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Current status of indirect decompression with lateral lumbar interbody fusion

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ABSTRACT

The adoption of lumbar fusion techniques, particularly lateral lumbar interbody fusion (LLIF), has significantly evolved the management of degenerative lumbar spinal conditions. LLIF, introduced as a minimally invasive surgical procedure, offers the advantage of indirect neural decompression and robust bone fusion using large interbody cages, reducing complications such as cage subsidence and nerve injuries. Systematic reviews have indicated that LLIF was effective for foraminal decompression, although evidence regarding its effectiveness for spinal canal and lateral recess decompression remains limited. Comparisons between indirect decompression techniques like LLIF and direct methods (posterior lumbar interbody fusion and transforaminal lumbar interbody fusion) have revealed that while indirect approaches generally promoted lower surgical times and blood loss, outcomes related to pain, disability, and complications were comparable. Indirect decompression with LLIF should be approached cautiously or avoided in patients with severe stenosis or preoperative neurological impairments due to the increased risk for postoperative complications. Furthermore, meticulous surgical planning and advanced imaging techniques are essential for mitigating risks such as vascular, bowel, and ureteral injuries. Continued advancements in surgical instrumentation and navigation technologies are expected to further refine the utility of LLIF in treating complex spinal pathologies, offering a promising minimally invasive option for achieving effective spinal stabilization and decompression.

Keywords: indirect decompression, lateral lumbar interbody fusion, minimally invasive spine surgery, complications, spinal canal stenosis

Abbreviation:
LLIF: lateral lumbar interbody fusion

INTRODUCTION

The landscape for the management of degenerative lumbar spinal conditions, including spinal stenosis and spondylolisthesis, has undergone significant evolution with the increasing adoption

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of surgical interventions, particularly lumbar fusion techniques. In the United States, a notable 62.3% surge in lumbar fusion procedures[1] had been observed from 2004 to 2015, accompanied by a substantial rise in hospital costs exceeding $10 billion in 2015. This trend underscores the growing reliance on surgical solutions to address the challenges posed by an aging population and the increasing prevalence of spinal disorders.

Lateral lumbar interbody fusion (LLIF), introduced by Ozgur et al in 2006, is a notable surgical innovation currently gaining prominence.[2] LLIF is a surgical procedure performed in the lateral decubitus position using specialized retractors and lighting to achieve sufficient visualization while minimizing tissue disruption. To access the intervertebral disc laterally via the transpsoas approach or through the anterior aspect of the psoas muscle, the procedure involves detaching the annulus fibrosus and inserting a large interbody cage extending to the transverse diameter of the vertebral body. This allows for wide-ranging disc removal and creation of a bony bed, facilitating stable vertebral body fixation using a large cage that supports the robust areas surrounding the vertebral body. Preserving the ligamentous structures essential for spinal stability (ie, the anterior and posterior longitudinal ligaments, yellow ligament, and interspinous ligament) during restoration of disc height enables ligamentotaxis, which promotes tension restoration within the ligaments. This technique facilitates coronal and sagittal plane corrections, contributing to effective spinal stabilization.[3-5]

LLIF offers several advantages, such as indirect neural decompression and robust bone fusion facilitated by large interbody cages.[6-11] These cages support the vertebral endplate epiphyseal ring, thereby minimizing complications, such as cage subsidence and nerve injuries, and potentially promoting better sagittal and coronal spinal alignment than that achieved with traditional posterior techniques. A systematic review of 20 studies encompassing 1,080 cases evaluated the surgical outcomes of indirect decompression using LLIF.[11] The review reported that LLIF was particularly effective in achieving foraminal decompression, producing a 30% increase in the foraminal area on average. Although evidence for spinal canal and lateral recesses decompression remains limited, reports have also indicated its efficacy in these areas.[11]

The emergence of minimally invasive spine surgery, which includes techniques utilizing percutaneous pedicle screws (PPS) and advanced interbody fusion devices like extreme lateral interbody fusion (XLIF) and oblique lateral interbody fusion (OLIF), underscores a trend toward reducing surgical morbidity while achieving effective spinal correction and decompression.[6,12,13] These developments highlight the evolving landscape of lumbar fusion surgery, which aims at optimizing patient outcomes amidst the increasing demand for effective, minimally invasive treatments.

Therefore, the current review aims to evaluate the clinical and radiological outcomes of indirect neural decompression for lumbar degenerative diseases by comprehensively analyzing the existing literature. By addressing these aspects, this review seeks to elucidate the potential benefits and limitations of indirect decompression with LLIF, thereby informing clinical decision-making in the management of degenerative lumbar spinal disorders.

EFFICACY OF INDIRECT DECOMPRESSION

Several studies have compared the outcomes of indirect decompression techniques, such as XLIF or OLIF, and direct decompression methods, like posterior lumbar interbody fusion (PLIF) or transforaminal lumbar interbody fusion (TLIF), in the treatment of lumbar degenerative conditions (Table 1). Du et al found that the indirect decompression group had significantly lower surgical times and blood loss than did the direct decompression group, although no significant difference in disability, pain, and complication rates were found between groups.[19] Hiyama et al reported similar findings, with lower surgical times and blood loss in the indirect decompression group for degenerative spondylolisthesis but no significant difference in pain at 12 months.[16] Nakashima et al[3] observed comparable pain, disability, and complication rates between the indirect decompression (OLIF) and direct decompression (PLIF) groups, despite some differences in patient characteristics. Overall, although indirect decompression techniques generally showed advantages in surgical efficiency, such as lower blood loss and shorter surgical times, outcomes related to pain, disability, and complications did not consistently favor indirect decompression over direct decompression approaches across the studies reviewed.

Table 1 Comparison of the outcome between indirect and direct decompression

Source	Patients number		Pain (VAS)		Blood loss (mL)		Surgical time (min)		Complication rate (%)	
	ID	DD	ID	DD	ID	DD	ID	DD	ID	DD
Lin,[14] 2018	25	25	1.7 ± 1.3	1.4 ± 1.3	106.4 ± 15.5	278 ± 133.9	96 ± 15.2	182.8 ± 35	32	24
Verla,[15] 2018	17	29	3.7 ± 1.2	2.6 ± 1.3	79.9 ± 63.4	119 ± 72.5	NA	NA	0	17.2
Hiyama,[16] 2020	62	44	2 ± 1.5	2.8 ± 1.5	85.4 ± 125.4	258.3 ± 220.4	109.9 ± 35.4	153.3 ± 50.9	17.7	18.2
Kotani,[17] 2020	92	50	2.4 ± 1.6	3.1 ± 2.1	51 ± 47.2	68.7 ± 66.7	108 ± 22.1	103.8 ± 22.3	14.1	14
Nakashima,[9] 2020	81	203	2.5 ± 1.4	2.8 ± 1.5	NA	NA	NA	NA	12.3	14.8
Sheng,[18] 2020	38	55	2 ± 0.6	2.3 ± 0.7	64 ± 23.3	186.4 ± 80.2	90.8 ± 7.9	100.2 ± 15	7.9	9.1
Du,[19] 2021	28	37	1.2 ± 0.9	1.2 ± 1.1	98.0 ± 12.1	155.8 ± 15.8	93.2 ± 5.9	125.4 ± 9.1	14.3	16.2
Koike,[20] 2021	38	48	2.8 ± 1.5	3.2 ± 2.1	51.7 ± 37.8	71.3 ± 66.8	111.9 ± 23.6	103.6 ± 22.3	10.5	10.4

ID: indirect decompression
DD: direct decompression
VAS: visual analog scale
NA: not available

A prospective cohort by Nakashima et al[7] evaluated the effects of indirect decompression using LLIF with posterior fixation over a 2-year period (Figure). The study, which involved 102 patients undergoing indirect decompression at 136 levels, found significant radiographic improvements. In particular, the cross-sectional area of the thecal sac increased from 62.0 ± 32.4 mm^2 before surgery to 126.2 ± 46.8 mm^2 (203.6% of the preoperative size) 2 years after surgery, whereas the cross-sectional area of the ligamentum flavum decreased from 150.9 ± 44.2 mm^2 before surgery to 88.4 ± 36.0 mm^2 (58.6% of the preoperative size) 2 years after surgery. Additionally, the anteroposterior diameter of the bulging disc reduced from 5.5 ± 1.4 mm before surgery to 2.6 ± 1.3 mm (46.6% of the preoperative size) 2 years after surgery. These radiographic changes contributed to significant spinal canal expansion and indirect decompression of lumbar stenosis,

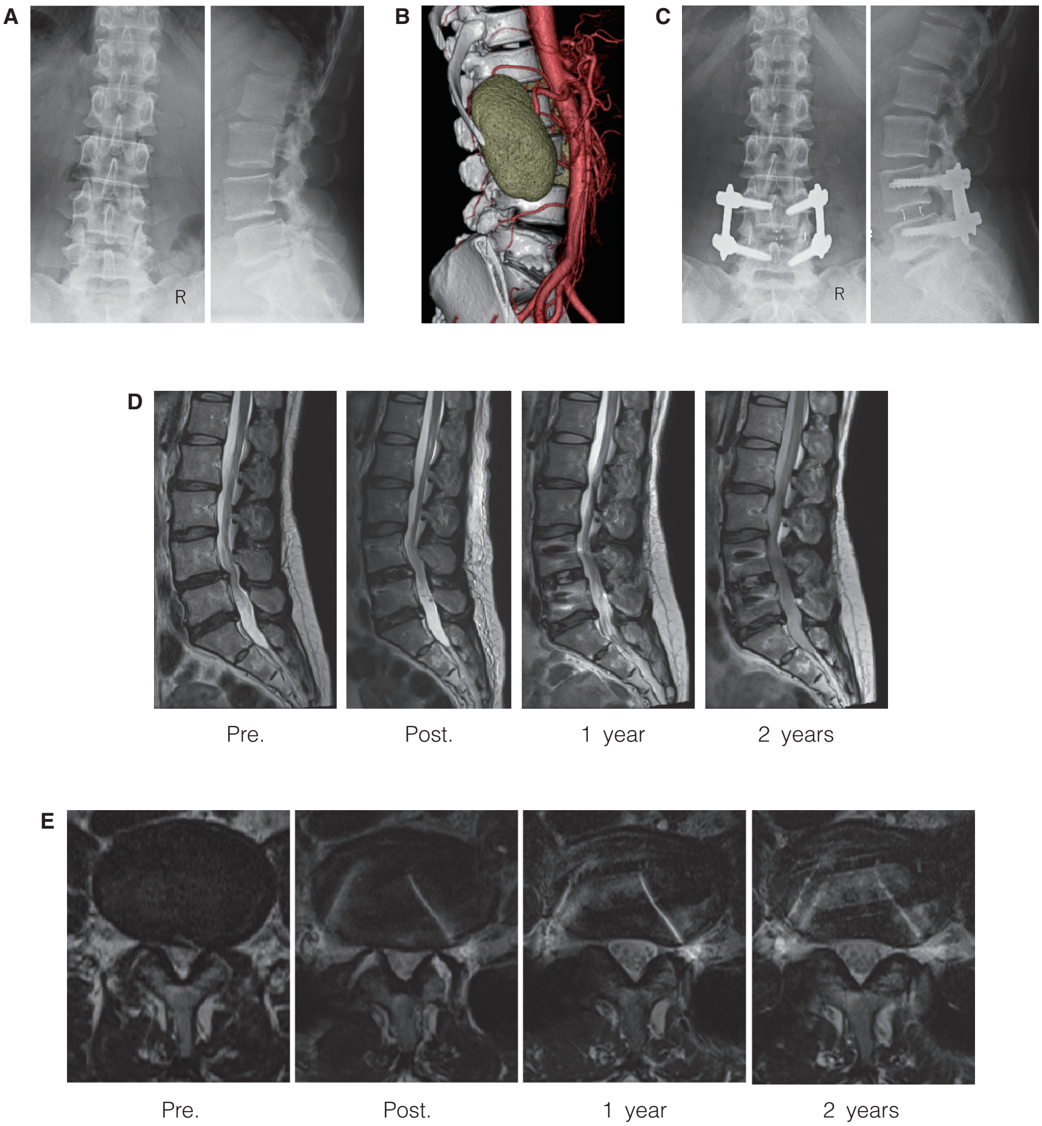

Figure A representative case involving a 48-year-old woman with L4 degenerative spondylolisthesis who underwent indirect decompression using lateral lumbar interbody fusion and posterior spinal fixation with percutaneous pedicle screws

A: Preoperative radiograph showing L4 degenerative spondylolisthesis.

B: Relationship between vascular structures and the intervertebral disc on 3-dimentional computed tomography, demonstrating no abnormalities in the vascular anatomy.

C: Postoperative radiograph showing improvement in L4 spondylolisthesis following L4–L5 lateral lumbar interbody fusion and posterior fixation with percutaneous pedicle screws.

D: Sagittal T2-weighted magnetic resonance imaging before and after surgery, showing progressive enlargement of the thecal sac over time.

E: Axial T2-weighted magnetic resonance imaging before and after surgery, demonstrating the expansion of the thecal sac over time.

although the clinical outcomes measured by the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire were not consistently correlated with radiographic improvements over the same period.

A meta-analysis by Gagliardi et al[21] found that the indirect decompression approach had a slight, nonsignificant advantage in 12-month pain outcomes over direct decompression (mean difference, −0.18; 95% CI, −0.50 to 0.14; involving 872 participants), despite considerable heterogeneity (I^2 = 67%). The indirect decompression group showed a marginal, statistically insignificant advantage in disability outcomes, assessed using a fixed-effect model due to low heterogeneity (I^2 = 39%), over the direct decompression group (standardized mean difference, −0.17; 95% CI, −0.35 to 0.00; involving 578 participants), with three studies omitting this metric. Postoperative complications were comparable between the groups, with no significant difference in risk (relative risk, 1.02; 95% CI, 0.74 to 1.41; I^2 = 0%), encompassing transient neurological deficits in the indirect decompression group and dural tears in the direct decompression group. The indirect decompression group exhibited significantly lesser blood loss and shorter surgical time than did the direct decompression group (blood loss: mean difference, −84.85 mL; 95% CI, −117.42 to −52.28; surgical time: mean difference, −24.45 min; 95% CI, −41.85 to −7.05), despite marked heterogeneity and incomplete reporting of measurement methods.

RISK OF COMPLICATIONS WITH INDIRECT DECOMPRESSION ASSOCIATED WITH THE LLIF APPROACH

Although LLIF offers distinct advantages in spinal surgery, including reduced tissue disruption and enhanced recovery, it also presents inherent risks, such as vascular, bowel, and ureteral injuries.[22,23] These risks underscore the importance of meticulous surgical planning, advanced imaging techniques, and ongoing training to mitigate complications associated with LLIF procedures. LLIF involves an anterior approach through the retroperitoneal space, necessitating the displacement or retraction of abdominal viscera and careful maneuvering to avoid injuring the major blood vessels and retroperitoneal organs. According to a nationwide survey[23] involving 13,245 cases conducted by the Japan Spine Society from 2015 to 2020, 2.76% of cases who underwent LLIF developed complications, with sensory impairment (0.5%), motor paralysis (0.43%), and major psoas muscle weakness (0.22%) being the most common. The same survey found a reoperation rate of 0.74% and a mortality rate due to complications of 0.03%.

Furthermore, Nakashima et al identified risk factors for unplanned second-stage decompression due to postoperative neurological deterioration following indirect lumbar decompression using LLIF with posterior fixation.[24] The study, which involved 158 patients with degenerative lumbar diseases, found that the presence of severe preoperative canal stenosis, preoperative neurological deficits, hemodialysis, and ligament ossification significantly increased the risk of postoperative neurological deterioration. The findings suggested that indirect decompression with LLIF should be approached cautiously or avoided in patients with severe stenosis or preoperative neurological impairments to prevent complications.[24]

THIGH–RELATED SYMPTOMS

Owing to its lateral disc space approach, LLIF can cause several thigh-related symptoms ranging from mild to severe.[25] Thigh-related symptoms primarily refer to sensory disturbances, such as numbness, tingling, or paresthesia, as well as motor weakness or pain localized to the anterior or lateral thigh. These symptoms are supposedly caused by transient or, in some cases, sustained irritation or injury to the lumbar plexus, particularly the femoral or lateral femoral cutaneous nerves, during the surgical approach to the psoas muscle.[25]

Although these symptoms often resolve within a few months, they can occasionally persist beyond a year. National surveys in Japan have indicated that thigh-related symptoms lasting over 3 months are more frequently associated with the transpsoas approach in LLIF than with the anterior approach.[22] The incidence of postoperative thigh symptoms varies widely, with up to 60.7% of patients experiencing some form of thigh symptom. Systematic reviews on thigh symptoms have reported anterior thigh or groin pain (9.3%–43.0%), hip flexion weakness (13.6%–30.8%), sensory changes (3.1%–60.7%), and motor deficits (0%–23.9%).[25]

To mitigate these symptoms, surgeons should adopt techniques that are gentle on the psoas major muscle and lumbar nerve plexus.[25] The inclusion of the L4–L5 disc space has been frequently associated with postoperative complications due to the dense concentration of neural structures within such a space. Moreover, longer surgical durations have been correlated with an increased risk of developing postoperative symptoms, particularly due to prolonged retraction of the psoas muscle.

VASCULAR INJURIES

The retroperitoneal space around the spine contains numerous vital blood vessels, highlighting the importance of preoperative imaging, such as contrast-enhanced 3-dimentional computed tomography, for assessing vessel courses and anatomical variations. Although LLIF is primarily an anterior procedure that does not directly manipulate segmental lumbar vessels, the variations in lumbar vascular anatomy require meticulous preoperative planning to avoid vascular injuries. The reported frequency of such injuries ranges from 0% to 0.4%,[26] with Japanese national data[23] indicating a 0.13% incidence rate for major vascular injuries involving the abdominal aorta, inferior vena cava, and iliolumbar vessels. Specific cases of major vascular injuries include fatal injury,[27] retroperitoneal hematoma,[28] and common iliac vein laceration.[29]

BOWEL INJURIES

The adherence of colon segments to the posterior abdominal wall through mesenteric attachments complicates LLIF approaches to the retroperitoneal space. Japanese national surveys have reported a 0.04% incidence rate for bowel injuries.[23] Uribe et al, who surveyed 13,004 patients undergoing XLIF, found that 11 patients (0.08%) experienced visceral complications, including bowel injuries.[30] Furthermore, a retrospective study on 590 transpsoas lumbar interbody fusion surgeries by Rustagi et al reported that three patients had bowel injuries, indicating an incidence rate of 0.51%.[31]

Though rare, bowel injuries following LLIF can cause severe complications if not promptly identified and treated. High clinical suspicion and routine postoperative imaging are crucial for the early detection and management of this potentially life-threatening complication.

URETERAL INJURIES

The ureter traverses the retroperitoneal space, often adhering closely to the anterior surface of the psoas muscle. LLIF, particularly via the anterior approach, poses a risk for ureteral injury, which can cause postoperative complications such as abdominal pain, fever, or serous discharge from the wound site. Timely identification and management are crucial considering that delayed diagnosis may complicate reconstruction efforts. Compared to other surgical complications, ureteral injury rarely occurs during LLIF. The reported frequency of ureteral injuries has varied across different studies. Fujibayashi et al reported an incidence of 0.1% (3 out of 2,998 cases),[22] whereas Yagi et al[23] reported an incidence of 0.05% (6 out of 13,245 cases).

Kagami et al investigated the anatomical positioning of ureters relative to the spine during LLIF and identified specific lumbar levels and left–right differences that increase the risk for ureteral injury during surgery. Accordingly, they revealed that ureters in the lower lumbar regions (L3–L4, L4–L5, and L5–S) and on the left side are more frequently positioned in the C region (between the vertebral body and psoas muscle) where the risk for injury is highest, especially among women, thereby emphasizing the necessity of preoperative imaging to avoid ureteral injury.[32]

Clinicians need to note that the onset of ureteral injuries can be either immediate or delayed. For instance, Lee et al reported that macrohematuria was noticed intraoperatively when the ureter was injured, necessitating immediate repair.[33] Conversely, Hey et al described symptoms appearing 6 months after surgery, highlighting the need for long-term monitoring.[34]

DISCUSSION

The LLIF procedure is primarily indicated for pathologies involving degenerative conditions causing spinal stenosis, instability, or deformity between vertebral bodies, such as degenerative spondylolisthesis, degenerative scoliosis, and degenerative kyphosis. Indirect decompression techniques, such as LLIF combined with PPS, allow for decompression without directly manipulating neural tissues. This approach has been known for its ability to avoid mechanical damage to the nerve roots, dura mater, and postoperative hematoma, presenting a significant advantage.

Evidence regarding the adjunct use of posterior fixation following LLIF remains insufficient to definitively recommend its application. Nonetheless, studies have reported a notable 10.3% reoperation rate due to nerve root injury or significant cage subsidence when only anterior cage insertion (stand alone) was performed.[35] Therefore, achieving circumferential fixation with a posterior adjunct is generally considered preferable. Techniques such as PPS and cortical bone trajectory screws, which allow for minimally invasive posterior fixation, help with spine construction while minimizing disruption to the ligaments and paraspinal muscles. Biomechanical experiments using cadaveric models have identified that vertebral endplate damage following LLIF and early instability due to cage subsidence were risk factors potentially leading to reoperation, underscoring the necessity of posterior fixation adjuncts to achieve effective indirect decompression.[36,37]

The application of LLIF and PPS for indirect decompression has broadened to address challenges such as recurrent stenosis following decompression surgery for lumbar spinal canal stenosis in which indirect decompression can potentially mitigate the risks of neurological and dural injury during revision surgeries. Challenges associated with these procedures, such as intraoperative positioning changes, have been addressed with innovations like lateral single position surgery, thereby enhancing surgical efficiency.[13] Technological advancements, including spinal navigation and emerging spinal surgery support robots, have further reduced surgical invasiveness and radiation exposure, promising additional benefits for these techniques.

Despite the evident advantages of LLIF, its limitations must also be considered. To provide a clearer understanding of the strengths and weaknesses of this procedure, we have summarized the key points in Table 2. This comparison highlights the minimally invasive benefits of LLIF,

Table 2 Advantages and disadvantages of lateral lumbar interbody fusion

Advantages	Disadvantages
Minimally invasive approach: LLIF utilizes a lateral retroperitoneal, transpsoas corridor, which reduces muscle dissection and preserves posterior structures, potentially decreasing postoperative pain and hastening recovery.	**Risk of nerve injury**: The approach involves traversing the psoas muscle, which can pose a risk to the lumbar plexus, potentially leading to thigh-related symptoms, such as numbness, tingling, or weakness.
Effective indirect decompression: By restoring the disc height and realigning the spine, LLIF can achieve indirect decompression of neural elements without direct manipulation, reducing the risk of nerve root or dural injury.	**Limited access to lower lumbar levels**: LLIF is generally not suitable for the L5–S1 level due to the obstruction of the iliac crest and the anterior position of the lumbar plexus at this level.
Enhanced spinal alignment: The technique allows for the insertion of larger interbody cages, facilitating the correction of coronal and sagittal plane deformities.	**Potential for cage subsidence**: The technique carries a risk for cage subsidence, especially in cases without supplemental posterior fixation, which may cause instability and necessitate reoperation.
Reduced blood loss: The minimally invasive nature of LLIF has been associated with decreased intraoperative blood loss compared to traditional open procedures.	**Requirement for neuromonitoring**: Owing to the proximity to neural structures, intraoperative neuromonitoring is essential, which may increase the complexity and cost of the procedure.
Preservation of the posterior tension band: By avoiding disruption of the posterior elements, LLIF maintains the integrity of the posterior tension band, which is important for spinal stability.	**Limited visualization**: The lateral approach provides a narrower visual field, which may make it challenging to address certain pathologies or perform direct decompression if needed.

LLIF: lateral lumbar interbody fusion

such as reduced blood loss and preservation of posterior structures, against potential challenges, including the risk of nerve injury and limited access to lower lumbar levels.

LLIF and anterior lumbar interbody fusion (ALIF) share a similar anterior approach through the retroperitoneal space for vertebral body fusion. Despite the historical efficacy of ALIF for spinal reconstruction, LLIF has revitalized interest in the anterior approach by offering reduced tissue disruption and enhanced procedural reproducibility. However, LLIF is still limited by its narrower visual field and limited operative space, despite adequate visualization for surgical maneuvers, necessitating meticulous anatomical understanding of the retroperitoneal space.

CONCLUSION

LLIF represents a significant advancement in spinal surgical techniques, particularly for its minimally invasive approach and effective indirect decompression capabilities. Continued advancements in surgical instrumentation and navigation technologies are expected to further refine and expand the utility of LLIF in treating complex spinal pathologies.

CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding this review.

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None.

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