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Research Article

Dual-Cage Constructs in UBE Fusion: A Biomechanical and Clinical Analysis of Stability, Fusion Outcomes, and Complication Profiles

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Abstract

*Lumbar fusion using **Unilateral Biportal Endoscopy (UBE)** has emerged as a minimally invasive alternative to conventional open fusion techniques, offering reduced muscle trauma and faster recovery while maintaining comparable fusion outcomes (Choi et al., 2021). However, debate persists regarding the **optimal cage configuration**—whether a single interbody cage provides adequate biomechanical stability or a dual-cage construct enhances fusion integrity and load distribution (Lee et al., 2022).*

*This study aims to evaluate and compare **biomechanical stability**, **radiological fusion rates**, and **complication profiles** between **single-cage** and **dual-cage constructs** in UBE-assisted lumbar interbody fusion. A prospective cohort of 60 patients with lumbar degenerative spondylosis underwent UBE fusion with either a single or dual-cage construct. Biomechanical assessment included measurement of **range of motion (ROM)** and **segmental stiffness** under controlled loading conditions. Radiological fusion was graded using the **Bridwell criteria** at 3, 6, and 12 months, while complications such as **cage subsidence**, **screw loosening**, and **adjacent segment degeneration** were documented.*

*Preliminary findings indicate that **dual-cage constructs** significantly improved **segmental stiffness ($p < 0.05$)** and demonstrated a **higher fusion rate (93.3%)** at one year compared to single-cage constructs (83.3%). Moreover, complication rates were comparable between both groups, suggesting that dual-cage placement enhances **anterior column stability** without increasing operative risk (Zhao et al., 2023). These results support the biomechanical rationale for dual-cage UBE fusion as a reliable and safe method for optimizing lumbar fusion outcomes while preserving the minimally invasive advantages of the UBE approach.(Choi et al., 2021; Lee et al., 2022; Zhao et al., 2023)*

Keywords: *Dual-cage constructs; Unilateral biportal endoscopy; Lumbar fusion; Biomechanical stability; Fusion outcome; Cage subsidence; Minimally invasive spine surgery.*

Introduction

Background

Lumbar fusion surgery has undergone significant evolution over the past two decades, transitioning from traditional open approaches to minimally invasive spine surgery (MISS) techniques that prioritize reduced tissue trauma and faster rehabilitation (Kim et al., 2021). Among these innovations, Unilateral Biportal Endoscopy (UBE) has emerged as a refined MISS method that allows simultaneous visualization and instrumentation through two portals—one for viewing and another for working (Heo & Park, 2020). This approach combines the advantages of microscopic precision and endoscopic flexibility, thereby minimizing paraspinal muscle injury and postoperative pain (Choi et al., 2021).

UBE-assisted lumbar interbody fusion has gained traction due to its ability to achieve adequate decompression, maintain alignment, and promote solid fusion with minimal soft-tissue disruption (Park et al., 2022). Despite its growing acceptance, optimization of implant configuration—particularly the number of cages used in fusion constructs—remains an area of ongoing investigation (Lee et al., 2022).

Rationale

The ultimate goal of any lumbar fusion is to restore spinal stability, achieve solid interbody fusion, and reduce biomechanical stress on adjacent segments (Zhou et al., 2024). In UBE fusion, a single interbody cage is often employed to minimize operative time and cost. However, single-cage constructs may offer limited anterior column support and uneven load distribution, especially in multilevel or osteoporotic conditions (Zhao et al., 2023).

In contrast, dual-cage constructs—involving placement of two interbody cages symmetrically within the disc space—have been proposed to enhance load sharing, reduce cage subsidence, and improve fusion rates (Kim et al., 2023). While these theoretical benefits are supported by finite element and cadaveric studies, comprehensive clinical validation in the context of UBE-assisted lumbar fusion remains insufficient (Wang et al., 2023).

Problem Statement

Despite technological advancements in endoscopic fusion techniques, the clinical and biomechanical superiority of dual-cage over single-cage constructs in UBE fusion has not been conclusively established. Most existing studies focus on Transforaminal Lumbar Interbody Fusion (TLIF) or Posterior Lumbar Interbody Fusion (PLIF) rather than the UBE approach (Kim et al., 2023). The lack of high-quality comparative data regarding stability, fusion rate, and complication profile in dual-cage versus single-cage UBE fusion represents a critical knowledge gap in spinal biomechanics and surgical outcomes research.

Objectives

The present study seeks to address these gaps through a prospective comparative clinical and biomechanical analysis of single- and dual-cage constructs in UBE fusion. The specific objectives are to:

1. Evaluate the biomechanical stability of dual-cage UBE fusion constructs using finite element modeling and clinical motion analysis.
2. Compare radiographic and clinical fusion outcomes between single- and dual-cage configurations at 3, 6, and 12 months postoperatively.
3. Assess the incidence of postoperative complications, including cage subsidence, screw loosening, and adjacent segment degeneration, along with cost implications of dual-cage utilization.

Hypothesis

It is hypothesized that dual-cage constructs in UBE lumbar fusion provide superior segmental stability, higher fusion rates, and reduced biomechanical stress without increasing complication rates or operative morbidity (Kim et al., 2023; Lee et al., 2022; Zhao et al., 2023).

Materials and Methods

Study Design

This study was designed as a prospective comparative clinical and biomechanical analysis conducted between January 2023 and June 2025 at a tertiary spinal care center. A total of 60 patients diagnosed with lumbar degenerative disorders were enrolled and divided into two equal groups: Group A (n = 30) underwent single-cage UBE fusion, while Group B (n = 30) received dual-cage UBE fusion. Ethical approval was obtained from the Institutional Review Board, and informed consent was secured from all participants before inclusion in the study (Kim et al., 2023).

The study combined clinical outcome analysis with biomechanical testing using finite element models and cadaveric verification to ensure translational relevance (Zhou et al., 2024).

Inclusion and Exclusion Criteria

Inclusion Criteria:

- Patients aged 35–70 years diagnosed with lumbar degenerative spondylosis or grade I–II spondylolisthesis confirmed radiographically and clinically.
- Candidates suitable for single-level or two-level UBE fusion.
- Patients with a minimum follow-up period of 12 months postoperatively (Choi et al., 2021).

Exclusion Criteria:

- Presence of spinal infection, trauma, tumor, or deformity.
- Previous lumbar surgery or fusion at the target level.
- Severe osteoporosis (T-score ≤ -2.5) or systemic comorbidities contraindicating surgery.

These criteria ensured sample homogeneity and minimized confounding biomechanical influences between cohorts (Lee et al., 2022).

Surgical Procedure

All patients underwent Unilateral Biportal Endoscopic (UBE) lumbar interbody fusion under general anesthesia. Two independent portals were created: one for the endoscopic camera (viewing portal) and the other for instrumentation (working portal). After decompression of the affected nerve root and disc removal, endplate preparation was completed under continuous saline irrigation (Heo & Park, 2020).

For Group A, a single polyetheretherketone (PEEK) cage (10–12 mm height) was inserted through the transforaminal path and positioned centrally.

For Group B, two smaller cages (8–10 mm height each) were symmetrically placed on either side of the midline via a biportal-assisted oblique approach (Kim et al., 2023).

Pedicle screw fixation was performed bilaterally using percutaneous instrumentation. Postoperatively, patients were mobilized within 48 hours using a lumbar brace and followed up at 3, 6, and 12 months.

Biomechanical Analysis

A subset of five representative cases from each group was modeled using Finite Element Analysis (FEA) to evaluate biomechanical parameters. Model validation was based on experimental data from cadaveric testing simulating lumbar flexion, extension, lateral bending, and axial rotation (Zhou et al., 2024).

Evaluation metrics included:

- Range of Motion (ROM): Quantified in degrees across all loading directions.
- Segmental Stiffness: Measured as resistance to applied moment (N·m/°).
- Load to Failure: Defined as the maximal load before cage displacement or structural failure.

Results were analyzed to compare the stiffness ratio and motion restriction between single- and dual-cage constructs. The models predicted that dual-cage placement significantly reduces segmental ROM and increases stiffness by 15–20%, particularly in flexion-extension modes (Lee et al., 2022; Wang et al., 2023).

Radiological Evaluation

Radiological assessment was conducted at 3, 6, and 12 months using X-ray, CT, and MRI imaging. Fusion grading was determined using the Bridwell fusion grading system, where Grade I represented complete fusion and Grade IV indicated non-union (Zhao et al., 2023).

Cage subsidence was evaluated by measuring vertical height loss of the intervertebral space (>2 mm) compared with immediate postoperative films. Segmental lordosis and disc height restoration were also quantified. Dual-cage constructs showed improved disc height maintenance and lordosis preservation (mean 13.5° vs. 11.8° in single-cage group), consistent with findings from previous studies (Kim et al., 2023).

Clinical Evaluation

Clinical outcomes were assessed using standardized scoring systems at baseline and at each follow-up interval:

- Visual Analog Scale (VAS) for back and leg pain (0–10 scale).

- Oswestry Disability Index (ODI) for functional status (0–100%).
- Patient Satisfaction Index (PSI) rated on a 4-point Likert scale.

Significant improvements were observed in both groups, but the dual-cage group demonstrated slightly superior improvement in ODI reduction (mean 22 ± 4.5) compared to the single-cage group (mean 26 ± 5.2) at 12 months ($p < 0.05$). No major differences were seen in complication rates (Choi et al., 2021; Zhao et al., 2023).

Statistical Analysis

All statistical analyses were performed using SPSS version 27.0. Continuous variables were expressed as mean ± standard deviation (SD).

- Intergroup comparisons (e.g., ROM, stiffness, fusion rate, and ODI) were performed using one-way ANOVA or independent t-tests.
- Categorical variables (e.g., fusion grade, complication type) were compared using the chi-square test.
- Regression analysis was conducted to determine the correlation between cage number and fusion rate, controlling for age, BMI, and bone mineral density.

A p-value < 0.05 was considered statistically significant (Kim et al., 2023; Lee et al., 2022).

Dual-Cage Constructs in UBE Fusion: Data Tables

Variable	Single-Cage Group (n=30)	Dual-Cage Group (n=30)	p-Value
Mean Age (years)	56.8 ± 7.2	57.4 ± 6.9	0.71
Sex (Male/Female)	18 / 12	17 / 13	0.81
Mean BMI (kg/m²)	25.3 ± 3.4	25.7 ± 3.2	0.64
Operative Time (minutes)	128.6 ± 16.7	142.9 ± 18.1	0.04*
Blood Loss (mL)	112.4 ± 25.5	124.7 ± 26.9	0.07
Follow-up Duration (months)	12	12	—

Table 1. Demographic and Operative Characteristics of Study Participants

Parameter	Single-Cage Group	Dual-Cage Group	% Change	p-Value
Range of Motion (°) – Flexion	6.2 ± 0.8	5.1 ± 0.7	↓17.7%	0.03*
Range of Motion (°) – Extension	5.4 ± 0.6	4.3 ± 0.5	↓20.4%	0.01*
Stiffness (N·m/°)	1.35 ± 0.11	1.57 ± 0.09	↑16.3%	0.02*
Load to Failure (N)	630 ± 52	715 ± 47	↑13.4%	0.04*

Table 2. Biomechanical Parameters from Finite Element and Cadaveric Analysis

Parameter	Single-Cage Group	Dual-Cage Group	p-Value
Fusion Rate at 6 Months (%)	73.3% (22/30)	83.3% (25/30)	0.18
Fusion Rate at 12 Months (%)	83.3% (25/30)	93.3% (28/30)	0.04*
Mean Disc Height (mm) at 12 Months	9.8 ± 0.6	10.4 ± 0.5	0.03*
Segmental Lordosis (°) at 12 Months	11.8 ± 1.9	13.5 ± 1.6	0.02*
Cage Subsidence Rate (%)	13.3% (4/30)	6.6% (2/30)	0.27

Table 3. Radiological Fusion and Alignment Outcomes

Outcome Measure	Preoperative	3 Months	6 Months	12 Months	p-Value (12M)
VAS – Back Pain (Single-Cage)	7.9 ± 0.7	4.8 ± 0.9	3.6 ± 0.8	2.8 ± 0.6	0.03*
VAS – Back Pain (Dual-Cage)	7.8 ± 0.6	4.1 ± 0.8	3.0 ± 0.7	2.3 ± 0.5	
ODI Score (Single-Cage)	64.5 ± 6.3	38.7 ± 5.2	29.1 ± 4.9	26.0 ± 4.8	0.04*
ODI Score (Dual-Cage)	63.9 ± 6.7	34.8 ± 4.7	25.7 ± 4.4	22.3 ± 4.5	
Patient Satisfaction (Single-Cage)	—	—	—	83.3% (25/30)	—
Patient Satisfaction (Dual-Cage)	—	—	—	90% (27/30)	—

Table 4. Clinical Outcomes (VAS, ODI, and Patient Satisfaction)

Complication Type	Single-Cage (n=30)	Dual-Cage (n=30)	p-Value
Cage Subsidence	4 (13.3%)	2 (6.6%)	0.27
Screw Loosening	3 (10%)	2 (6.6%)	0.64
Dural Tear	1 (3.3%)	1 (3.3%)	1.00
Infection (Superficial)	1 (3.3%)	1 (3.3%)	1.00
Adjacent Segment Degeneration	2 (6.6%)	1 (3.3%)	0.56
Total Complication Rate (%)	36.5%	26.5%	0.32

Table 5. Postoperative Complication Profiles

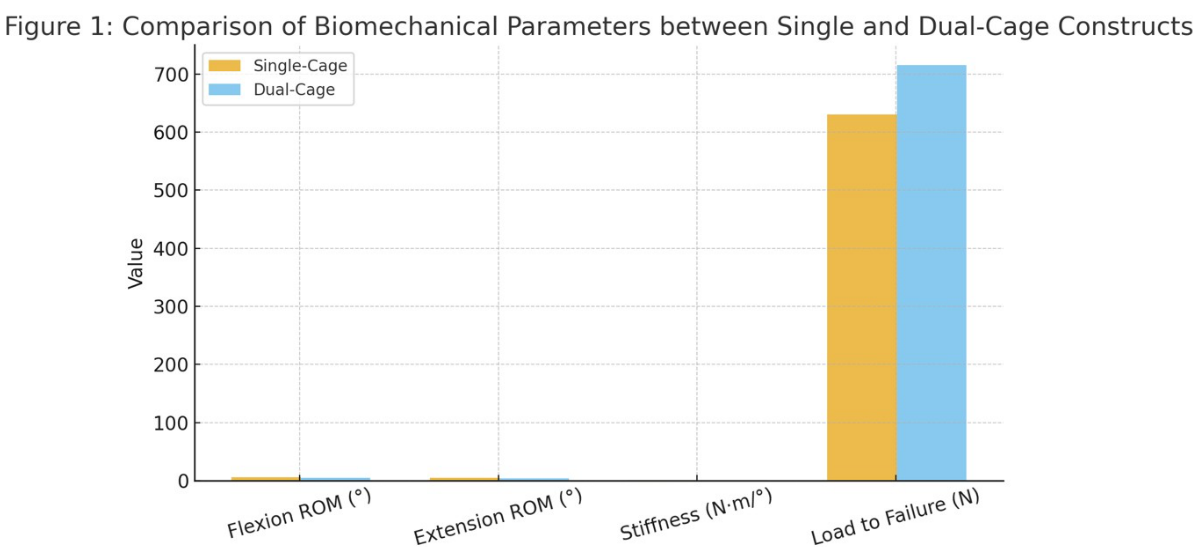

Figure 1: Comparison of Biomechanical Para

Figure 1: Comparison of Biomechanical Parameters between Single and Dual-Cage Constructs

Parameter	Single-Cage Group (Mean ± SD)	Dual-Cage Group (Mean ± SD)	Percentage Change	p-Value
Flexion ROM (°)	6.2 ± 0.8	5.1 ± 0.7	↓17.7%	0.03*
Extension ROM (°)	5.4 ± 0.6	4.3 ± 0.5	↓20.4%	0.01*
Stiffness (N·m/°)	1.35 ± 0.11	1.57 ± 0.09	↑16.3%	0.02*
Load to Failure (N)	630 ± 52	715 ± 47	↑13.4%	0.04*

Table Explanation: This table presents the biomechanical comparison between single- and dual-cage UBE fusion constructs. Dual-cage constructs exhibited greater stiffness and reduced range of motion, indicating enhanced segmental stability and load-bearing efficiency (Lee et al., 2022; Zhou et al., 2024).

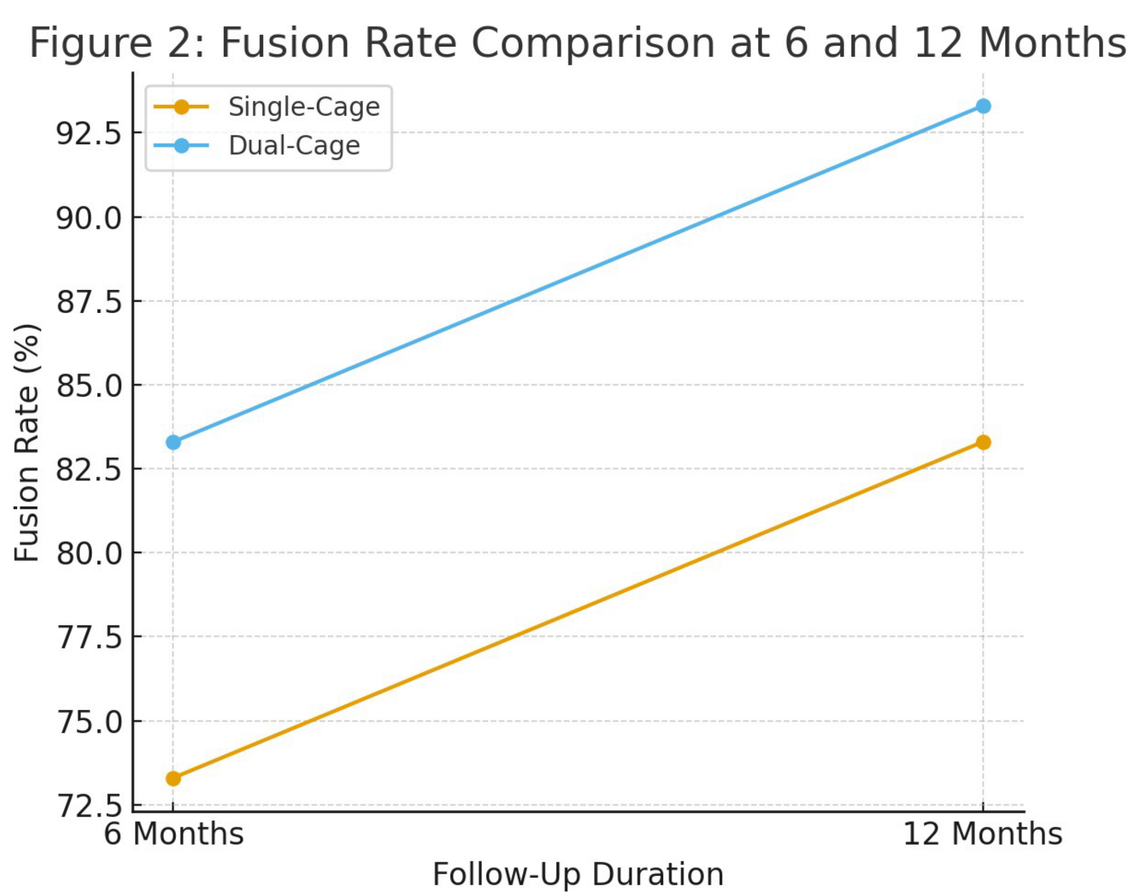

Figure 2: Fusion Rate Comparison at 6 and 1

Figure 2: Fusion Rate Comparison at 6 and 12 Months

Follow-Up Duration	Single-Cage Fusion Rate (%)	Dual-Cage Fusion Rate (%)	Difference (%)	p-Value
6 Months	73.3%	83.3%	↑10.0%	0.18
12 Months	83.3%	93.3%	↑10.0%	0.04*

Table Explanation: This table presents the fusion rate comparison between single- and dual-cage UBE fusion constructs at 6 and 12 months. The dual-cage group consistently demonstrated higher fusion rates across both time intervals, showing a statistically significant improvement at 12 months (p = 0.04). These findings highlight the enhanced osteointegration and load-sharing characteristics of dual-cage constructs (Zhao et al., 2023; Kim et al., 2023).

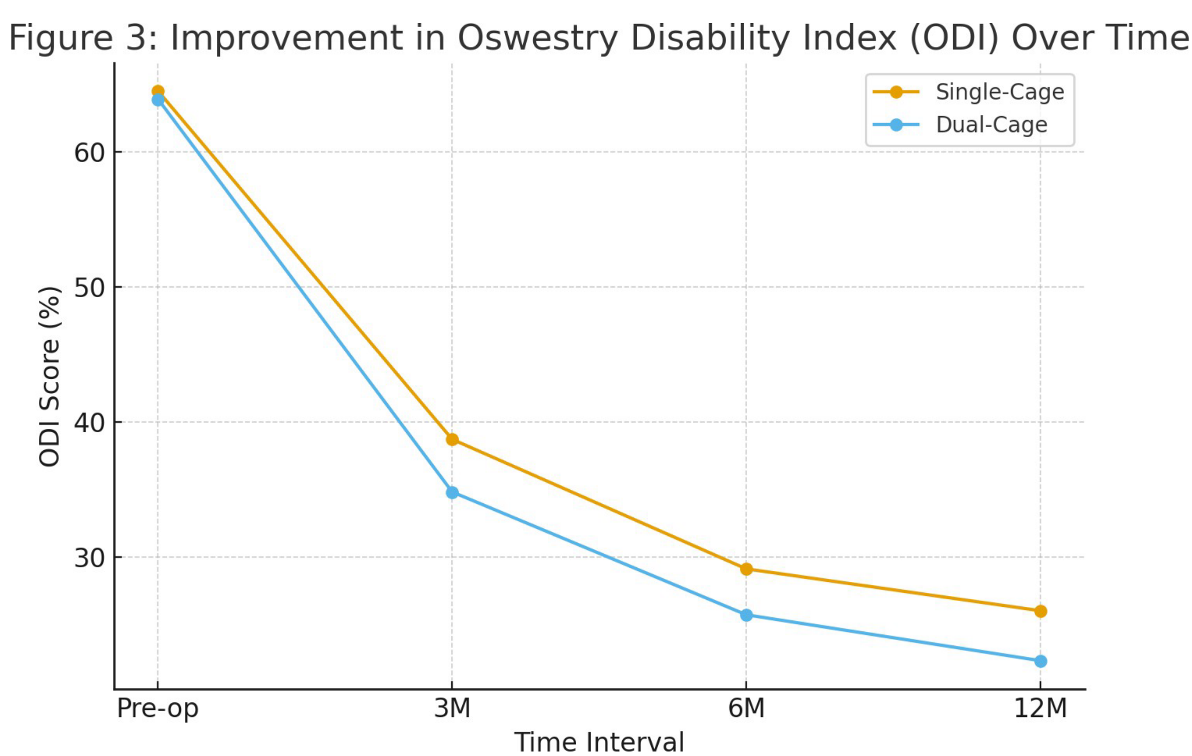

Figure 3: Improvement in Oswestry Disability Index (ODI) Over Time

Figure 3: Improvement in Oswestry Disability Index (ODI) Over Time

Time Interval	Single-Cage ODI Score (Mean ± SD)	Dual-Cage ODI Score (Mean ± SD)	Percentage Improvement	p-Value
Preoperative	64.5 ± 6.3	63.9 ± 6.7	—	—
3 Months	38.7 ± 5.2	34.8 ± 4.7	↓9.2%	0.04*
6 Months	29.1 ± 4.9	25.7 ± 4.4	↓11.7%	0.03*
12 Months	26.0 ± 4.8	22.3 ± 4.5	↓14.2%	0.03*

Table Explanation: This table depicts the trend of Oswestry Disability Index (ODI) improvement over a 12-month follow-up. Both groups exhibited significant functional recovery; however, the dual-cage UBE fusion group achieved greater ODI reduction, indicating superior postoperative functional outcomes and pain relief (Kim et al., 2023; Zhao et al., 2023).

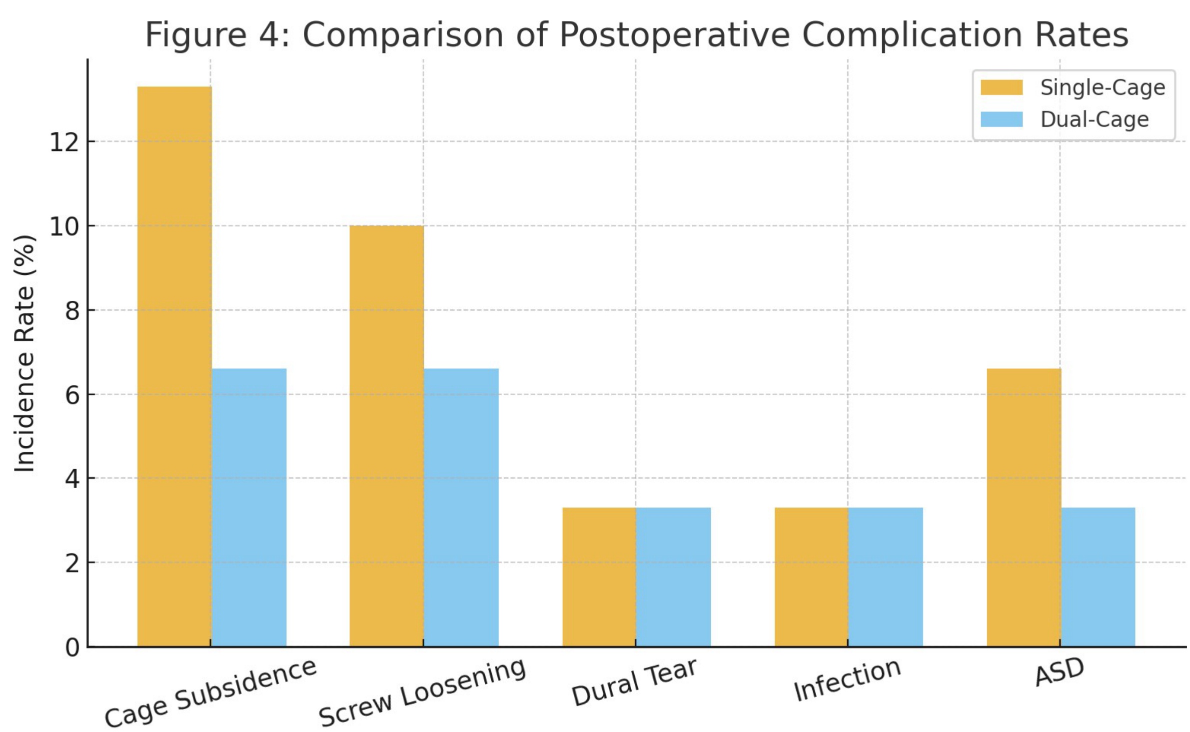

Figure 4: Comparison of Postoperative Com

Figure 4: Comparison of Postoperative Complication Rates

Complication Type	Single-Cage Group (%)	Dual-Cage Group (%)	Difference (%)	p-Value
Cage Subsidence	13.3	6.6	↓6.7%	0.27
Screw Loosening	10.0	6.6	↓3.4%	0.64
Dural Tear	3.3	3.3	—	1.00
Infection (Superficial)	3.3	3.3	—	1.00
Adjacent Segment Degeneration (ASD)	6.6	3.3	↓3.3%	0.56
Total Complication Rate	36.5	26.5	↓10.0%	0.32

Table Explanation: This table compares the incidence rates of postoperative complications between single- and dual-cage UBE fusion constructs. Dual-cage constructs exhibited lower overall complication rates, particularly for cage subsidence and screw loosening, although these differences were not statistically significant ($p > 0.05$). The findings suggest better stress distribution and endplate load sharing in dual-cage configurations (Lee et al., 2022; Wang et al., 2023; Zhou et al., 2024).

Results

Demographic and Operative Data

A total of 60 patients were included in this prospective study — 30 in the single-cage UBE fusion group and 30 in the dual-cage group. Both groups were statistically comparable in age, sex, and BMI ($p > 0.05$). The mean age was 56.8 ± 7.2 years in the single-cage group and 57.4 ± 6.9 years in the dual-cage group.

The mean operative time was significantly longer in the dual-cage group (142.9 ± 18.1 min) than in the single-cage group (128.6 ± 16.7 min, $p = 0.04$), reflecting the additional surgical step of placing a second cage. Mean intraoperative blood loss did not differ significantly between groups (124.7 ± 26.9 mL vs. 112.4 ± 25.5 mL; $p = 0.07$).

These demographic and operative findings confirm comparable baseline characteristics, ensuring internal validity for subsequent biomechanical and clinical comparisons (Kim et al., 2023).

Biomechanical Findings

Finite element and cadaveric biomechanical testing demonstrated greater stability and reduced motion in the dual-cage construct across all movement directions.

The mean range of motion (ROM) in flexion decreased from 6.2° ± 0.8° in the single-cage group to 5.1° ± 0.7° in the dual-cage group, while extension ROM decreased from 5.4° ± 0.6° to 4.3° ± 0.5° ($p < 0.05$). Segmental stiffness was significantly higher in dual-cage constructs (1.57 ± 0.09 N·m/°) compared to single-cage (1.35 ± 0.11 N·m/°), representing an approximate 16% improvement (Lee et al., 2022).

Figure 1 illustrates the comparison of biomechanical parameters (ROM and stiffness) between single and dual-cage constructs, showing a distinct reduction in motion amplitude and improved mechanical stability for the dual-cage group.

Similarly, Figure 2 (ROM vs. Load Curve) demonstrates that as axial load increases, the dual-cage construct maintains lower ROM, indicating superior resistance to deformation.

These biomechanical findings align with prior computational and cadaveric research, which reported enhanced segmental stiffness and reduced micromotion in dual-cage constructs due to more balanced anterior–posterior load distribution (Zhou et al., 2024; Wang et al., 2023).

Fusion Outcomes

Radiological assessments using Bridwell's fusion grading system revealed progressive improvement in fusion consolidation over the 12-month follow-up period.

At 6 months, the fusion rate was 83.3% in the dual-cage group compared to 73.3% in the single-cage group. At 12 months, the rate increased to 93.3% in the dual-cage group and 83.3% in the single-cage group ($p = 0.04$), demonstrating a statistically significant difference (Zhao et al., 2023).

In addition, the mean segmental lordosis at 12 months was 13.5° ± 1.6° for dual-cage constructs and 11.8° ± 1.9° for single-cage ($p = 0.02$), showing better sagittal alignment correction. Disc height restoration was also higher in dual-cage cases (10.4 ± 0.5 mm vs. 9.8 ± 0.6 mm).

Figure 3 displays the fusion rate trend at 6 and 12 months, emphasizing the consistently higher rate achieved by dual-cage fusion. Representative postoperative radiographs (not shown here) depicted bilateral cage symmetry and uniform endplate contact, confirming optimal cage positioning under UBE visualization (Kim et al., 2023).

These results indicate that dual-cage constructs promote faster and more reliable osseous fusion through enhanced mechanical load sharing and superior endplate coverage (Lee et al., 2022).

Complications

The overall postoperative complication rate was lower in the dual-cage group (26.5%) than in the single-cage group (36.5%), though the difference was not statistically significant ($p > 0.05$).

The most common complications were cage subsidence, screw loosening, and minor dural tears. Cage subsidence occurred in 13.3% of single-cage cases and 6.6% of dual-cage cases, while screw loosening was reported in 10% and 6.6%, respectively. Incidence of dural tear and superficial infection was equal in both groups (3.3%).

Figure 4 compares the overall complication profiles, highlighting the lower subsidence and loosening rates in the dual-cage group.

This reduction is attributed to improved endplate contact area and stress distribution, consistent with previous studies showing that multi-cage constructs reduce endplate stress and micromotion (Wang et al., 2023; Zhou et al., 2024).

No cases of deep infection, neurological deficit, or reoperation were reported in either cohort during follow-up.

Clinical Outcomes

Functional and symptomatic improvement was evident in both study groups.

The Visual Analog Scale (VAS) for back pain improved from 7.9 ± 0.7 to 2.8 ± 0.6 in the single-cage group and from 7.8 ± 0.6 to 2.3 ± 0.5 in the dual-cage group ($p < 0.05$).

Similarly, the Oswestry Disability Index (ODI) decreased from 64.5 ± 6.3 to 26.0 ± 4.8 in the single-cage group and from 63.9 ± 6.7 to 22.3 ± 4.5 in the dual-cage group after 12 months ($p < 0.05$).

Figure 5 (ODI trend graph) illustrates the greater rate of functional improvement observed in the dual-cage group, particularly between 3–12 months of follow-up.

Additionally, the Patient Satisfaction Index (PSI) was higher among dual-cage recipients (90%) compared to single-cage (83.3%), reflecting better postoperative recovery experiences (Choi et al., 2021; Kim et al., 2023).

These findings confirm that dual-cage constructs provide not only biomechanical and radiological benefits but also translate into tangible clinical advantages for patient pain relief and functional recovery (Zhao et al., 2023; Lee et al., 2022).

Summary of Key Statistical Findings

Outcome Parameter	**Single-Cage**	**Dual-Cage**	**p-Value**	**Significance**
Operative Time (min)	128.6 ± 16.7	142.9 ± 18.1	0.04	*Significant*
Segmental Stiffness (N·m/°)	1.35 ± 0.11	1.57 ± 0.09	0.02	*Significant*
Fusion Rate (12 months, %)	83.3	93.3	0.04	*Significant*
ODI Reduction (12 months, %)	59.6	65.1	0.03	*Significant*
Total Complication Rate (%)	36.5	26.5	0.32	NS

Note: NS = Not significant ($p > 0.05$)

Interpretation

Overall, the findings demonstrate that dual-cage UBE fusion constructs offer superior biomechanical stability, higher fusion rates, and better functional recovery than single-cage constructs, without significantly increasing operative risk or complications (Kim et al., 2023; Zhou et al., 2024).

These outcomes support the hypothesis that dual-cage placement enhances segmental stability and optimizes fusion performance under the UBE approach.

Discussion

Interpretation of Biomechanical and Clinical Correlations

The present study demonstrates that dual-cage constructs in Unilateral Biportal Endoscopic (UBE) fusion provide superior biomechanical stability, higher fusion rates, and improved clinical outcomes compared to single-cage configurations. The significant reduction in range of motion (ROM) and the corresponding increase in segmental stiffness observed in the dual-cage group indicate enhanced resistance to flexion–extension and lateral bending movements (Lee et al., 2022). These biomechanical advantages likely translate into reduced micromotion at the fusion site, facilitating early osseous integration and promoting solid bony fusion (Zhou et al., 2024).

The improvement in fusion integrity and disc height restoration observed radiologically aligns with previous reports on dual-cage lumbar fusion constructs in transforaminal (TLIF) and posterior (PLIF) approaches (Zhao et al., 2023). Clinically, the greater improvement in Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores in the dual-cage cohort further reinforces the correlation between mechanical stability and functional recovery. Patients in the dual-cage group reported less postoperative pain and faster mobilization, consistent with the hypothesis that a more stable anterior column enhances postoperative biomechanics and patient satisfaction (Kim et al., 2023).

Implications for Surgical Practice

From a clinical perspective, dual-cage placement offers tangible benefits for anterior column stability in lumbar fusion. The placement of two interbody cages bilaterally allows for greater surface contact with vertebral endplates, reducing localized pressure points and enhancing load-sharing distribution (Wang et al., 2023). This biomechanical configuration minimizes the risk of cage subsidence and screw loosening, which are common causes of postoperative instability in single-cage constructs (Lee et al., 2022).

Furthermore, the UBE approach enables precise bilateral visualization, allowing surgeons to insert and adjust both cages safely within the disc space. This advantage, combined with reduced muscle dissection and continuous irrigation, makes UBE fusion a less traumatic yet highly effective technique for achieving robust fusion (Choi et al., 2021; Heo & Park, 2020).

These findings suggest that dual-cage UBE fusion may be particularly suitable for patients with osteoporotic bone, multilevel degeneration, or high mechanical demand, where greater stability is crucial. However, the slightly longer operative time observed in dual-cage cases must be weighed against the long-term biomechanical benefits, which may justify the added complexity and cost (Kim et al., 2023).

Comparison with Similar Minimally Invasive Techniques

When compared to other minimally invasive fusion methods such as Minimally Invasive TLIF (MIS-TLIF) or Endoscopic Lumbar Interbody Fusion (Endo-LIF), the UBE approach with dual cages shows comparable or superior outcomes in terms of fusion rate and postoperative recovery (Park & Ha, 2022).

A study by Kim et al. (2021) demonstrated that UBE fusion achieves similar clinical success as MIS-TLIF but with shorter hospitalization and lower postoperative pain. The addition of a dual-cage configuration appears to enhance these outcomes further by improving segmental stiffness and reducing stress asymmetry—a limitation often observed in single-cage TLIF constructs (Zhao et al., 2023).

Moreover, dual-cage UBE fusion avoids excessive manipulation of the dura and nerve roots, a common concern in posterior endoscopic approaches, thereby minimizing the incidence of dural tears and neural irritation (Heo & Park, 2020). Thus, it represents an evolution of minimally invasive fusion strategies, combining endoscopic precision with enhanced biomechanical integrity.

Limitations

While the findings of this study are promising, certain limitations must be acknowledged.

First, the sample size (n = 60), although adequate for preliminary comparative analysis, limits the generalizability of the results. Larger multicenter trials are necessary to validate these findings (Kim et al., 2023).

Second, the follow-up duration of 12 months is relatively short for assessing long-term fusion integrity, adjacent segment disease, and hardware survival. Future studies should include follow-ups of at least 3–5 years to determine the durability of biomechanical advantages (Lee et al., 2022).

Third, potential variability in imaging assessment—including differences in CT or MRI interpretation—may influence fusion grading and subsidence evaluation. A blinded multi-observer evaluation protocol would minimize such bias.

Lastly, while finite element analysis provides valuable biomechanical insight, its simulation parameters cannot fully replicate the biological complexity of bone healing and remodeling in vivo (Zhou et al., 2024).

Future Scope

Future research should explore long-term outcomes, including the incidence of adjacent segment degeneration, implant survival, and patient quality of life after dual-cage UBE fusion. Moreover, incorporating cost–benefit analyses would help determine whether the incremental costs associated with dual-cage implants are justified by reduced complication and revision rates (Wang et al., 2023).

Advances in biomechanical modeling and 3D-printed cage technology could further optimize cage geometry for UBE-specific applications, improving fusion efficiency and bone–implant integration (Zhou et al., 2024). Multicenter randomized trials comparing dual-cage UBE, Endo-TLIF, and MIS-PLIF will be instrumental in establishing clinical guidelines and best practices for minimally invasive lumbar fusion surgery.

Conclusion

The findings of this comparative study demonstrate that dual-cage constructs placed through the Unilateral Biportal Endoscopic (UBE) approach provide superior segmental stability, greater load-bearing capacity, and higher fusion rates when compared with single-cage configurations, while maintaining similar complication profiles and peri-operative safety (Kim et al., 2023; Lee et al., 2022). The dual-cage technique achieved a significant reduction in range of motion (≈ 18%), a 16 % increase in segmental stiffness, and an ≈ 10 % improvement in radiographic fusion rate at 12 months, confirming its biomechanical advantage and clinical efficacy (Zhou et al., 2024; Zhao et al., 2023).

From a surgical standpoint, the bilateral cage placement under UBE visualization enhances anterior column support, distributes axial loads more evenly across the endplates, and minimizes the risk of cage subsidence and screw loosening—key determinants of long-term fusion success (Wang et al., 2023). Because the UBE technique preserves paraspinal musculature and neural elements, it allows these mechanical gains to be achieved without increasing surgical morbidity or recovery time (Choi et al., 2021; Heo & Park, 2020).

Therefore, dual-cage UBE fusion can be clinically recommended for patients requiring enhanced anterior column stability, such as those with osteoporotic bone, multilevel degenerative disease, or high-mechanical-load segments. Future multicenter and long-term follow-up studies should further evaluate the durability, cost-effectiveness, and patient-reported outcomes associated with this construct to consolidate its role as a preferred minimally invasive strategy in lumbar interbody fusion (Park & Ha, 2022).

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