channels of TSAP-LIF are integrated into a single portal, precluding simultaneous bilateral decompression of the intervertebral foramina and lateral recesses. The mean hospital stay for patients in this study was 12.7±3.2 days, influenced by China's universal healthcare system (40), which reduces hospitalization costs, thereby enabling patients to discharge upon clinical improvement or to undergo in-hospital rehabilitation prior to discharge.

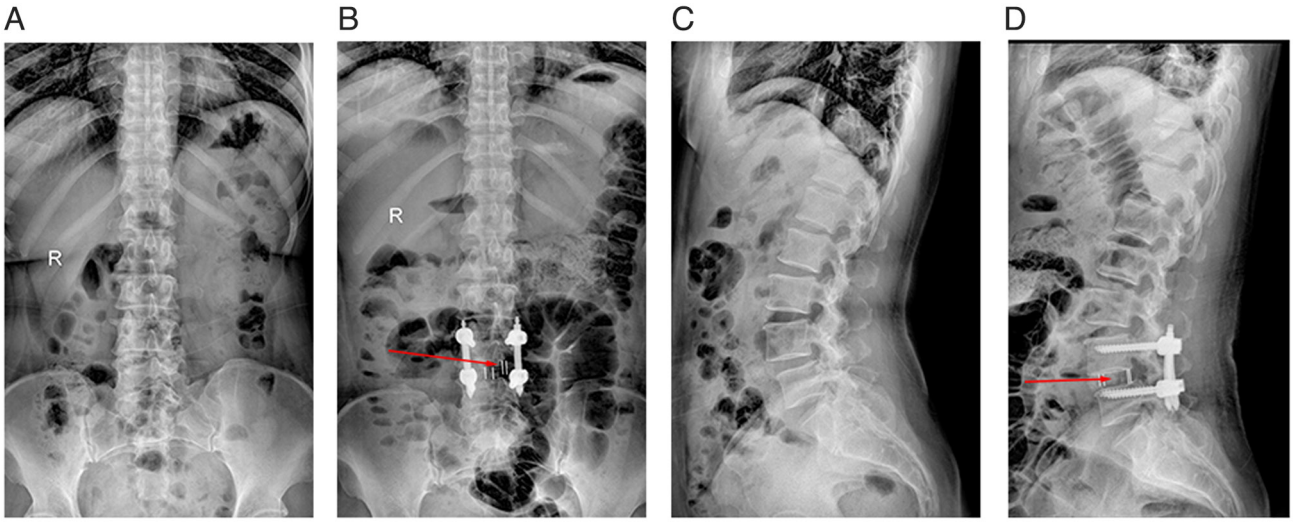

Figure 4. Preoperative vs. postoperative radiographic outcomes. (A) Preoperative lumbar AP image, (B) postoperative lumbar AP image, (C) preoperative lumbar lateral image and (D) postoperative lumbar lateral image in patients with transforaminal upper facet joint lumbar interbody fusion. AP, anteroposterior.

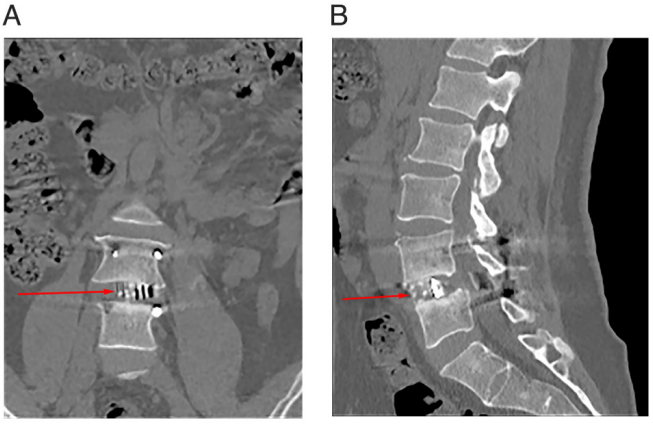

Figure 5. Postoperative 6-month CT fusion assessment. (A) Anteroposterior CT bone window of the lumbar segment with the interbody fusion device at 6 months postoperatively. (B) Lateral CT bone window of the lumbar segment with the interbody fusion device at 6 months postoperatively in patients who underwent transforaminal upper facet joint lumbar interbody fusion. CT, computed tomography.

Additionally, the preoperative and postoperative ODI and VAS scores from the present study were compared with those reported in other studies on endoscopic LIF techniques. Brusko and Wang (10) reported a significant improvement in the average ODI score by 12.3 points at the 1-year follow-up of 100 patients. Morimoto *et al* (28) showed improvements in VAS scores for back pain to 4.4-6.0 and for leg pain to 4.3-6.9, with ODI score improvements ranging from 19.5 to 41.5. In the study by Xie *et al* (41), the VAS scores decreased from 7.43±0.50 preoperatively to 3.20±0.48 at the first postoperative week, 2.97±0.41 at 1 month and 2.80±0.41 at 1 year. The improvements in ODI and VAS scores from the present study are generally consistent with those achieved by other minimally invasive lumbar spine surgical techniques (42-45), indicating significant relief of preoperative symptoms of lower back and leg pain, as well as favorable outcomes in interbody fusion.

There are certain limitations to the present study. As TSAP-LIF is a novel surgical technique evaluated in a single-center institutional study, the retrospective analysis is limited by a relatively small sample size. Although paired sample tests revealed significant differences ($P<0.05$) in the changes in VAS scores for back pain and ODI indices in TSAP-LIF patients, the limited sample size could result in broad confidence intervals, increasing uncertainty in the outcomes and potentially affecting inferences about the effects of TSAP-LIF. A small sample size may lead to unstable effect size estimates, potentially resulting in an inaccurate assessment of the superiority of TSAP-LIF over other techniques. Additionally, selection bias may influence the results due to factors such as patient selection criteria and willingness to participate, limiting the generalizability of the findings. Future prospective studies should employ strategies such as randomization and stratified sampling, and involve larger multicenter cohorts to verify these results and enhance their applicability to a broader population.

The primary aim of this retrospective study was to evaluate the initial safety and short-term efficacy of TSAP-LIF. A 6-month follow-up period is commonly used in similar studies to assess early postoperative recovery and functional improvements. In clinical practice, significant recovery and symptom improvement typically occur within the first 6 months post-surgery, providing sufficient data to evaluate the direct effects of the surgery. Research by Uçar *et al* (46) showed that patients could be allowed to engage in full activity and return to work 6 months after lumbar spine fusion surgery. Woods *et al* (47) conducted a retrospective study on 137 patients who underwent LIF, and the CT fusion rate at all fusion levels was 97.9% at 6 months after surgery. A 6-month follow-up period is adequate for early efficacy and safety assessments, and it can provide some insight into long-term outcomes, such as fusion durability and sustained clinical improvement. However, it is essential to extend the follow-up duration beyond 12 months to thoroughly evaluate the long-term success of TSAP-LIF. This is particularly important due to the progressive nature of LSS and the potential for recurrence of symptoms over time.

Table V. Intraoperative and postoperative patient metrics.

Patient no.	Surgical time, min	Intra-operative blood loss, ml	Duration of hospital stay, days	Inter-vertebral fusion
1	115	102	18	Yes
2	100	88	12	Yes
3	120	116	9	Yes
4	95	84	12	Yes
5	125	107	10	No
6	105	92	18	Yes
7	115	104	12	Yes
8	140	127	11	Yes
9	105	94	12	Yes

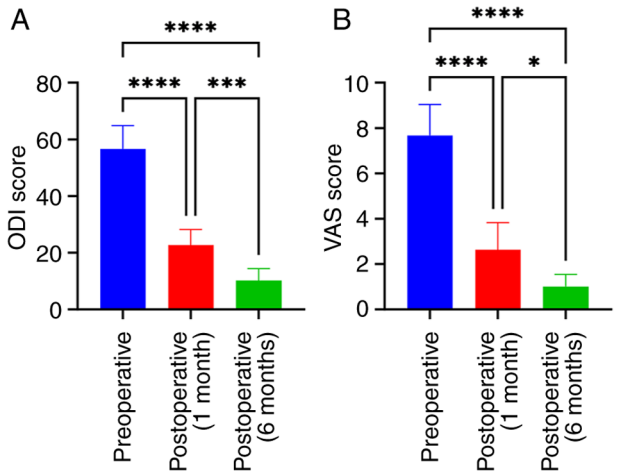

Figure 6. Clinical outcome metrics after TSAP-LIF. (A) Changes in ODI index of patients with TSAP-LIF. (B) Changes in VAS scores for lower back pain in patients with TSAP-LIF. *P<0.05, ***P<0.001 and ****P<0.0001. VAS, Visual Analog Scale; ODI, Oswestry Disability Index; TSAP-LIF, transforaminal upper facet joint lumbar interbody fusion.

The technical and instrumentation limitations of TSAP-LIF are important considerations, particularly for patients with unilateral or central stenosis. The lumbar spine features substantial upper and lower laminar spaces, which allow for the removal of the upper articular process to decompress the contralateral affected side. Due to the specific anatomy of the lumbar spine, there is often ipsilateral blockage from the upper and lower articular eminences or lamina, making it difficult to decompress the lateral recess or foramen on both sides simultaneously via the superior articular eminence. Consequently, the intervention primarily addresses the affected side and the central region through this approach. In cases where there is bilateral compression in the lumbar spine, it may be necessary to remove portions of the upper and lower articular processes or even the vertebral plate on the same side for ipsilateral decompression. This demands a high level of skill on the part of the surgeon in manipulating the instrumentation. Furthermore, the option exists to perform simultaneous surgeries using a dual- or multichannel system, which facilitates enhanced decompression of both sides of the intervertebral foramen and lateral recess. The integration of more flexible and maneuverable endoscopes and surgical instruments can better accommodate diverse anatomical structures, thus overcoming some limitations in instrument maneuverability. Additionally, the utilization of real-time imaging and navigation technologies, along with robotic-assisted systems, can enhance the precision and adaptability of surgical instruments. This advancement not only aids surgeons in accurately localizing the surgical site but also enables them to execute more complex procedures effectively.

In conclusion, TSAP-LIF represents a promising minimally invasive technique for addressing lumbar spine pathologies. The technique offers significant advantages, including reduced operative time, minimized intraoperative blood loss and the ability to achieve effective decompression of the affected and central regions through a unilateral approach. This allows for the efficient completion of discectomy and endplate preparation. Despite the challenges posed by the limited maneuverability of current instruments, advancements in surgical tools and the growing expertise of surgeons in endoscopic spinal procedures enhance the potential for improved clinical outcomes. Future efforts will focus on extending patient follow-up to 12 months, employing postoperative imaging techniques such as plain films and CT scans to thoroughly evaluate long-term fusion success. By addressing the current limitations and with ongoing innovations in surgical technology, TSAP-LIF has the potential to deliver superior clinical and radiological outcomes, thereby extending the capabilities of the Kambin approach.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

HL and JL conceptualized the study design, performed surgical interventions, analyzed data and drafted the manuscript. YG and SQ conducted data acquisition and postoperative follow-up evaluations. PH and YX supervised the study, validated analytical methods and critically revised the manuscript. PH and YX confirm the authenticity of all the raw data. All authors participated in drafting/revising the manuscript, provided final approval of the published version and agree to be accountable for all aspects of the work. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

The present study was approved by the Ethics Committee of Yunfeng Hospital (approval no. YFHETH2024006). All patients provided written informed consent to participate in the study.

Patient consent for publication

Written informed consent for publication of their clinical details and/or clinical images was obtained from the patients.

Competing interests

The authors declare that they have no competing interests.

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