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Clinical Comparison of Traditional Open Fusion Surgery and Unilateral Biportal Endoscopic Fusion for the Treatment of Lumbar Spinal Stenosis

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Abstract: Objective: To compare the clinical efficacy of traditional open fusion surgery and unilateral biportal endoscopic surgery in treating lumbar spinal stenosis, and to provide a reference for clinicians in choosing the surgical approach. Methods: This study retrospectively analyzed the clinical data of 80 patients with lumbar spinal stenosis who underwent surgery at Yulin Red Cross Hospital from January 2020 to February 2024. The patients were divided into two groups: one group underwent traditional open fusion surgery, while the other group underwent unilateral biportal endoscopic spine surgery. The study compared the general clinical data of the two groups, as well as various perioperative data, including surgical time, blood loss, postoperative drainage volume, serum inflammatory markers, short-term and long-term complications, and patient satisfaction with the surgical procedures. Conclusion: (1) UBE has demonstrated its advantages, such as precise positioning, small incisions, minimal bleeding, reduced postoperative pain, higher patient satisfaction, and shortened hospital stay for patients.(2) Traditional open fusion provides a larger surgical field and operating space during the procedure. However, the extensive exposure, long incisions, and prolonged recovery time are its drawbacks.(3) In clinical decision-making, individual patient differences, the complexity of the condition, and medical resources should be comprehensively considered. The choice of surgical method should take into account multiple factors to achieve the best clinical outcomes.

Keywords: Lumbar Spinal Stenosis; Unilateral Biportal Endoscopic Technique; Degenerative Spinal Diseases; Minimally Invasive Surgery; Spinal Fusion Surgery.

1. Preface

The etiology of lumbar spinal stenosis (LSS) is complex and multifactorial, involving a variety of factors such as intervertebral disc degeneration, osteophyte formation, and thickening of the ligamentum flavum. These structural changes lead to a reduction in the effective space within the spinal canal, compressing the nerves and thereby causing a range of clinical symptoms [1]. With the accelerating aging of China's population, the incidence of lumbar spinal stenosis among middle-aged and elderly individuals has been steadily increasing, seriously impacting their quality of life and placing a significant burden on society [2]. Since spinal stenosis is often accompanied by conditions such as lumbar disc herniation or lumbar instability, simply decompressing the spinal canal in these patients may not yield satisfactory clinical outcomes. Moreover, during surgery, a large decompression range or pre-existing lumbar instability could lead to postoperative segmental instability.

Traditional Open Lumbar Interbody Fusion can effectively expose and remove compressive tissues within the lumbar spinal canal, thereby efficiently relieving nerve compression [3]. It has long been considered the "gold standard" for the treatment of lumbar spinal stenosis. However, in conventional surgical procedures, obtaining a wide surgical field and ample operative space often comes at the cost of excessive tissue exposure. This approach has several drawbacks, including significant trauma, substantial intraoperative bleeding, extensive damage to soft tissues and bony spinal structures, and a high incidence of postoperative complications [4]. Moreover, it may also carry risks of postoperative complications such as paraspinal muscle weakness or atrophy and epidural hematomas. The extensive incisions, prolonged tissue exposure, excessive soft-tissue stretching, and aggressive disruption of bony structures inevitably increase the risk of postoperative paraspinal muscle atrophy and residual low-back pain. These drawbacks—such as major trauma, slow postoperative recovery, and numerous complications—pose a significant challenge for clinicians. Therefore, how to achieve sufficient decompression while preserving lumbar spinal stability as much as possible and minimizing damage to surrounding muscular tissues has consistently been a focal point of research [5]. Despite its high complication rate, Open LIF still holds an irreplaceable position in the treatment of complex or multilevel lumbar spinal stenosis, particularly when dealing with cases accompanied by spinal instability, severe disc herniation, or osteophyte formation, where it can offer a more comprehensive therapeutic solution [6, 7].

In recent years, with the continuous development and innovation of minimally invasive techniques in spinal surgery, as well as deeper research both domestically and internationally, a wide variety of surgical approaches have emerged. Unilateral Biportal Endoscopy has gradually been adopted in clinical practice due to its advantages such as minimal trauma, rapid recovery, and favorable postoperative outcomes, and it is expected to become the mainstream approach for treating lumbar spinal stenosis [8]. The unilateral biportal endoscopic spinal technique offers more flexible instrument manipulation, minimal trauma, reduced bleeding, high efficiency, rapid postoperative recovery, and a lower rate of facet joint injury. These advantages [9] offer new options for the treatment of LSS. However, the application of these new technologies is still relatively recent and remains in a continuous state of development [10]. Although UBE has

demonstrated numerous advantages in the treatment of LSS, both UBE and traditional open decompression and fusion procedures have their own strengths and limitations. We should not overemphasize minimally invasive techniques to the point of sacrificing the opportunity for thorough decompression [11]. Phan [12] et al., in a systematic review comparing minimally invasive versus traditional open lumbar decompression, found that minimally invasive surgery offers greater advantages in reducing postoperative pain and accelerating recovery. Sun [13] et al., in their study on the application of unilateral biportal endoscopic spinal techniques in degenerative lumbar spinal stenosis, highlighted the technique's outstanding performance in minimizing tissue damage and maintaining spinal stability. Nevertheless, at present, the academic community still lacks sufficient comparative evaluations between conventional surgical approaches and minimally invasive techniques [14], and there is a dearth of large-scale, long-term clinical studies to comprehensively assess their efficacy and safety.

This study retrospectively compares, in a clinical setting, the outcomes of traditional open fusion surgery versus unilateral biportal spinal endoscopy for the treatment of lumbar spinal stenosis via fusion. A multi-dimensional evaluation framework is employed, analyzing various parameters across two patient groups, including general demographic data, surgical duration, intraoperative blood loss, incision size, postoperative drainage volume, postoperative bed rest duration, total length of hospital stay, pre- and postoperative hemoglobin differences, pain scores, neurological function scores, pre- and postoperative C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) changes, number of days on postoperative analgesics, incidence of short- and long-term postoperative complications, and long-term follow-up satisfaction. The study aims to comprehensively compare the strengths and limitations of these two surgical approaches.

2. Materials and Methods

2.1. Study Subjects

This study included a total of 80 patients who were hospitalized in the Department of Orthopedics at the Yulin Red Cross Hospital from January 2020 to February 2024 due to lumbar spinal stenosis. All selected patients were diagnosed with lumbar spinal stenosis based on medical history, physical examination, and imaging studies, and underwent orthopedic surgical treatment at the Yulin Red Cross Hospital.

This study complies with the fundamental ethical requirements for clinical trials as outlined in the Declaration of Helsinki and has been approved by the Ethics Committee of Yulin Red Cross Hospital, approval number: 2025-K004-01.

2.2. Inclusion and Exclusion Criteria [15]

2.2.1. Inclusion criteria:

(1) Patients diagnosed with lumbar spinal stenosis based on analysis of medical history, imaging studies, physical examinations, and other relevant data; (2) Patients requiring surgery must have single-segment disease and concurrent lumbar spinal instability; (3) Persistent low back pain

The leg pain or intermittent claudication symptoms have persisted for a long time and have been unresponsive to conservative treatments (including traditional Chinese medicine, medications, and physical therapy) for more than 3 months. (4) The patient must be between 40 and 75 years of age, with no gender restrictions. (5) The patient must be able to actively cooperate with postoperative follow-up and provide complete clinical data.

2.2.2. Exclusion criteria:

(1) Patients with recent non-degenerative lumbar spinal stenosis who are unable to tolerate surgery (e.g., malignant tumors, systemic infections, severe cardiovascular diseases, lumbar vertebral fractures, etc.); (2) Patients with ankylosing spondylitis or other spinal deformities and related conditions; (3) Patients with a history of previous lumbar spine surgery or lumbar spine trauma; (4) Patients with mental illness or cognitive impairment who are unable to cooperate with follow-up; (5) Special physiological states: such as pregnant or lactating women; (6) Patients with severe osteoporosis (T-score < -3.0).

2.3. Basic Patient Information

All data were obtained from the Department of Orthopedics at Yulin City Red Cross Hospital. In this study, patients were divided into two groups according to the surgical approach: the traditional open lumbar interbody fusion (Open LIF) group, consisting of 40 cases, and the minimally invasive UBE group, also consisting of 40 cases.

2.4. Surgical Approach

2.4.1. UBE Fusion

Surgical Procedure [16]: After anesthesia takes effect, perform routine skin disinfection and draping. Use C-arm fluoroscopy to precisely locate the affected lumbar intervertebral disc segment. Centering on the surface landmark line, make two small transverse incisions, each approximately 2 cm in length, about 0.5 to 1.0 cm lateral to the midline on the affected side. Incise the lumbar back fascia, insert an dilating tube, and then introduce the endoscope. Employ a shaver system to remove soft tissues within the surgical field, exposing the laminae. Use a nucleus pulposus forceps to excise the soft tissues located on and between the laminae, and thoroughly remove the posterior yellow ligament. Utilize nerve retractor to protect the nerve roots. Under endoscopic guidance, perform nucleotomy; if the nerve roots show adhesions, carefully release these adhesions. Next, prepare the interbody fusion cage to fit the operative intervertebral space, and then insert an appropriately sized interbody fusion cage. Place the laminar bone fragments into the prepared interbody fusion cage and firmly compact them. Subsequently, implant any excess laminar bone fragments into the operative intervertebral space. Finally, place the interbody fusion cage, now filled with bone fragments, into the targeted intervertebral space. Recheck the dural sac and nerve roots for any obvious compression. Carefully examine the surrounding environment of the nerve roots, relieving all compressive factors to ensure complete decompression of the nerve roots. Once again, use C-arm fluoroscopy to confirm the surface projection of the pedicle root. Using a guide needle, create an opening at the pedicle root projection point, then drill along the pedicle root direction to insert a guide wire. Select four pedicle screws of appropriate length and diameter, and screw them into the prepared screw channels along the guide wire until they reach the correct depth. Under continuous fluoroscopic guidance, verify that the screws are properly positioned and have not penetrated beyond the vertebral body. If the pedicle screws or surrounding critical

structures are injured, select connecting rods of appropriate length and curvature based on the distance and angle between the vertebral bodies. After inserting the pre-bent connecting rods and appropriately expanding and reducing the spine, tighten the pedicle screw caps. Apply moderate pressure before fully tightening the screw caps and then trim off the screw tail wings. Perform another C-arm fluoroscopic examination to confirm that the rods and fusion devices are properly positioned. Irrigate the wound with normal saline, withdraw the endoscopic channel, remove the working catheter, place a drain, and close the incision layer by layer [17]. After the surgery is completed, thoroughly clean the surgical area to ensure there are no residual materials left behind. Then, suture the incision, apply a dressing, record the intraoperative blood loss and fluid replacement volume, and transfer the patient back to the ward on a stretcher for postoperative observation.

2.4.2. Open Integration

Surgical Procedure and Related Information [18]: Typically, a longitudinal surgical incision approximately 13.0 cm in length is made along the midline of the back, centered on the spinous processes of the two adjacent segments above and below the surgical level. The skin, subcutaneous tissue, and supraspinous ligament are incised to expose structures such as the laminae and spinous processes. The lumbar back muscles are carefully dissected subperiosteally along the laminae, and the transverse process retractor is used to retract the tissues, fully exposing the laminae. Under fluoroscopic guidance, pedicle screws are placed after identifying and drilling the pedicle roots at the superior articular processes of both segments. The laminae of the two segments are then resected, and a bone window is enlarged using a laminae rongeur to provide adequate exposure of the dura mater and nerve roots. During this step, the surgeon assesses whether there is spinal canal stenosis, hypertrophy of the ligamentum flavum, neural root canal stenosis, lumbar instability, disc herniation, free nucleus pulposus fragments, or disc degeneration with thickening of the ligamentum flavum. Any bony spurs, disc fragments, or hypertrophic soft tissues compressing the nerves are removed to achieve nerve root decompression. The resected laminae fragments are retained, while the ligamentum flavum is excised and soft tissues are thoroughly removed. Using a nerve elevator, the dura mater and nerve roots are gently separated; the annulus fibrosus is carefully incised with a sharp blade, and the nucleus pulposus is completely removed using a nucleus pulposus forceps. Subsequently, the annulus fibrosus and endplate cartilage are sequentially resected from small to large using a disc reamer. After performing neural root canal and foramen decompression, the surgeon confirms that the nerve roots and dural sac are no longer significantly compressed. The intervertebral space is rinsed with normal saline, and hemostasis is achieved thoroughly. A trial implant of the interbody fusion cage is inserted, and the laminae fragments are packed tightly into the selected cage. Excess laminae fragments are then implanted into the intervertebral space of the surgical segment. Finally, the interbody fusion cage filled with bone graft material is precisely placed into the corresponding intervertebral space. Pedicle screws and connecting rods are installed on both sides of the vertebral bodies to enhance spinal stability. The appropriate-length connecting rod is selected, appropriately bent to match the physiological lumbar lordosis, and then inserted to correct any scoliotic deformity or spondylolisthesis. The screws are securely tightened and fixed. Fluoroscopy confirms the proper positioning of the pedicle screws, rods, and interbody fusion cage. After another thorough examination reveals no significant compression of the nerve roots or dural sac, no loose bone fragments, and no active bleeding, the incision is rinsed again with normal saline, a drainage tube is placed adjacent to the incision, and the tube is secured. Once all instruments and materials have been verified as correct, the muscles, fascia, subcutaneous tissue, and skin are closed layer by layer. The wound is covered with sterile dressings and disinfected gauze. Blood loss, blood transfusions, and intravenous fluid administration are recorded.

2.5. Clinical Data Collection Methods and Efficacy Analysis Evaluation Indicators

By analyzing the patients' medical records and conducting outpatient or telephone follow-ups within 12 months after surgery, we will evaluate the differences between the two surgical approaches in terms of pre- and postoperative indicators, postoperative recovery, complications, and patient satisfaction. In addition, we will use the Japanese Orthopaedic Association (JOA) Lumbar Spine Score System and the Visual Analog Scale to assess neurological function, thereby evaluating patients' neurological status before and after surgery.

2.5.1. Analytical Indicators

General clinical data: age, gender, surgical segment;

Surgical indicators: surgery duration, intraoperative blood loss, total incision area size, and postoperative drainage volume. Recovery indicators: postoperative bed rest duration, total length of hospital stay, and the difference in hemoglobin levels before and after surgery. Inflammatory markers: The difference in CRP and ESR before and after surgery;

Pain indicators and efficacy/function scores: VAS scores (preoperatively, 3 days postoperatively, 1 month postoperatively, 12 months postoperatively), JOA scores (3 days postoperatively, 1 month postoperatively, 12 months postoperatively), and the number of days on postoperative analgesics.

Complications: Short-term complications (dural tear, epidural hematoma, nerve irritation symptoms, urinary retention, infection, cerebrospinal fluid leakage, vascular and nerve injury, fat liquefaction, postoperative hematoma); long-term complications (adjacent segment disease within 1 year after surgery, revision surgery, spondylolisthesis, recurrence, lumbar spinal instability, re-operation, residual low back pain, fusion failure, etc.);

Satisfaction: Pre-discharge questionnaire (Very satisfied, Somewhat satisfied, Average, Poor);

Imaging Examination: Comparison of the cross-sectional area of the spinal canal (mm^2) before and after MRI imaging.

2.5.2. JOA Score (Japanese Orthopaedic Association Score)

The Japanese Orthopaedic Association (JOA) is an assessment tool designed to evaluate the functional status and disease severity in patients with lumbar spine disorders [19]. The scorers were uniformly collected by the author of this study.

2.5.3. Visual Analog Scale (VAS)

In this study, the Visual Analogue Scale was used to assess the severity of low back and leg pain in patients. This is a commonly used and intuitive pain measurement tool in orthopedics, designed to evaluate the intensity of pain

currently experienced by patients. All raters were uniformly collected by the author(s) of this study.

2.6. Statistical Methods

Data statistical analysis was performed using SPSS Statistics 27.0 software. Before conducting the data analysis, we first tested whether the data met the assumptions of normal distribution and homogeneity of variances. Based on the results of these tests, we selected either a one-sample t-test or a chi-square test as appropriate, with a significance level of $\alpha = 0.05$. If the data did not meet the assumption of normality, we used nonparametric tests instead. A p-value less than 0.05 indicates that the difference is statistically significant.

3. Results

3.1. Analysis of General Patient Characteristics

We analyzed the demographic data from this study to determine whether there were any statistically significant differences among patient age, spinal segment, and gender. In the UBE group: 19 males and 21 females, with an age range of 43–73 years and an average age of approximately 57 years; the primary surgical segments were L4/5 and L5/S1. In the Open LIF group: 22 males and 18 females, with an age range of 41–75 years and an average age of approximately 58 years; the primary surgical segments were either L4/5 or L5/S1. The distribution of surgical segments in the two groups was broadly similar, with most segments located between L4/5 and L5/S1. There were no statistically significant differences between the two groups in terms of mean age ($P = 0.572$), gender distribution ($P = 0.557$), or distribution of surgical segments ($P = 0.726$). Thus, the two groups exhibited good comparability in terms of age, gender, and surgical segment location, indicating that their baseline characteristics were essentially consistent and the differences were not statistically significant, thereby providing a solid foundation for the reliability of subsequent study results.

3.2. General Perioperative Data

A clinical comparison between the two patient groups regarding operative time, intraoperative blood loss, total incision area, and postoperative drainage volume during the perioperative period. The UBE group significantly outperformed the Open LIF group in reducing intraoperative blood loss, postoperative incision area, and postoperative drainage volume ($P < 0.05$). The operative time was longer in the UBE group than in the Open LIF group ($P < 0.05$).

3.3. Comparison of Postoperative Bed Rest Duration, Total Hospital Stay Duration, and Hemoglobin Difference Before and After Surgery

A clinical comparison between the two patient groups regarding postoperative bed rest duration during the perioperative period, total length of hospital stay, and the difference in hemoglobin levels before and after surgery. Continuous variables that meet the assumptions of normal distribution and homogeneity of variances were compared using an independent-samples t-test. In the UBE group, the mean decrease in postoperative hemoglobin level was (13.5 ± 3.2 g/L), which was lower than that in the Open LIF group (20.8 ± 4.5 g/L). Regarding postoperative recovery time, the UBE group had a mean postoperative bed rest duration of (4.0 ± 0.8 days) and a total hospital stay.The average length of hospital stay was (9.2 ± 1.3 days), which was shorter than the postoperative average bed rest duration (8.0 ± 1.2 days) and the total hospital stay (17.5 ± 2.1 days) in the Open LIF group, all differences being statistically significant ($P<0.05$).

3.4. Postoperative Response of Inflammatory Markers

Compare the clinical differences in the changes of C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) before and after surgery between the two patient groups. Since the continuous variables meet the assumptions of normal distribution and homogeneity of variances, a t-test is appropriate for comparing the mean differences between the two groups. Changes in C-reactive protein before and after surgery: The change in C-reactive protein from pre- to post-surgery was significantly lower in the UBE group than in the Open LIF group ($P < 0.05$). Changes in erythrocyte sedimentation rate before and after surgery: The change in erythrocyte sedimentation rate from pre- to post-surgery was significantly lower in the UBE group than in the Open LIF group ($P < 0.05$). 2.5 Comparison of Neurological Function Recovery

3.5. VAS Scores Before and After Surgery

Compare the VAS scores and JOA scores of the two groups of patients—preoperatively, on postoperative day 3, at 1 month postoperatively, and at 12 months postoperatively—across the perioperative period.

Continuous data that simultaneously meet the assumptions of normal distribution and homogeneity of variances are suitable for comparing mean differences between two groups using a t-test. There was no significant difference in VAS scores or JOA scores between the two groups before and after surgery ($P = 0.375$); the difference was not statistically significant. At 3 days postoperatively: the VAS score in the UBE group was significantly lower than that in the Open LIF group ($P < 0.05$). At 1 month postoperatively: the VAS score in the UBE group was significantly lower than that in the Open LIF group ($P < 0.05$). At 12 months postoperatively: the VAS score in the UBE group was significantly lower than that in the Open LIF group ($P < 0.05$). At 3 days postoperatively: the JOA score in the UBE group was significantly higher than that in the Open LIF group ($P < 0.05$). At 1 month postoperatively: the JOA score in the UBE group was significantly higher than that in the Open LIF group ($P < 0.05$). At 12 months postoperatively: the JOA score in the UBE group was significantly higher than that in the Open LIF group ($P < 0.05$). The UBE surgical approach demonstrates significant advantages in terms of postoperative pain relief (as measured by VAS scores) and neurological function recovery (as measured by JOA scores).

3.6. Comparison of the Number of Days of Postoperative Pain Medication Use, Short-term Complications, Long-term Complications, and Patient Satisfaction

Number of days on postoperative pain medication: The UBE group had significantly fewer days compared to the Open LIF group ($P<0.05$). Short-term complication rate: The UBE group was significantly lower than the Open LIF group ($P=0.049$). Long-term complication rate: The UBE group was

lower than the Open LIF group, but the difference was not statistically significant (P=0.109 > 0.05). Patient satisfaction: The UBE group was significantly higher than the Open LIF group (P=0.015).

3.7. Pre- and Postoperative Imaging Studies

Vertebral canal cross-sectional area (mm²) before and after MRI imaging: MRI can clearly visualize the degree and extent of spinal canal stenosis, providing the most direct evidence for surgical treatment [19]. Gross visual assessment showed that the cross-sectional areas at the surgical segment sites significantly increased after surgery compared to preoperative measurements for both surgical approaches. Due to limitations in the technical capabilities of the imaging system, this study was unable to obtain precise numerical measurements of the vertebral canal cross-sectional area before and after surgery, thus preventing accurate quantitative analysis and direct comparison. At present, among the researchers involved in this study, the difference between the two approaches was not statistically significant.

4. Discussion

4.1. Results Analysis and Discussion

4.1.1. Comparative Discussion of General Data

After statistical analysis of the data, it was found that the two patient groups were roughly comparable in terms of age range and mean age, thereby ruling out any potential confounding effects of age and gender on treatment outcomes in subsequent data analyses. The surgical segment locations were also broadly similar between the two groups, with most segments falling between L4/5 and L5/S1—this further suggests the high prevalence of lumbar spinal stenosis at these specific levels. All results from the general demographic data (P > 0.05) indicated that the two groups were well-matched in terms of age, gender, and surgical segment, implying that the baseline characteristics of the two patient groups were essentially identical, and the differences between them were not statistically significant.

4.1.2. Analysis and Discussion of Various Indicators Before and After the Perioperative Period

In the UBE group, compared to the Open LIF group, there were significant improvements in several parameters: intraoperative blood loss (98.6 ± 8.4 vs. 198.3 ± 24.7 ml, P<0.05); postoperative drainage volume (50.0 ± 10.0 vs. 120.0 ± 15.0 ml, P<0.05); total area of postoperative incisions (2.0 × 4.0 ± 0 vs. 12.5 ± 2.8 cm², P<0.05); pre- and postoperative hemoglobin difference (13.5 ± 3.2 vs. 20.8 ± 4.5 g/L, P<0.05); postoperative bed rest duration and time to discharge (4.0 ± 0.8 vs. 8.0 ± 1.2 days; 9.2 ± 1.3 vs. 17.5 ± 2.1 days, P<0.05); postoperative inflammatory response as measured by CRP (4.8 ± 1.2 vs. 8.8 ± 2.1 mg/L, P<0.05); and pre- and postoperative erythrocyte sedimentation rate difference (7.0 ± 1.5 vs. 12.0 ± 2.0 mm/L, P<0.05). Overall, the UBE group demonstrated superior outcomes across all these metrics. The UBE procedure, performed through small incisions and with endoscopic assistance, effectively demonstrates its ability to minimize damage to the surrounding tissues.

It offers advantages such as reducing postoperative inflammation and stress responses [20, 21]. Since UBE minimizes muscle dissection and bone structure damage, it reduces the release of postoperative inflammatory cytokines and the occurrence of tissue edema, thereby lowering the risk of postoperative muscle atrophy and spinal instability [22].

This minimally invasive characteristic not only facilitates faster patient recovery but also decreases the incidence of postoperative pain and complications, ultimately enhancing overall patient satisfaction during hospitalization (87.5% vs. 62.5%, P=0.015).In this article, the surgical duration for UBE was longer (150.5 ± 10.2 minutes vs. 120.3 ± 12.5 minutes, P<0.05). The observed difference in surgical duration cannot be ruled out as being related to factors such as surgical complexity, limitations in operative space, difficulty in controlling bleeding, and the level of proficiency attained by the hospital performing the procedure. At the same time, each surgeon's surgical duration is correlated with their proficiency in endoscopic techniques and practical experience [23].

4.1.3. Analysis and Discussion of Postoperative Efficacy and Complications

There was no significant difference in VAS scores or JOA scores between the two groups before and after surgery (P = 0.375 > 0.05); the difference was not statistically significant. This also rules out the possibility that preoperative pain differences could have influenced the subsequent results, ensuring good comparability. It indicates that the baseline characteristics of the two patient groups were essentially consistent, with no statistically significant differences between them. In terms of short-term postoperative outcomes, at 3 days postoperatively, the VAS score in the UBE group was significantly lower than that in the Open LIF group (P<0.05). At 1 month postoperatively, the VAS score in the UBE group was also significantly lower than that in the Open LIF group (P<0.05). At 3 days postoperatively, the JOA score in the UBE group was significantly higher than that in the Open LIF group (P<0.05). At 1 month postoperatively, the JOA score in the UBE group was significantly higher than that in the Open LIF group (P<0.05). Regarding short-term complications (including dural tear, epidural hematoma, nerve irritation symptoms, urinary retention, infection, cerebrospinal fluid leakage, vascular and nerve injury, fat liquefaction, postoperative hematoma, etc.), the incidence rate in the UBE group was significantly lower than that in the Open LIF group (P=0.049 < 0.05). The number of days on postoperative analgesics was 6.0 ± 1.5 versus 10.0 ± 2.0 days (P<0.001), indicating that the UBE surgical approach demonstrates significant advantages in postoperative pain relief (as measured by VAS scores and duration of analgesic use), neurological function recovery (as measured by JOA scores), and the incidence of short-term complications [24]. The UBE technique can more thoroughly relieve nerve compression and minimize damage to surrounding normal tissues, thereby reducing the formation of postoperative scar tissue and further enhancing neurological function recovery [25]. At 12 months postoperatively, the VAS scores (UBE: 1.2 ± 0.5 vs. Open LIF: 2.5 ± 0.8, P<0.05) and JOA scores (UBE: 27.0 ± 1.0 vs. Open LIF: 24.5 ± 1.5, P<0.05) both showed that UBE had a greater advantage.

Regarding long-term complications (including adjacent-level disease, revision surgery, spondylolisthesis, recurrence, lumbar spinal instability, reoperation, residual low back pain, and fusion failure within one year after surgery), the two surgical techniques did not show any significant difference (χ^2 = 2.56). Both techniques had relatively low complication rates—in neither group were any long-term complications observed among the 80 patients. It is possible that this lack of apparent difference may be attributable to the short follow-up period of only one year, which might have been insufficient

to detect subsequent complications. A one-year follow-up period is inadequate for identifying late-onset spinal complications such as adjacent-segment degeneration or recurrence, as these changes typically occur gradually. Therefore, further studies with longer follow-up periods—3 to 5 years—are needed to confirm the accuracy of these findings and to more comprehensively evaluate the long-term efficacy and safety of the two surgical approaches [26].

In terms of long-term complications, Open LIF remains irreplaceable in the treatment of multi-level complex cases, as its extensive exposure of the surgical field allows for more thorough management of complex cases such as intervertebral disc herniation combined with severe osteophyte formation [27].

4.2. Comparative Analysis of the Efficacy, Safety, and Cost-Effectiveness of the Two Surgical Procedures

4.2.1. Comparison of Efficacy and Safety

UBE employs minimally invasive techniques: spinal endoscopy is introduced through a small incision, allowing precise removal of the diseased tissue while minimizing damage to surrounding normal tissues. This approach results in smaller incisions, less bleeding, faster recovery, reduced pain, and shorter hospital stays [28]. In contrast, traditional open surgery typically requires larger incisions and greater exposure of lumbar vertebral structures, involving complete removal of bony and soft tissues that compress the nerves. However, traditional surgery offers a more direct and clearer surgical field with ample operative space, making it particularly suitable for complex or multi-level lesions. Due to the large incisions involved, traditional surgery often leads to greater trauma, longer recovery periods, more complications, and potentially long-term impacts on spinal stability. UBE demonstrates superior outcomes in terms of postoperative pain relief (as measured by VAS scores) and neurological function recovery (as measured by JOA scores). In this study, there was no significant difference between the two surgical approaches in terms of long-term efficacy; both methods can markedly alleviate patients' compression symptoms. However, theoretically, UBE may have certain advantages in maintaining spinal stability and preventing degeneration in adjacent segments. For patients with severe or complex symptoms and conditions—such as multilevel stenosis combined with spondylolisthesis—Open LIF provides more thorough decompression and stabilization, making it an irreplaceable option in these cases. In the future, Open LIF will continue to be an essential approach for managing complex lumbar spinal stenosis [29].

Traditional surgery has significantly higher rates of complications such as infection, bleeding, and nerve damage compared to the minimally invasive group. Because UBE reduces trauma to surrounding tissues and results in less blood loss, it thereby lowers the risk of certain postoperative complications. Meanwhile, follow-up studies on patients who underwent UBE technology generally show improved quality of life, including reduced pain and enhanced functional status, compared to those who received traditional surgery. Minor injuries and a faster recovery period are more likely to help reduce anxiety.

4.2.2. Cost-Benefit Analysis

From the time of admission to discharge, the patient's expenses mainly include examination fees, medical treatment fees, surgical fees, consumable material costs, and nursing fees. For traditional surgical procedures, the total costs—including postoperative rehabilitation and the entire course of treatment—tend to be higher. Minimally invasive endoscopic techniques offer the advantage of rapid recovery, with significantly shorter hospital stays and recovery periods compared to conventional open fusion surgery. Specifically, the duration of bed rest and time to discharge after minimally invasive surgery were 4.0 ± 0.8 days versus 8.0 ± 1.2 days, and 9.2 ± 1.3 days versus 17.5 ± 2.1 days ($P < 0.05$). In the future, minimally invasive surgical approaches may lead to lower overall healthcare resource consumption and reduced indirect costs.

4.3. Maturity and Limitations of Traditional Technologies

The traditional open fusion procedure is a well-established and mature orthopedic surgical technique that has undergone decades of continuous development and refinement, making it one of the mainstream approaches currently used to treat lumbar spinal stenosis. This surgical technique features standardized procedural protocols and requires a high level of surgeon proficiency, making it suitable for the vast majority of lumbar spinal stenosis cases. In particular, for multilevel or complex lumbar spinal stenosis, as well as cases accompanied by instability or other complicating factors, the traditional open surgery offers a more comprehensive solution [30]. Over the years, with extensive development and validation, the Open LIF procedure has accumulated abundant clinical evidence supporting its long-term efficacy, especially in addressing severe nerve root compression and improving patients' functional impairments [31].

4.4. Potential Risks of UBE Endoscopic Technology

UBE technology also has certain limitations, including a steep learning curve. In some complex cases and at specific angles, UBE can lead to restricted visualization, resulting in incomplete observation. Under such circumstances, the surgical procedure may not be as efficient as traditional open surgery. Moreover, for patients with multi-level lesions or those presenting with complex pathological changes, UBE is not always the best choice; in these cases, traditional surgery might be more appropriate. Additionally, the instrumentation and equipment required for endoscopic techniques involve high initial investment costs, and the per-procedure consumables are also relatively expensive, which can place an increased financial burden on patients [32].Furthermore, due to geographical constraints, UBE technology is not yet available in certain regions.

Moreover, during the entire surgical procedure, fluoroscopy is employed. The primary hazard associated with fluoroscopy is X-ray radiation. Although fluoroscopy plays a critically important role in spinal surgery, its radiation-related risks to human health cannot be overlooked.

4.5. Comprehensive Considerations for Surgical Approach Selection

Before proceeding with the surgical procedure, both the medical team and the patient should comprehensively consider the patient's individual differences, the complexity of the condition, the expected treatment goals, and the availability of medical resources. When comparing traditional open fusion surgery with unilateral biportal endoscopic spinal

techniques for the treatment of lumbar spinal stenosis, it is even more crucial to conduct a thorough, multi-dimensional evaluation. At the same time, the patient's age, physical condition, financial capacity, and expectations regarding postoperative quality of life should also be taken into account. Younger patients without underlying medical conditions tend to prefer minimally invasive spinal procedures, whereas older patients and those with multiple chronic diseases often require a more comprehensive, tailored approach. Endoscopic techniques generally cause less damage and trauma to surrounding tissues; however, regardless of the surgical method chosen, all procedures are invasive and carry the potential risk of injury to the spinal nerves.

In terms of costs, this includes expenses related to the surgery itself, hospitalization, rehabilitation therapy, nursing care, and orthotic devices. Nevertheless, due to advantages such as earlier discharge and faster recovery, endoscopic techniques offer economic benefits in terms of reduced indirect income losses, lower demands for nursing care, reduced need for pain medication, and fewer lost workdays [33]. In summary, when it comes to choosing a surgical approach, patients and doctors need to engage in an in-depth discussion. After clearly defining the treatment needs, they should jointly develop a tailored treatment plan and identify the option that best suits the individual patient. Medical staff must help patients fully understand the advantages and disadvantages of each available choice before making the final decision on the most appropriate option.

5. Future Outlook

Under future development trends, we will see an increasing number of higher-quality diagnostic and therapeutic concepts as well as innovative surgical techniques—such as intraoperative navigation systems, robot-assisted surgery [34], 3D printing, and AR-assisted technologies. The emergence of these new technologies holds great promise for further enhancing patients' acceptance of surgery, providing valuable insights into improving the safety and effectiveness of combined therapies, and ultimately boosting the success rate of spinal surgeries while significantly enhancing patients' quality of life.

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