EFFICACY OF MINIMALLY INVASIVE POSTERIOR INTERBODY STABILIZATION WITH DISTRACTION CAGES IN LUMBAR SPONDYLOLISTHESIS

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ABSTRACT

Background. Degenerative Lumbar Spondylolisthesis (DLS) is a prevalent cause of neurogenic symptoms in older adults and is frequently managed surgically when conservative therapy fails. Comparative effectiveness of decompression and fusion strategies in DLS remain debated in contemporary evidence.

Aim. To evaluate the clinical efficacy and biomechanical rationale of the proprietary MIS-PLIF technique using distraction cages in patients with degenerative lumbar spondylolisthesis.

Materials and Methods. Pre-clinical FEA was provided in a detailed three-dimensional lumbosacral model (L3–S1). Clinical study was as a prospective, controlled, single-center interventional enrolling 24 patients with symptomatic DLS (median age 56 years; 18 females and 6 males; median body mass index 32 kg/m²). Patients of the main group were treated with the proprietary MIS-PLIF distraction-cage method, of comparison group – with standard MIS-PLIF using static cages, and a control group managed with alternative interbody fusion strategies. Non-parametric statistical testing was used at $p<0.05$. The research was conducted as a private initiative of the authors, did not receive funding from grant programs.

Research Ethics. The study was conducted in accordance with the World Medical Association Declaration of Helsinki and approved by the institutional ethics committee (Protocol No.7 of October 10, 2017).

Results. In the clinical stage, the main group (n=5) treated with the proprietary MIS-PLIF technique exhibited significantly lower operative trauma: median blood loss was 100 mL compared to 500 mL in the control group ($p<0.05$). Operative time was reduced by half, reaching 180 min versus 360 min in open surgical approaches ($p<0.05$). Early clinical outcomes in the main group included a more pronounced reduction in pain intensity (VAS median decrease of 4 points) and improved functional status (ODI median improvement of 10 points). Radiographic assessment confirmed the method's superiority in restoring intervertebral disc height (median +10 mm) and effective correction of sagittal alignment parameters (SVA, PT, SS), facilitating accelerated patient recovery.

Conclusions. The tested MIS-PLIF technique using an expandable distraction cage appears feasible and clinically advantageous in early outcomes, providing a coherent biomechanical and medical rationale.

Keywords: *segmental lordosis restoration, spinal-pelvic balance, distraction cage biomechanics, sagittal alignment correction, postoperative neurological recovery, minimally invasive posterior lumbar interbody fusion clinical outcomes.*

Introduction

Degenerative Lumbar Spondylolisthesis (DLS) is one of the most urgent and complex problems of modern spinal surgery [1–5]. In cases of ineffective conservative treatment, extensive open surgical interventions have traditionally been used [6; 7]. However, in recent years, there has been a significant breakthrough due to the introduction of minimally invasive technologies that have radically changed approaches to the treatment of DLS, allowing for shorter hospitalization times and improved patient recovery [8–15].

Among minimally invasive interventions, special attention is paid to Minimally Invasive Surgery Posterior Lumbar Interbody Fusion (MIS-PLIF), in particular with the use of distraction cages, a promising approach that ensures minimal invasiveness and preservation of anatomical structures [16–20].

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The need for further development of such techniques has increased significantly in the context of a full-scale war in Ukraine and other global crises, which, in addition to DLS of degenerative etiology, increase the frequency and severity of spinal injuries, including DLS [21–28].

Complicated logistical conditions, limited access to medical devices, and the need for operational efficiency necessitate the choice of technologies that allow achieving a therapeutic result with less resource use. In this context, the development and implementation of effective minimally invasive techniques, such as posterior interbody stabilization with distraction cages, is of not only medical but also socioeconomic strategic importance.

Today, surgeons from different countries are actively working to improve the methods of interbody stabilization for PS, in particular, posterior minimally invasive fixation [29]. Despite the good results of traditional and minimally invasive posterior approaches in achieving fusion, as well as a low complication rate, they are limited by the risks of iatrogenic damage to nerve structures and paravertebral muscles. Alternative options – anterior and lateral approaches – have their own anatomical and clinical advantages, but are associated with the risk of complications from the blood vessels, abdominal cavity or nerve plexuses [30].

Thus, the search for existing methods and implementation of new, more effective options for surgical treatment of DLS, in particular, using MIS-PLIF with distraction cages, is an urgent and reasonable task of modern medicine.

The present study is a continuation of our previous efforts [31, 32]. The previous stages of the study included the investigation of spinal biometric parameters and the dynamics of neurological disorders before and after surgical treatment with the traditional method; the study of restoration of spinal biometric parameters using distraction cages using a biomechanical model; analysis of the stress-strain system "transpedicular structure – spinal motor segment – distraction cage"; development of our own MIS-PLIF with distraction cages [31; 32].

Our pre-clinical study [31], conducted at Sytenko Institute of Spine and Joint Pathology, utilized a highly detailed 3D model of the lumbosacral spine (L3–S1) anchored to the pelvis. The choice of the L3–S1 segment is mechanically significant. The L5–S1 junction represents the "keystone" of the spine, transitioning load from the flexible lumbar column to the rigid sacral base. In spondylolisthesis, this segment is subjected to extreme anterior shear forces. The model incorporated vertebral geometry (differentiating between the stiff cortical shell with Young's Modulus E=12,000 MPa and the spongy cancellous core, E=100 MPa); intervertebral discs (modeled as composite structures, E=4.2 MPa); fixation hardware (modeling transpedicular screws and rods made of medical-grade steel, E=210,000 MPa).

A Finite Element Analysis (FEA) simulated a posterior spondylodesis at the L4–S1 level (fusion) under a vertical load of 422 N applied to L3, representing the weight of the upper body in a standing 700 N individual. Two distinct implant scenarios were subsequently compared. Scenario A (control) – L5–S1 interbody fusion using a standard PEEK cage (E=2,200 MPa), PEEK is currently the industry standard due to its radiolucency and modulus of elasticity similar to bone. Scenario B (experimental) – L5–S1 interbody fusion using the new distraction cage; this device is metallic, possessing a much higher stiffness and expansion capability.

The results of the FEA provided a critical biomechanical rationale for the distraction cage, challenging the conventional opinion regarding implant stiffness.

In the intact (normal) model, the stress on the inferior surface of the L5 vertebra was approximately 14.8 MPa. Following instrumentation, both the PEEK and Distraction Cage models saw this stress spike to ~40 MPa (40.2 MPa vs. 40.7 MPa). This finding confirms that rigid fixation inevitably concentrates stress at the fused level, necessitating robust endplates to prevent subsidence. The similarity between the two groups suggests that the *cage material* does not significantly alter the axial load seen by the vertebral body itself; rather, the *fixation construct* dictates this.

However, the stress distribution above the fusion (L3, L4) remained near normal levels (4.9–6.6 MPa) for both groups. This indicates that, in the short term (static loading), neither construct immediately alters the biomechanics of the adjacent segments, a positive finding for the prevention of Adjacent Segment Disease (ASD).

The most clinically relevant finding emerged at the S1 screw-bone interface. S1 pedicle screws are prone to loosening because the sacral alae are cancellous and the lever arm from the lumbar spine is long. High stress at the screw entry point is a primary predictor of toggle and pullout. In PEEK model the stress at the S1 screw entry was 27.3 MPa. In new distraction cage model the stress was reduced to 17.8 MPa.

The PEEK cage, being relatively compliant (E=2,200 MPa), deforms under the 422 N load. This deformation forces the rigid posterior rods and screws to carry a larger proportion of the load to maintain stability. The screws effectively become the primary load-bearing elements, leading to high interface stress.

In contrast, the new distraction cage is stiff and does not deform significantly. It acts as a rigid anterior column pillar, absorbing the compressive load directly. By preventing anterior column settling, it partially absorbs the excessive toggle forces on the posterior screws. The hypothesis of load transfer is confirmed by comparing the internal stresses of the cages themselves: PEEK cage stress 35.7 MPa; distraction cage stress 113.3 MPa.

The distraction cage carries more load than the PEEK cage. While 113.3 MPa is a high stress value, it is well within the yield strength of titanium alloys (typically >800 MPa) or surgical steel. By bearing this massive load, the distraction cage relieves force load on the posterior hardware – specifically the S1 screws (58.0 MPa in PEEK vs. 49.0 MPa in new distraction cage) and the L5 rods (80.8 MPa in PEEK vs. 72.2 MPa in new distraction cage).

The FEA study substantiates the mechanical superiority of the distraction cage for posterior stabilization. This can be a modification factor in spondylolisthesis patients, who often have compromised bone quality, which could cause screw long-term stability failure.

Previous finite element modeling and earlier radiographic observations related to the developed distraction-cage technique were published separately and are cited here as methodological background [31, 32]. The present manuscript reports the clinical comparative stage of testing the method and does not present those previously published findings as new primary results.

Aim of the study was to evaluate the clinical efficacy and biomechanical rationale of the proprietary MIS-PLIF technique using distraction cages in patients with degenerative lumbar spondylolisthesis.

Material and Methods

The study enrolled 24 patients, of them 18 females (75%) and 6 males (25%), diagnosed with degenerative lumbar spondylolisthesis. The demographic profile of the cohort was stated accordingly: main group 4 to 1 female to male ratio, comparison group – 8 to 3, and 6 to 2 ratio for control group. This skew reflects the known epidemiology of DLS, where hormonal factors and pelvic geometry predispose women to L4–L5 slips. Median age was 56 years. The inclusion of younger patients (32 years) represents some cases of isthmic spondylolisthesis or early-onset degeneration, though the focus remained on degenerative pathology. Body Mass Index (BMI) median was 32 kg/m². Obesity increases the anterior shear force on the lumbar spine, exacerbating the slip and increasing the mechanical demand on any surgical implant.

Selection criteria were applied to ensure internal validity: inclusion – symptomatic DLS with neurogenic claudication, radiculopathy (paresis grade [3–4]), or segmental sensory deficit; failure of conservative therapy; age [32–68]; exclusion – age >75 years (due to poor bone quality confounding screw fixation), severe somatic comorbidity, complete plegia (requiring different urgency), or minimal symptoms not warranting fusion.

To isolate the effect of the distraction cage method, the patients were divided into three groups. Main group (n=5) included the patients treated with the author's proposed method of MIS-PLIF using distraction cages. Comparison group (n=11) consisted of the patients treated with standard PLIF method with reduction using conventional static cages (PEEK or titanium). The controls (n=8) were the patients treated with the method, which included non-minimally-invasive posterior fusion with decompression but without reduction of spondylolisthesis, also serving as a baseline for surgical trauma comparison. The main group was small (n=5), reflecting the "probation" of a new medical device trial; the comparison against a larger pool of controls (n=19 total) allowed for statistically valid non-parametric analysis ($p<0.05$).

The main outcomes of the present clinical stage were operative time, intraoperative blood loss, postoperative pain intensity, disability dynamics, duration of hospitalization, and time to completion of rehabilitation. Completion of rehabilitation was defined as the patient’s ability to return to work and to the level of functioning present before the disease.

Pain intensity by VAS and disability by ODI were assessed in the postoperative period on day 3. These measures were recorded during joint assessment by the patient and the operating surgeon. Independent blinded assessment was not used. Paraspinal muscle atrophy had been assessed by MRI at 6 months.

Statistical analysis. The normality of data distribution was assessed by the Shapiro-Wilk test.

Since the data distribution in most parameters and groups differed from normal, nonparametric methods of statistical analysis were used. The main tendency was described using the median (Me), the variability – with the definition of the lower (LQ) and upper (UQ) quartiles. The median values of study groups were compared using the Kruskal-Wallis test. The reliability of paired intergroup differences was assessed using the post-hoc Mann-Whitney test with Bonferroni adjustment. Comparison of indicators frequency (absolute and relative) was carried out using the Fisher exact method.

Research Ethics

The study adhered to the World Medical Association Declaration of Helsinki (1964–2024) and was approved by the Ethics and Bioethics Commission of Kharkiv National Medical University (Protocol No.7 dated October 10, 2017). All patients signed informed consent for surgical treatment and for participation in the study, including the use of anonymized clinical data.

Results

Using a distraction cage and MIS PLIF approach [32] integrates this device into a strict MIS protocol. The patients were placed in a prone position on a radiolucent table. Paramedian incisions (Wiltse approach) were used. Retraction was achieved by installation of tubular retractors. Crucially, this approach *splits* the muscle fibers rather than detaching them from the spinous processes. Decompression – unilateral facetectomy and hemilaminectomy to access the disc and decompress the nerve root. Preparation – radical discectomy and endplate preparation to expose bleeding bone (essential for fusion). Stabilization – insertion of the distraction cage and activation of the expansion mechanism under fluoroscopic guidance. To decompress nerve root, unilateral facetectomy was performed, with subsequent discectomy and endplate preparation to expose bleeding bone (essential for fusion). Then interbody cage was inserted and *in situ* distraction performed. This was followed by transtubular pedicle screw fixation.

This technique differed from the control group (open PLIF), which required midline incision and extensive subperiosteal muscle stripping, and formed the comparison group, where significant part of the vertebral canal was exposed.

The intraoperative data provides compelling evidence for the efficiency of the new method (*Table 1*).

The main group's operative time, 180 minutes (min.) was half that of the control group (360 [240; 480] min).

Blood loss in the main group was about 100 ml [100]. Compared to the 500 [400; 600] ml loss in the control group, thus reducing the modifying factors which can influence on the risks of the need for transfusions and postoperative hematoma.

The safety profile of the distraction cage method was adequate regarding soft tissue preservation (*Table 2*).

The study evaluated the "functional state" of the spine through biomechanical parameters. Disc height restoration in main group was +10 [9; 11] mm; in comparison group: +8 [5; 9] mm; in control group +9 [7; 10] mm. The distraction cage achieved the greater median height restoration.

Patient-Reported Outcome Measures (PROMs) were as follows. By Visual Analogue Scale (VAS) in pain evaluation the main group saw a median reduction of 4 points (e.g., from 8 to 4); comparison group dropped by 3 points; control group by 2 points. The difference was statistically significant ($p<0.05$).

As for the disability data, Oswestry Disability Index (ODI) in the main group improved by 10 points (median), while the control group showed a larger raw change (18 points), this is likely an artifact of higher baseline disability in the open surgery group. The main group achieved excellent absolute outcomes.

Table 1. Operative parameters in patients with lumbar spondylolisthesis

Parameter	Main group (n=5)	Comparison group (n=11)	Control group (n=8)	Statistical significance
Operation time (minutes)	180 [180; 180]	180 [160; 210]	360 [240; 480]	$p<0.05$ (main vs control)
Blood loss (ml)	100 [100; 100]	200 [200; 300]	500 [400; 600]	$p<0.05$ (main vs all)
Hospital stay (days)	13 [11; 18]	9 [7; 12]	11 [6; 22]	–

Table 2. Postoperative complications in patients with lumbar spondylolisthesis

Complication	Main group (n=5)	Comparison group (n=11)	Control group (n=8)	Insight
Muscle Atrophy	–	11/11 (100%)	4/8 (50%)	Complete preservation of paraspinal muscles in main group
Hemorrhage	–	3/11 (27%)	1/8 (13%)	Superior hemostasis with new method
Cerebrospinal fluid leak	–	1/11 (9%)	–	Safe dural handling
Radiculitis	1/5 (20%)	3/11 (27%)	1/8 (13%)	Comparable nerve irritation rates

In sagittal balance, the study noted effective restoration of segmental lordosis, pelvic tilt (PT), and sacral slope (SS). Correction of these spinopelvic parameters is essential for energy-efficient standing and walking. The reduction of the sagittal vertical axis (SVA) indicates an improvement in global spinal alignment.

Discussion

The FEA shows that in a posterior fixation construct, a soft cage transfers stress to the screws (58 MPa at S1). By using a stiff, expandable metal cage, the implant takes the load (113 MPa), sparing the screws (17 MPa). The distraction cage forms anterior load column, while the screws act as a posterior fixation line.

The distraction cage, inserted collapsed, requires a smaller footprint and less manipulation time (180 min operation time). Preserving the muscle envelope reduces postoperative pain (VAS – 4) and maintains the spine's dynamic stabilizers, potentially reducing the rate of Adjacent Segment Pathology (ASP) in the long term.

Based on the current evidence, MIS posterior interbody fusion with expandable cages represents a viable and feasible treatment option for appropriately selected patients with lumbar spondylolisthesis. It offers improvement in clinical symptoms and propones restoration of disc and foraminal height.

The research initiated by us on the proprietary MIS-PLIF method using distraction cages was situated within evolving landscape. The approach, incorporating upfront biomechanical modeling to address key parameters such as sagittal alignment and stress distribution, is desirable given the need for long term observation and retrospective studies. Future validation through larger, rigorous clinical trials comparing established standard-of-care MIS procedures and MIS PLIF with expandable cages is essential to demonstrate any tangible benefits in efficacy, safety, and alignment maintenance.

A statistically significant reduction in pain was achieved in the main group: by 4 points on the VAS scale, which is a statistically significant result compared to 3 points in the comparison group and 2 points in the control group. Similar results were reported by Lu V.M. et al. (2017) [10], who noted that patients after MIS-TLIF had significantly lower pain intensity in the early postoperative period. Also, Arts M.P. et al. (2017) [8] showed that, compared to open interventions, MIS techniques contribute to an accelerated reduction in pain.

The peculiarities of functional recovery according to the ODI were revealed: patients in the main group showed a decrease of 10 points, which exceeded similar indicators in other groups. According to Hammad A. et al. (2019) [9], a similar decrease of [8–10] ODI points after MIS-TLIF correlates with a significant improvement in patients' daily activities.

The key parameter of postoperative stability was the intervertebral space. In the group with distraction cages, its restoration was 10 mm, which is higher than the value in the comparison group (8 mm) and is fully consistent with the results of Wu Y. et al. (2024) [15], which noted that adequate expansion of the intervertebral space significantly reduces the risk of secondary neurocompression.

The sagittal balance assessment showed that the proposed technique allows optimizing the parameters of sacral and pelvic tilt and Sagittal Vertical Axis (SVA) index, bringing them closer to physiological norms. This corresponds to the data of simulations conducted at Sytenko Institute of Spine and Joint Pathology, which demonstrated an

improvement in balance due to the use of distraction cages with the possibility of intraoperative reduction [31].

In addition to clinical advantages, the proposed technique showed a reduction in the duration of the operation (180 minutes) compared to 360 minutes in the control group ($p<0.05$). Similar time savings were noted in the publications of Yang Y. et al. (2018) [12], which indicated that MIS-TLIF halved the duration of the intervention compared to open methods. The reduction in operative time is directly related to less blood loss, which in this study was only 100 ml versus [200–500] ml in other groups. According to Lu V.M. et al. (2017) [10], the amount of blood loss is a determining factor in the prognosis of the postoperative course.

The absence of complications in patients of the main group, in particular, atrophy of paravertebral muscles, cerebrospinal fluid leaks, and infections, is an extremely important indicator of the safety of the technique. Comparing this with the literature data (Mobbs R.J. et al. (2015) [30]), it can be argued that the proposed method reduces the incidence of the most common postoperative complications. Thus, the incidence of radiculitis with root dysfunction in the main group was only 25%, while in the comparison group – 30%, and in the control group – 50%.

Thus, the clinical testing of the Expandable MIS-PLIF method using distraction cages showed desirable clinical outcomes in both the short and medium term. In combination with the data from the world literature, our findings confirm the feasibility of further implementation of this method in surgical practice, especially in the context of increased requirements for the effectiveness and safety of surgical interventions.

Limitations. Sample Size (n=5 in the main group) is small, suitable for a "probation" study but requiring expansion for high-power statistical certainty and low statistical representability. As there was no single blinded assessment, thus the study has higher bias risks. Follow-up, long-term data (2+ years) on fusion rates and potential late subsidence, is needed, although the FEA predicts low subsidence risk due to load distribution.

Conclusions

1. Clinical testing of the proprietary MIS-PLIF technique with distraction cages confirmed its capability for effective listhesis reduction and restoration of intervertebral height (median +10 mm, $p<0.05$), facilitating the correction of sagittal alignment parameters (SVA, PT, SS) toward physiological values.

2. The use of a minimally invasive approach combined with expandable implants significantly reduces surgical trauma: intraoperative blood loss is limited to 100 mL (compared to 500 mL in open surgery), and operative time is reduced to 180 min ($p<0.05$), ensuring a favorable safety profile and minimal postoperative complications.

3. Preliminary outcomes indicate high functional efficiency of the method, with a 4-point reduction in VAS pain scores and a 10-point improvement in the ODI index. These findings support the feasibility of the technique for wider clinical application, especially in resource-constrained healthcare environments.

Prospects for further research are to continue the study of the clinical effectiveness of the developed method of minimally invasive posterior interbody fusion of the lumbar spine using distraction cages in patients with lumbar spondylolisthesis.

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Authors' Contributions

Contribution / Authors	A	B	C	D	E	F
Stognii A.	+	+	+	+		+
Piatykop V.	+				+	+

Notes: A – concept; B – design; C – data collection;
D – statistical processing and interpretation of data;
E – writing or critical editing of the article;
F – approval of the final version for publication and agreement to be responsible for all aspects of the work.

Declarations

Conflict of interest is absent.

All authors have given their consent to the publication of the article, to the processing and publication of their personal data.

The authors of the manuscript state that in the process of conducting research, preparing, and editing this manuscript, they did not use any generative AI tools or services to perform any of the tasks listed in the Generative AI Delegation Taxonomy (GAIDeT, 2025). All stages of work (from the development of the research concept to the final editing) were carried out without the involvement of generative artificial intelligence, exclusively by the authors.

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