Functional Outcome and Recurrent Lumbar Disc Herniation Following Minimally-invasive Surgical Interventions: A Systematic Review and Meta-analysis

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Abstract:

Background: *Low back pain (LBP), affecting ~10% of the global population, is a major public health challenge, with elevated prevalence in China (20.88–29.88%). Lumbar disc herniation (LDH), a leading cause of LBP (12–43% of cases), involves nucleus pulposus displacement and annulus fibrosus compromise. While conservative therapies resolve symptoms in 75% of patients, refractory cases necessitate surgery. Percutaneous Endoscopic Lumbar Discectomy (PELD) is a minimally invasive option with favorable outcomes. This systematic review and meta-analysis evaluate the efficacy of minimally invasive surgeries for LDH, focusing on pain reduction, functional improvement, and recurrence.*

Methods: *Following PRISMA guidelines, PubMed, Scopus, and Web of Science were systematically searched using keywords related to LDH, minimally invasive surgery, and clinical outcomes. Eligible studies included confirmed LDH diagnoses, detailed surgical data, and postoperative outcome measures. Two researchers independently screened articles and extracted data. Meta-analyses (RevMan 5.4, STATA 17.0) employed random-effects models to calculate mean differences (MDs) and odds ratios (ORs). Sensitivity and publication bias analyses were conducted.*

Results: *Among 11,626 screened articles, 14 studies (1,108 patients) met inclusion criteria. All procedures significantly reduced back and leg pain at 3, 6, and 12 months postoperatively. Unilateral Biportal Endoscopic (UBE) surgery demonstrated the largest improvements in Visual Analog Scale (VAS) scores for back and leg pain across all intervals. PELD with annular suture yielded the highest Oswestry Disability Index (ODI) improvements (MD: 65.32 at 3 months; 70.93 at 12 months). UBE also outperformed other techniques in functional outcomes. Recurrence rates between Microendoscopic Lumbar Discectomy (MELD) and PELD were comparable (OR: 0.90; 95% CI: 0.37–2.22).*

Conclusion: *Minimally invasive surgeries, particularly UBE and PELD with annular suture, significantly improve pain and function in LDH patients. Despite methodological heterogeneity, results robustly support their efficacy. Personalized surgical selection and standardized protocols are critical to optimizing outcomes. Future research should prioritize identifying patient-specific predictors of success to guide precision interventions. This analysis provides evidence-based insights to enhance clinical decision-making and patient quality of life.*

Keywords: *Low Back Pain; Visual Analog Scale; Lumbar Disc Herniation; Percutaneous Endoscopic Lumbar Discectomy; Micro-endoscopic Lumbar Discectomy; Unilateral Biportal Endoscopic.*

1. Introduction:

Low back pain (LBP) has emerged as a global health concern, affecting approximately 10% of the world's population. In China, LBP prevalence among adults is notably higher, ranging from 20.88% to 29.88% [1]. Of those affected by LBP, an estimated 12% to 43% have experienced lumbar disc herniation (LDH) at some point in their lives [2].

The intervertebral disc, composed of an inner nucleus pulposus and an outer annulus fibrosus, plays a central role in LDH pathology, which involves the displacement of the nucleus pulposus beyond the disc space limits and potential rupture of the annulus fibrosus. Treatment strategies for LDH predominantly include both conservative and surgical interventions [3]. Conservative management, encompassing rest and analgesic therapy, alleviates pain in about 75% of patients within four weeks. However, when pain becomes intractable, surgical intervention may be warranted [2].

Among the various surgical options available for LDH, including open discectomy (OD), laminectomy, percutaneous endoscopic lumbar discectomy (PELD), spinal fusion, and nucleolysis, PELD stands out as a preferred choice due to its minimally invasive nature and favourable outcomes [3]. A recent meta-analysis compared PELD with conventional surgery, revealing no significant differences in post-operative pain on the visual analogue scale (VAS), length of stay, or recurrence rate between the two groups. Nevertheless, PELD was associated with shorter operative times and a lower risk of complications [4]. Comparisons between PELD and micro-endoscopic lumbar discectomy (MELD) indicated that PELD had a lower complication rate (10.8%) compared to MELD (13.3%). In contrast, open microdiscectomy demonstrated a slightly better success rate concerning neurological deficits, hematoma, and need for reoperation, although it showed relatively higher rates of direct nerve root injury and recurrent disc complications [5]. Despite these findings, current studies are focusing on the comparative effect of PELD, open Microdiscectomy, microscope-assisted tubular discectomy and others, reported literature exhibits limitations related to sample size, patient classification, study design, and outcome measure significance, complicating the determination of optimal clinical practices [6–10].

This systematic review and meta-analysis aim to provide a comprehensive comparison of the effectiveness of minimally invasive surgeries for LDH, focusing on leg pain, back pain, functional capacity, success rates, and predicting recurrence after surgery. Through this analysis, we seek to contribute valuable insights into the ongoing debate regarding the most efficacious treatment pathways for LDH.

2. Methods:

This review article followed the preferred reporting item for systematic review and meta-analysis (PRISMA) methods for data collection and presentation [11]. The PRISMA checklist is provided in the supplementary file Table 1.

2.1. Literature search and selection:

All literature was searched according to the PICO(S) (population, intervention, comparison, outcome, and study design) formula [12,13]. Population: All adult males and females who have undergone lumbar disc herniation (LDH) surgery. Intervention: Any minimally invasive surgical procedures performed for LDH. Comparators: Various conventional surgical strategies used for comparison in terms of postoperative outcomes. Outcomes: Patients' back pain, leg pain measured on the Visual Analog Scale (VAS), and functional capacity assessed through the Oswestry Disability Index (ODI) were compared between baseline and postoperative stages across different time frames. Eligible criteria: studies were eligible for selection if they fulfilled specific criteria such as (1) all participants had a confirmed diagnosis of LDH, (2) studies reported any study outcome, (3) detailed information about surgical intervention and patient selection process, (4) available data on different time frames such as baseline and postoperative (5) articles were in English or Chinese language. Exclusion criteria: Articles were excluded if they matched the following criteria: (1) Participants were from different diseases with LDH (2) Basic studies without involving or comparing human samples (3) studies did not report required data or after contacting the author data was not acquired (4) any review studies, editorial letters, case studies.

Two researchers independently searched articles using keywords such as "Lumbar Disc Herniation" [MeSH], "lumbar herniated disc", "LDH", "intervertebral disc displacement", "Minimally Invasive Surgical

Procedures" [MeSH], "minimally invasive surgery", "laparoscopic discectomy", "endoscopic discectomy", "microdiscectomy", "percutaneous discectomy", "Pain" [MeSH], "Back Pain", "lower back pain", "LBP", "Sciatica", "Referred Pain", "recurrence rate", "recurrent herniation", and "recurrent lumbar disc herniation". Additionally, Medical Subject Headings (MeSH) terms and Boolean operators (AND/OR) were employed to refine the search from three renowned search engines (PubMed, Scopus and Web of Science) (supplementary table 2). Articles found from the initial search were screened for duplicates and the title, abstract using the citation manager software 'Zotero' [14] and 'Rayyan'[15] and if writing fulfilled the primary inclusion criteria were screened for full-text for validating all inclusion criteria. If any disagreement occurs during article selection, the supervising author makes the final decision.

2.2. Data extraction:

We have extracted all necessary data from all eligible studies and tabulated them in Table 1. We have also separated articles on different surgical procedures. We have categorized all study data according to follow-up time. Two researchers independently extracted all available data.

2.3. Statistical analysis and Quality assessment:

Among all available data, we ran a meta-analysis to assess the effect of different surgeries on our study variables. We utilized RevMan 5.4 and STATA version 17.0 (StataCorp Ltd.) software for the meta-analysis. We analyzed mean and standard deviation (SD) as continuous outcome and considered the random effect model in the meta-analysis. However, if there was substantial heterogeneity (I2>60% and X2, P-value < 0.05), we calculated using the fixed effect method. If the value of 95% CI does not cross the line of significance and the P-value is below 0.05, then it is considered statistically significant.

We performed a sensitivity analysis using the leave-one-out meta-analysis method in STATA. Eager's test and a funnel plot were used to find any potential publication bias where a P-value less than 0.05 was considered a significant publication bias among studies. Meta-regression was not possible due to data availability. We have assessed the quality of all retrospective studies on the Newcastle-Ottawa Scale (NOS)[16], which scores articles from 0 to 9 based on three categories (selection, comparability, and outcome) and scored from nine to zero as the highest (9) to lowest (0) category. Further, RCT studies were assessed for quality and risk of bias using 'RoB 2.0' [17]. Categorization and selection of studies were performed following the recommended tools of the Cochrane collaboration. No studies were excluded based on quality.

Since this systematic review relies solely on publicly available data, ethical approval is not deemed necessary.

3. Results:

An initial search from three databases yielded 11,626 articles. After duplication removal and screening of the title and abstract, 59 articles were selected for full-text screening and data availability. Finally, only 14 articles[2,6,9,10,18–27] met all inclusion criteria (Figure 1). The thorough article selection process and search strategy are available in the supplementary file (Table 2).

3.1. Characteristics of eligible articles:

A summary of all included articles is presented in Table 1. Across 14 articles, a total of 1,108 patients with lumbar intervertebral disc herniation (PLID) were analyzed, including 463 patients at the L4-5 level. The overall age range (mean ± SD) was from 34.8 ± 9.1 to 57.19 ± 14.25 years, with 563 patients being male. Demographically, nine studies were conducted in China [6,7,9,10,18,22,25–27], two in Japan [20,23], one in India [2], one in Egypt [21], and one in South Korea [19].

Preoperative pain history, as measured by the Visual Analog Scale (VAS) for leg and back pain, ranged from 3.5 ± 1.7 to 8.42 ± 2.3 for leg pain and from 3.6 ± 1.8 to 8.7 ± 1.4 for back pain. The Oswestry Disability Index (ODI) scores ranged from 26.35 ± 6.6, indicating the moderate disability index, to 82.62 ± 7.15, reflecting bed-bound or exaggerated symptoms with highest disability.

Regarding surgical interventions, eight articles compared Percutaneous Endoscopic Lumbar Discectomy (PELD) [6,9,10,21,24–27]. Three articles focused on lumbar open microdiscectomy [2,10,20,21], while other procedures included microendoscopic discectomy [18,25], PELD with annular suture visualization [24], lumbar percutaneous hydrodiscectomy [20], and unilateral biportal endoscopy (UBE) [26].

Among the 14 articles, eight were designed as prospective randomized controlled trials (RCTs) [6,18–23,26]. Risk of bias assessments revealed that four articles had a low risk of bias [18–21] , while others raised concerns regarding randomization processes and selection of reported results (Figure 2). Six retrospective studies [2,9,10,24,25,27] were evaluated using the Newcastle-Ottawa Scale, with three studies achieving a high score of 9 [2,9,24], two scoring 8 [10,25], and one scoring 7 due to selection and comparability biases [27] (Table 2). .

3.2. Back and Leg Pain Intensity Following Surgical Interventions:

Following various surgical interventions, the intensity of lower back pain was assessed using the VAS to determine the mean difference from baseline to post-operative follow-ups at three months, six months, and one year. All surgical procedures significantly reduced back pain compared to baseline levels. For instance, among 484 patients who underwent PELD, the VAS scores showed a mean difference (MD) of 4.41 (95% CI: 3.50, 5.32; $P < 0.01$) at three months, an MD of 4.22 (95% CI: 3.01, 5.44; $P < 0.01$) at six months, and an MD of 4.73 (95% CI: 3.70, 5.77; $P < 0.01$) at twelve months (Figures 3a, 3b, 3c and Figure 4).

Similarly, all other surgical procedures demonstrated significant reductions in back pain at the twelve-month follow-up. Notably, Unilateral Biportal Endoscopic (UBE) surgery exhibited the highest mean differences across all time points. Among 55 patients, UBE achieved VAS MDs of 5.99 (95% CI: 5.72, 6.26; $P < 0.01$) at three months, 6.49 (95% CI: 6.19, 6.79; $P < 0.01$) at six months, and 6.99 (95% CI: 6.73, 7.25; $P < 0.01$) at twelve months (Figures 3a, 3b, 3c and Figure 4).

A total of 910 patients were evaluated for leg pain or sciatica before and after surgery. All patients reported significant improvements from baseline to three months post-operatively. However, the improvement in VAS score mean differences was relatively consistent across different procedures at six months, with PELD achieving an MD of 5.55 (95% CI: 4.92, 6.18) and lumbar open microdiscectomy (LOM) an MD of 5.37 (95% CI: 4.68, 6.05). At the twelve-month follow-up, PELD, LOM, microendoscopic discectomy (MED), and visualization of PELD with annular suture groups also showed comparable reductions from baseline, while UBE consistently demonstrated higher changes at all three-time points (Supplementary Figures 1a, 1b, 1c, and Figure 2).

3.3 Functional outcome after different surgery:

The Oswestry Disability Index (ODI) assesses patients' functional capacity across ten domains: Pain Intensity, Personal Care, Lifting, Walking, Sitting, Standing, Sleeping, Sex Life, Social Life, and Traveling. Scores range from 0 to 100, with higher scores indicating greater disability.

Among 903 patients, the ODI scores from higher levels of disability at baseline indicated moderate levels of disability at follow-up three months post-surgery. Significant changes were observed in mean differences following all surgical interventions. Notably, visualization of PELD with annular suture demonstrated the highest improvement, with a mean difference (MD) of 65.32 (95% CI: 62.55, 68.09; $P < 0.01$). This substantial improvement persisted at twelve months, with an MD of 70.93 (95% CI: 68.86, 73.00; $P < 0.01$).

UBE surgery also showed significant improvements compared to other surgical groups. In contrast, PELD, LOM, and MED exhibited relatively similar improvements across the three-time points (Supplementary Figures 3a, 3b, 3c, and Figure 4).

3.4 Recurrent LDH:

Among all studies five articles [2,9,19,22,27] reported recurrence of LDH after different surgery. We have compared the recurrence of LDH between MELD (10 out of 196) and PELD (12 out of 211). The forest plot indicates that there is no significant difference in the recurrence rate of LDH between MELD and PELD. The overall odds ratio of 0.90 (95% CI 0.37, 2.22) suggests that both procedures have similar outcomes in terms of recurrence. The lack of significant heterogeneity among the studies supports the reliability of this conclusion (Figure 5).

3.5 Justification of Heterogeneity, Publication Bias, and Sensitivity Analysis:

To evaluate the robustness of our meta-analysis findings, we conducted a leave-one-out sensitivity analysis. This approach involved systematically excluding each study one at a time to assess its impact on the overall effect size. Our results indicated that no single study significantly altered the aggregate outcome, thereby confirming the stability of our findings.

Despite this stability, we observed substantial heterogeneity among the included studies, with an I^2 value exceeding 90%. Such high heterogeneity suggests significant variability in effect sizes that cannot be attributed solely to random chance. We attribute this heterogeneity to several factors, including differences in patient demographics, surgical techniques, and postoperative management strategies. To explore these potential sources of variation, we performed subgroup analyses and reported the detailed results.

Additionally, we conducted meta-regression analyses to further investigate the impact of patient age on postoperative outcomes. Using mean age and standard deviation as covariates, and changes in VAS scores as the outcome measure, we found that the Q-statistic was highly significant ($p < 0.00001$). This result underscores the substantial influence of patient age on postoperative outcomes across different age groups, as detailed in Supplementary Table 3.

Regarding publication bias, due to the limited number of studies (less than ten), we were unable to perform a reliable funnel plot analysis. Consequently, assessing publication bias within our dataset remains challenging.

However, given the small sample size, it is important to interpret our findings with caution, acknowledging the potential limitations in detecting publication bias.

In summary, our comprehensive sensitivity analysis and exploration of heterogeneity provide a thorough understanding of the factors influencing postoperative outcomes. The significant impact of patient age, as revealed by our meta-regression, highlights the importance of considering demographic variables when evaluating surgical interventions. Future research should aim to include a larger number of studies to better assess publication bias and further validate our findings.

4. Discussion:

This meta-analysis is the first study to comprehensively evaluate the efficacy of multiple minimum surgical interventions of LDH in three time periods on back and leg pain, and functional outcomes using the VAS and ODI. This study assessed 1108 patients for leg pain or sciatica, lower back pain, following surgical procedures including PELD, UBE, LOM, and microendoscopic discectomy MED and others. The key findings indicate that all surgical procedures significantly reduced back pain compared to baseline levels at three months, six months, and one-year post-surgery. Notably, UBE surgery demonstrated the highest mean differences in VAS scores across all time points, achieving MDs of 5.99, 6.49, and 6.99 at three, six, and twelve months, respectively. For leg pain, while improvements were consistent across different procedures at six months, UBE consistently showed higher changes at all three-time points. In terms of functional outcomes, significant improvements were observed in ODI scores following all surgical interventions. Visualization of PELD with annular suture exhibited the highest improvement in ODI scores, with MDs of 65.32 at three months and 70.93 at twelve months. UBE also showed substantial improvements compared to other surgeries. The innovation of this study lies in its detailed comparison of multiple surgical techniques over extended follow-up periods, providing robust evidence for the effectiveness of UBE and PELD with annular sutures in reducing pain and improving function. This comprehensive analysis offers valuable insights for clinicians in selecting optimal surgical approaches for patients with back and leg pain.

PELD represents a minimally invasive surgical option that offers several advantages over traditional open surgery for patients with LDH. These benefits include reduced intraoperative bleeding, minimal disruption to surrounding soft tissues, and accelerated return to daily activities. However, PELD poses challenges in addressing central LDH cases, particularly when the intervertebral disc protrusion deviates from the midline. In such scenarios, maneuvering the catheter may inadvertently compress nerves or the dural sac, potentially leading to post-surgical complications like perineal numbness or weakness in dorsalis pedis muscle function [26].

In contrast, percutaneous transforaminal endoscopic discectomy (PTED) provides a lateral approach for LDH treatment that decompresses the nerve root under direct visualization. This technique preserves the posterior spine's structural integrity, maintains the ligamentum flavum, and mitigates clinical symptoms associated with postoperative bleeding, adhesion, and scar tissue formation. Additionally, PTED allows for thermocoagulation of degenerated nucleus pulposus tissue, aiding in the repair of the annulus fibrosus and thereby decreasing the likelihood of recurrence. It also results in smaller incisions and promotes faster recovery [10].

Full-endoscopic transforaminal discectomy and open lumbar microdiscectomy (OLM) have both demonstrated positive clinical outcomes. The full-endoscopic method has achieved comparable improvements in leg pain (VAS), back pain (VAS), and disability index (ODI) scores at one-year follow-up relative to the conventional microdiscectomy standard, while offering shorter hospital stays, less blood loss, and quicker return to work [21].

Studies comparing different microdiscectomy techniques have reported varying results regarding the reduction of back pain. Some research indicates that conventional microdiscectomy leads to greater relief compared to tubular microdiscectomy, whereas other studies found no significant differences between these approaches and open discectomy concerning postoperative back pain. Instances of cerebrospinal fluid leakage and infection were observed but managed conservatively or with appropriate antibiotics. Tubular microdiscectomy was linked with a case of postoperative discitis, possibly influenced by an unrelated preexisting urinary tract infection [18,23].

Previous research on these procedures has been subject to limitations, including potential biases in patient selection and study objectives. For instance, Mayer et al.'s randomized controlled trial in 1993 highlighted the effectiveness of full-endoscopic transforaminal discectomy for contained disc herniations but excluded more complex cases [21,28]. Kim et al.'s retrospective analysis of 915 patients showed equivalent success rates and complication profiles for both techniques, though transforaminal discectomy performed less effectively in treating far-migrated disc fragments below the lower vertebra's pedicle or L5-S1 level herniations in high-riding pelvises [21,29]. Gibson et al.'s comparison also favored the transforaminal endoscopic approach for leg pain improvement at two-year follow-up [21,30].

UBE discectomy represents a hybrid technique that combines elements of both open and endoscopic spinal surgery. Like traditional open procedures, UBE utilizes an interlaminar approach, allowing for the deployment of a broad array of standard surgical tools such as curettes, Kerrison punches, osteotomes, high-speed drills, and forceps. The integration of separate visualization and operative channels in UBE provides instruments with greater maneuverability, resulting in more extensive decompression and improved exploration compared to percutaneous endoscopic methods. Studies have highlighted dural tears as the most prevalent complication associated with UBE, with contributing factors including instrument or radiofrequency-induced damage, spinal canal adhesions, large disc fragments, and loose dura mater. Consequently, careful dissection of the meningo-vertebral ligament is critical to minimizing this risk. In contrast, nerve root injuries following percutaneous endoscopic interlaminar discectomy (PEID) are generally related to cannula-induced rotation and compression within the spinal canal, symptoms of which typically resolve within three months. It should be noted that UBE procedures incur higher costs relative to PEID [24,26,27].

When considering the anatomical challenges posed by the L5/S1 segment, such as a high iliac crest and narrow foramen, Microscope-Assisted Tubular Discectomy (MTD) presents itself as a favorable option for treating LDH at this level. This is due to several reasons: the larger interlaminar space at L5/S1 directly aligns with the intervertebral disc, eliminating the need for additional lamina removal; the preganglionic distance at L5 is the greatest among lumbar levels, reducing the risk of ganglion injury; and the S1 nerve root predominantly originates above the L5/S1 disc, with only a quarter originating at the disc level. Moreover, herniations in the L5/S1 segment tend to occur near the axilla, compressing the dura and nerve roots due to their proximity [10,23].

The choice of surgical method is influenced by the type of disc herniation present. Both PTED and MTD are effective for intraspinal disc herniations, but PTED offers distinct advantages for foraminal and extraforaminal types due to the limitations of a posterior tubular approach in reaching far lateral herniations. Yoshimoto et al.'s work underscores the necessity of positioning the tube at the junction of the articular and transverse processes when addressing far-lateral disc herniations [22,31]. In elderly patients with multi-level disc herniations and stenosis, MED may not be the optimal treatment choice. Compared to MED, PTED involves less muscle disruption, preserves the vertical segments of the spinalis muscles, protects facet joints, does not compromise the ligamentum flavum, and allows for electrocautery hemostasis, leading to reduced blood loss. However, it is important to recognize that not all patients with lumbar disc herniation are suitable candidates for PEID, and individualized assessment remains crucial for determining the most appropriate surgical intervention.

4.1. Limitation and clinical implementation:

The present meta-analysis reveals significant improvements in functional outcomes following various minor orthopaedic surgeries, with all surgical interventions demonstrating favorable results compared to baseline. Despite the observed high heterogeneity among studies, which we have meticulously addressed by exploring potential sources such as differences in patient demographics, surgical techniques, and postoperative management, our findings robustly support the efficacy of these procedures in enhancing patients' quality of life. The substantial heterogeneity underscores the need for cautious interpretation and highlights the importance of considering individual patient characteristics when selecting an appropriate surgical approach.

These findings provide valuable guidance for healthcare providers, suggesting that minor orthopaedic surgeries can reliably lead to meaningful improvements in functional capacity and pain reduction. However, the considerable variability in outcomes indicates that a one-size-fits-all approach may not be optimal. Future research should aim to identify specific patient profiles that benefit most from each type of surgery, potentially through personalized medicine approaches. Moreover, efforts should focus on standardizing surgical protocols and postoperative care to minimize variability and optimize patient outcomes. This study's limitations, including the inherent challenges in controlling for unmeasured confounders and the potential impact of publication bias, should be considered when applying these findings in clinical practice. Nonetheless, this meta-analysis provides a strong foundation for evidence-based decision-making in orthopaedic surgery.

Conclusion

This meta-analysis confirms significant improvements in functional outcomes and pain reduction following various minor orthopaedic surgeries, with all procedures demonstrating favorable results compared to baseline. Notably, UBE surgery and PELD with annular suture showed superior outcomes. Despite high heterogeneity, likely due to diverse patient demographics and surgical techniques, the overall evidence supports the efficacy of these interventions. The findings provide a robust foundation for clinical decision-making, emphasizing the importance of personalized surgical approaches. Future research should focus on standardizing protocols to optimize patient outcomes.

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List of tables and figures:

Table 1: Summary of all included articles.

Author	Country	Study Design	Total Sample Size	Name of surgery	Group Size	Male	Female	Age (mean, SD)	Preoperative VAS leg pain, (mean ± SD)	Preoperative VAS back pain, (mean ± SD)	Preoperative ODI, (mean ± SD)	Operated level		
												L3–L4	L4–L5	L5–S1
Sonawane et al. 2024	India	Retrospective	63	Conventional microdiscectomy	32	24	8	41.62 ± 13.91	6.37 ± 1.87	4.71 ± 1.19	49.3 ± 15.73	3	16	13
				Tubular microdiscectomy	31	20	11	42.80 ± 13.48	6.41 ± 1.76	4.22 ± 1.17	54.45 ± 17.69	2	17	11
Kandeel et al. 2024	Egypt	RCT	65	Percutaneous full- endoscopic transforaminal discectomy	32	25	7	35.47 ± 9.34	5.65 ± 0.77	8.47 ± 0.51	64.75 ± 5.41	2	19	11
				OLM	33	19	14	39.27 ± 7	5.42 ± 0.88	8.4 ± 0.65	64.18 ± 7.92	2	16	15
Wei et al. 2024	China	RCT	115	Percutaneous endoscopic interlaminar discectomy (PEID)	60	23	37	57.19±14.25	7.83±0.99	7.88±0.80	82.62±7.15	n/a	n/a	n/a
				Unilateral biportal endoscopic (UBE)	55	19	36	56.89±15.01	7.53±0.98	7.67±0.79	79.13±6.77	n/a	n/a	n/a
Lin et al. 2023	China	Retrospective	55	OLM	32	17	15	56.7±18.4	6.7±2.3	7.1±1.6	57.0±14.9	6	17	8
				PELD	23	13	10	49.3±19.6	7.0±1.9	6.3±2.0	54.9±18.8	3	10	10
Shi et al. 2023	China	Retrospective	106	Visualization of PELD combined with annular suture	33	15	18	47.81±11.61	6.07±1.00	6.07±1.00	82.20±5.06	10	13	10
				PELD	73	31	42	52.81±9.45	6.47±1.09	6.97±1.30	78.47±7.09	17	35	21

Author	Country	Study Design	Total Sample Size	Name of surgery	Group Size	Male	Female	Age (mean, SD)	Preoperative VAS leg pain, (mean ± SD)	Preoperative VAS back pain, (mean ± SD)	Preoperative ODI, (mean ± SD)	Operated level		
												L3–L4	L4–L5	L5–S1
Chen et al. 2022	China	RCT	91	Transforaminal ELD	46	25	21	34.8 ± 9.1	3.5 ± 1.7	3.6 ± 1.8	58.7 ± 14.6	n/a	n/a	n/a
				Interlaminar ELD	45	24	21	36.2 ± 8.6	4.8 ± 2.2	4.6 ± 2.1	56.5 ± 15.7	n/a	n/a	n/a
Liu et al. 2020	China	Retrospective	120	PTED	60	27	33	50.70 ± 15.2	5.20 ± 2.02	2.65 ± 2.02	29.8 ± 10.27	3	33	22
				Microscopic Tubular Discectomy (MTD)	60	32	28	53.40 ± 14.3	5.25 ± 1.80	2.88 ± 1.95	31.75 ± 9.19	3	31	25
Meyer et al. 2020	Brazil	RCT	47	Microdiscectomy	24	Not Estimated	Not Estimated	45.2 ± 10.6	6.5 ± 2.6	8.7 ± 1.4	29.0 ± 8.8	2	10	12
				PELD	23	Not Estimated	Not Estimated	47.2 ± 10.6	5.4 ± 2.6	8.4 ± 1.7	28.9 ± 10.0	2	8	12
Li et al. 2019	China	RCT	71	PELD (Unilateral Approach)	35	19	16	47.1±8.6	7.7±1.9	5.3±1.6	64.5±17.2	11	24	
				PELD (Bilateral Approach)	36	21	15	45.2±10.1	7.8±2.1	5.1±1.8	66.7±16.8	10	26	
Wang et al. 2019	China	Retrospective	90	MED	45	26	19	47.54±3.29	7.09±0.92	6.34±0.72	57.17±2.96	n/a	29	16
				PTED	45	27	18	48.52 ± 2.65	7.21±0.96	6.40±0.83	58.21±3.48	n/a	27	18
Wu et al. 2019	China	Retrospective	40	Two-level PELD	14	5	14	47.3 ± 13.3	8.2 ± 1.5	7.4 ± 1.9	60.6 ± 14.7	5	7	2
				Foramino-plasty PELD	26	9	12	42.4 ± 9.4	7.7 ± 1.5	6.9 ± 1.7	56.8 ± 11.2	4	14	8
Chen et al. 2018	China	RCT	153	Percutaneous transforaminal endoscopic	80	52	28	40.2 ± 11.4	5.5 ± 1.9	3.9 ± 2.6	44.2 ± 21.8	4	35	41

Author	Country	Study Design	Total Sample Size	Name of surgery	Group Size	Male	Female	Age (mean, SD)	Preoperative VAS leg pain, (mean ± SD)	Preoperative VAS back pain, (mean ± SD)	Preoperative ODI, (mean ± SD)	Operated level		
												L3–L4	L4–L5	L5–S1
				discectomy										
				Micro-endoscopic Discectomy (MED)	73	37	36	40.7 ± 11.1	5.5 ± 2.2	3.7 ± 2.6	43.8 ± 20.4	0	35	38
Cristante et al. 2016	Brazil	RCT	40	OLM	20	10	10	41.2±9.4	8.42±2.3	7.52±2.7	33.65±9.33	n/a	n/a	n/a
				Lumbar percutaneous hydro-discectomy	20	10	10	44.9±9.4	7.36±2.2	6.3±3	26.35±6.6	n/a	n/a	n/a
Choi et al. 2011	South Korea	RCT	52	PELD and Annuloplasty (favorable)	34	21	12	36.4 ± 15.9	7.4 ± 2.1	6.7 ± 1.9	55.6 ± 18.4	4	27	2
				PELD and Annuloplasty (unfavorable)	18	12	6	35.8 ± 11.5	8.1 ± 1.3	6.5 ± 1.7	56.6 ± 17.0	2	14	2

Foot Note: PELD: Percutaneous Endoscopic Lumbar Discectomy, OLM: Open Lumbar Microdiscectomy, RCT: Randomized Controlled Trials, SD: standard deviation

Table 2: The Newcastle Ottawa scale of included studies

Study (year)	Selection				Comparability	Outcome			Score
	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Adequate follow-up duration	Adequate follow-up rate	
Sonawane et al. 2024	★	★	★	★	★★	★	★	★	9
Lin et al. 2023	★	★	★	★	★★	★	★	★	9
Shi et al. 2023	★	★	★	★	★★	★	★	★	9
Liu et al. 2020	★	★	★	★	★	★	★	★	8
Wang et al. 2019	★	★	-	★	★★	★	★	★	8
Wu et al. 2019	★	★	★	-	★	★	★	★	7

Figure 1: PRISMA flow diagram for identification of studies from the databases.

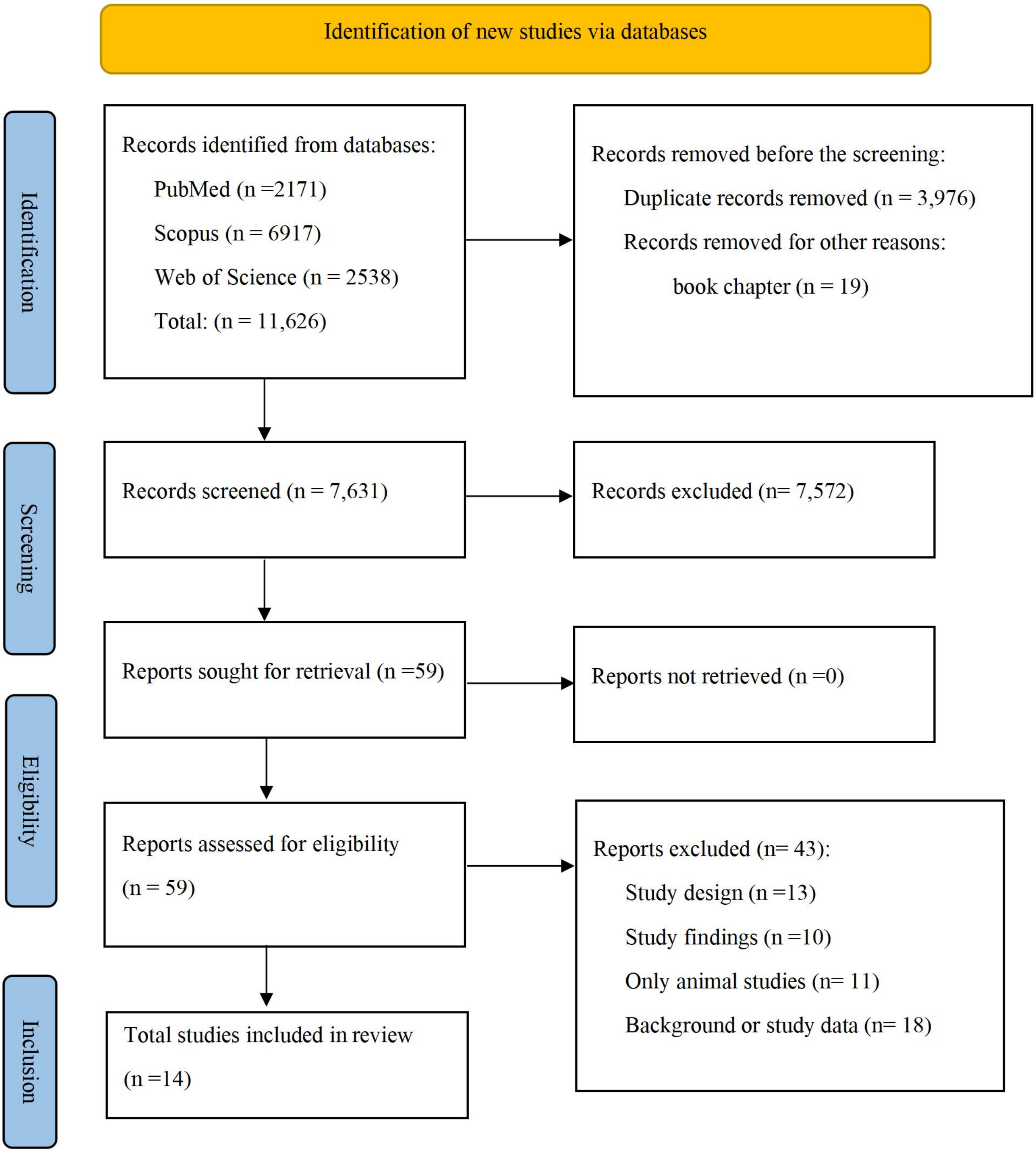


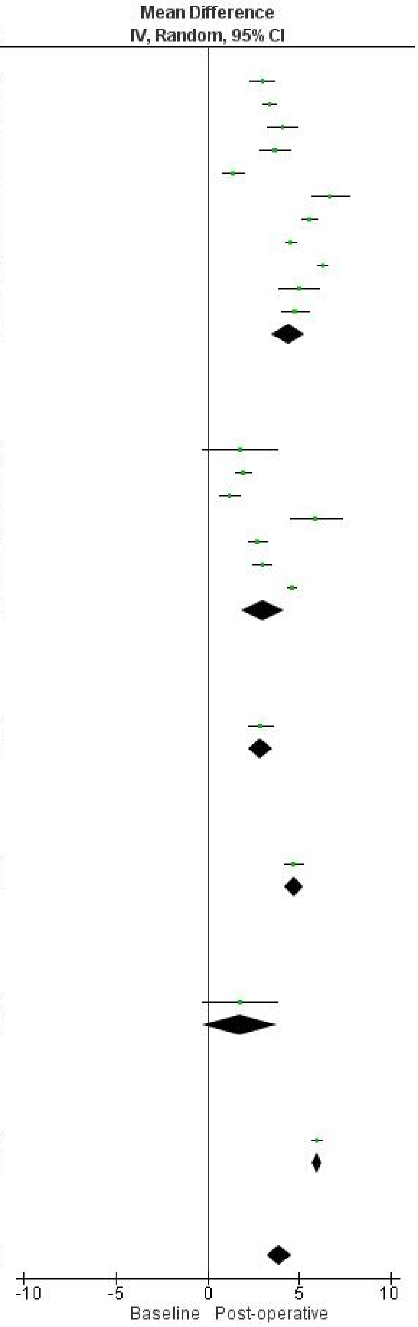
Figure 2: Risk of Bias assessment among studies.

Criterion	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Kandeel et al. 2024	LR	LR	LR	LR	LR	LR
Wei et al. 2024	SC	LR	LR	LR	LR	SC
Chen et al. 2022	LR	LR	LR	LR	LR	LR
Meyer et al. 2020	SC	LR	LR	LR	LR	SC
Li et al. 2019	SC	LR	LR	LR	SC	SC
Chen et al. 2018	SC	LR	LR	LR	LR	SC
Cristante et al. 2016	LR	LR	LR	LR	LR	LR
Choi et al. 2011	LR	LR	LR	LR	LR	LR

Figure 3: Changes of Back pain on VAS from baseline after different time periods: (a) three months, (b) six months, (c) Twelve months

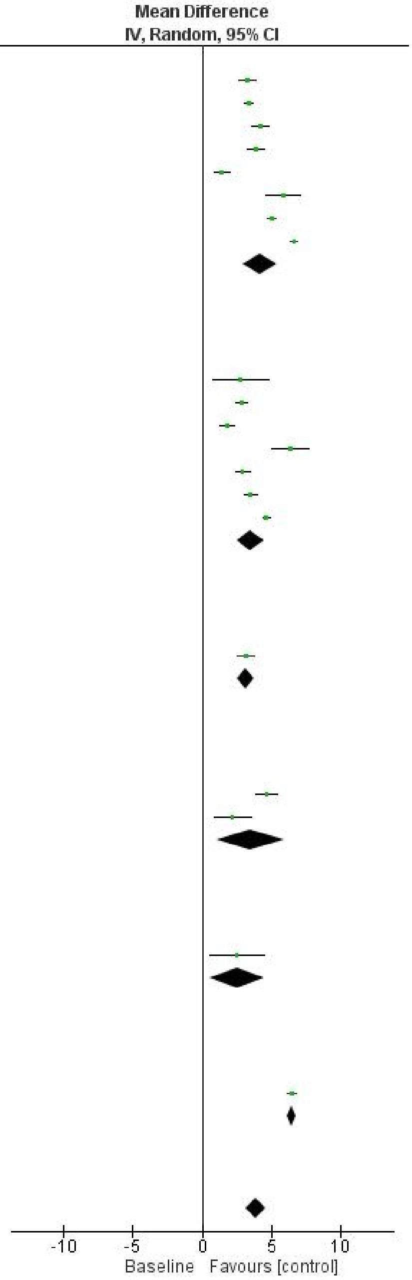
(a)

Study or Subgroup	Baseline Mean	Baseline SD	Baseline Total	Post-operative Mean	Post-operative SD	Post-operative Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 Percutaneous Endoscopic Lumbar Discectomy (PELD)								
Chen et al. 2018_A	3.9	2.6	80	0.9	1.5	77	4.7%	3.00 [2.34, 3.66]
Kandeel et al. 2024_A	5.65	0.77	32	2.25	0.68	32	4.8%	3.40 [3.04, 3.76]
Li et al. 2020_A	5.3	1.6	35	1.2	1.8	35	4.6%	4.10 [3.30, 4.90]
Li et al. 2020_B	5.1	1.8	36	1.4	1.9	36	4.5%	3.70 [2.85, 4.55]
Liu et al. 2021_A	2.65	2.02	60	1.23	1.1	60	4.7%	1.42 [0.84, 2.00]
Meyer et al. 2020_A	8.4	1.7	23	1.7	1.8	23	4.4%	6.70 [5.69, 7.71]
Shi et al. 2023_A	6.97	1.3	73	1.38	1.27	73	4.8%	5.59 [5.17, 6.01]
Wang et al. 2019_A	6.4	0.83	45	1.84	0.46	45	4.8%	4.56 [4.28, 4.84]
Wei et al. 2024_A	7.88	0.8	60	1.57	0.63	60	4.9%	6.31 [6.05, 6.57]
Wu et al. 2019_A	7.4	1.9	14	2.4	0.9	14	4.3%	5.00 [3.90, 6.10]
Wu et al. 2019_B	6.9	1.7	26	2.1	1	26	4.6%	4.80 [4.04, 5.56]
Subtotal (95% CI)			**484**			**481**	**51.1%**	**4.41 [3.50, 5.32]**
Heterogeneity: Tau² = 2.25; Chi² = 388.91, df = 10 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 9.48 (P < 0.00001)								
1.1.2 Lumbar Open Microdiscectomy (LOM)								
Cristante et al. 2016_A	6.3	3	20	4.53	3.47	20	3.4%	1.77 [-0.24, 3.78]
Kandeel et al. 2024_B	5.42	0.88	33	3.45	0.88	33	4.8%	1.97 [1.55, 2.39]
Liu et al. 2021_B	2.88	1.95	60	1.68	1.07	60	4.7%	1.20 [0.64, 1.76]
Meyer et al. 2020_B	8.7	1.7	24	2.8	3.1	24	4.0%	5.90 [4.49, 7.31]
Sonawane et al. 2024_A	4.71	1.19	32	1.96	0.91	32	4.7%	2.75 [2.23, 3.27]
Sonawane et al. 2024_B	5.22	1.17	31	2.22	0.88	31	4.8%	3.00 [2.48, 3.52]
Wang et al. 2019_B	6.34	0.72	45	1.73	0.4	45	4.9%	4.61 [4.37, 4.85]
Subtotal (95% CI)			**245**			**245**	**31.3%**	**3.02 [1.82, 4.22]**
Heterogeneity: Tau² = 2.39; Chi² = 221.28, df = 6 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 4.94 (P < 0.00001)								
1.1.3 Microendoscopic Discectomy (MED)								
Chen et al. 2018_B	3.7	2.6	73	0.8	1.3	64	4.7%	2.90 [2.22, 3.58]
Subtotal (95% CI)			**73**			**64**	**4.7%**	**2.90 [2.22, 3.58]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 8.41 (P < 0.00001)								
1.1.4 Visualization of PELD with annular suture								
Shi et al. 2023_B	6.07	1	33	1.35	1.07	33	4.8%	4.72 [4.22, 5.22]
Subtotal (95% CI)			**33**			**33**	**4.8%**	**4.72 [4.22, 5.22]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 18.51 (P < 0.00001)								
1.1.5 Lumbar Percutaneous Hydrodiscectomy								
Cristante et al. 2016_B	6.3	3	20	4.53	3.47	20	3.4%	1.77 [-0.24, 3.78]
Subtotal (95% CI)			**20**			**20**	**3.4%**	**1.77 [-0.24, 3.78]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.73 (P = 0.08)								
1.1.6 Unilateral Biportal Endoscopic (UBE)								
Wei et al. 2024_B	7.67	0.79	55	1.68	0.66	55	4.8%	5.99 [5.72, 6.26]
Subtotal (95% CI)			**55**			**55**	**4.8%**	**5.99 [5.72, 6.26]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 43.15 (P < 0.00001)								
Total (95% CI)			**910**			**898**	**100.0%**	**3.91 [3.24, 4.57]**
Heterogeneity: Tau² = 2.36; Chi² = 904.43, df = 21 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 11.50 (P < 0.00001)								
Test for subgroup differences: Chi² = 107.18, df = 5 (P < 0.00001), I² = 95.3%								



(b)

Study or Subgroup	Baseline Mean	Baseline SD	Baseline Total	Post-operative Mean	Post-operative SD	Post-operative Total	Weight	Mean Difference IV, Random, 95% CI
1.2.1 Percutaneous Endoscopic Lumbar Discectomy (PELD)								
Chen et al. 2018_A	3.9	2.6	80	0.6	1.2	75	5.2%	3.30 [2.67, 3.93]
Kandeel et al. 2024_A	5.65	0.77	32	2.24	0.57	32	5.3%	3.41 [3.08, 3.74]
Li et al. 2020_A	5.3	1.6	35	1.1	0.8	35	5.2%	4.20 [3.61, 4.79]
Li et al. 2020_B	5.1	1.8	36	1.2	0.8	36	5.2%	3.90 [3.26, 4.54]
Liu et al. 2021_A	2.65	2.02	60	1.23	1.1	60	5.2%	1.42 [0.84, 2.00]
Meyer et al. 2020_A	8.4	1.7	23	2.5	2.5	23	4.7%	5.90 [4.66, 7.14]
Wang et al. 2019_A	6.4	0.83	45	1.36	0.54	45	5.3%	5.04 [4.75, 5.33]
Wei et al. 2024_A	7.88	0.8	60	1.19	0.71	60	5.3%	6.69 [6.42, 6.96]
Subtotal (95% CI)			**371**			**366**	**41.4%**	**4.22 [3.01, 5.44]**
Heterogeneity: Tau² = 2.97; Chi² = 423.04, df = 7 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 6.81 (P < 0.00001)								
1.2.2 Lumbar Open Microdiscectomy (LOM)								
Cristante et al. 2016_A	6.3	3	20	3.5	3.54	20	3.8%	2.80 [0.77, 4.83]
Kandeel et al. 2024_B	5.42	0.88	33	2.56	0.71	33	5.3%	2.86 [2.47, 3.25]
Liu et al. 2021_B	2.88	1.95	60	1.07	0.9	60	5.2%	1.81 [1.27, 2.35]
Meyer et al. 2020_B	8.7	1.7	24	2.3	3	24	4.5%	6.40 [5.02, 7.78]
Sonawane et al. 2024_A	4.71	1.19	32	1.77	0.89	32	5.2%	2.94 [2.43, 3.45]
Sonawane et al. 2024_B	5.22	1.17	31	1.67	0.79	31	5.3%	3.55 [3.05, 4.05]
Wang et al. 2019_B	6.34	0.72	45	1.65	0.49	45	5.3%	4.69 [4.44, 4.94]
Subtotal (95% CI)			**245**			**245**	**34.6%**	**3.54 [2.57, 4.50]**
Heterogeneity: Tau² = 1.49; Chi² = 146.91, df = 6 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 7.19 (P < 0.00001)								
1.2.3 Microendoscopic Discectomy (MED)								
Chen et al. 2018_B	3.7	2.6	73	0.5	0.8	63	5.2%	3.20 [2.57, 3.83]
Subtotal (95% CI)			**73**			**63**	**5.2%**	**3.20 [2.57, 3.83]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 9.98 (P < 0.00001)								
1.2.4 PELD and Annuloplasty								
Choi et al. 2011_A	6.7	1.9	34	2	1.3	34	5.1%	4.70 [3.93, 5.47]
Choi et al. 2011_B	6.5	1.7	18	4.3	2.4	18	4.5%	2.20 [0.84, 3.56]
Subtotal (95% CI)			**52**			**52**	**9.6%**	**3.51 [1.07, 5.96]**
Heterogeneity: Tau² = 2.81; Chi² = 9.82, df = 1 (P = 0.002); I² = 90%								
Test for overall effect: Z = 2.82 (P = 0.005)								
1.2.5 Lumbar Percutaneous Hydrodiscectomy								
Cristante et al. 2016_B	6.3	3	20	3.79	3.34	20	3.8%	2.51 [0.54, 4.48]
Subtotal (95% CI)			**20**			**20**	**3.8%**	**2.51 [0.54, 4.48]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 2.50 (P = 0.01)								
1.2.6 Unilateral Biportal Endoscopic (UBE)								
Wei et al. 2024_B	7.67	0.79	55	1.18	0.83	55	5.3%	6.49 [6.19, 6.79]
Subtotal (95% CI)			**55**			**55**	**5.3%**	**6.49 [6.19, 6.79]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 42.00 (P < 0.00001)								
Total (95% CI)			**816**			**801**	**100.0%**	**3.92 [3.20, 4.65]**
Heterogeneity: Tau² = 2.52; Chi² = 859.03, df = 19 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 10.65 (P < 0.00001)								
Test for subgroup differences: Chi² = 123.91, df = 5 (P < 0.00001), I² = 96.0%								



(c)

Study or Subgroup	Baseline Mean	Baseline SD	Baseline Total	Post-operative Mean	Post-operative SD	Post-operative Total	Weight	Mean Difference IV, Random, 95% CI
1.3.1 Percutaneous Endoscopic Lumbar Discectomy (PELD)								
Chen et al. 2018_A	3.9	2.6	80	0.5	1.3	74	4.9%	3.40 [2.76, 4.04]
Kandeel et al. 2024_A	5.65	0.77	32	1.87	0.64	32	5.0%	3.78 [3.43, 4.13]
Li et al. 2020_A	5.3	1.6	35	1	0.7	35	4.9%	4.30 [3.72, 4.88]
Li et al. 2020_B	5.1	1.8	36	0.9	0.8	36	4.9%	4.20 [3.56, 4.84]
Liu et al. 2021_A	2.65	2.02	60	1.23	1.1	60	4.9%	1.42 [0.84, 2.00]
Meyer et al. 2020_A	8.4	1.7	23	2.1	1.9	23	4.6%	6.30 [5.26, 7.34]
Shi et al. 2023_A	6.97	1.3	73	1.1	1.07	73	5.0%	5.87 [5.48, 6.26]
Wang et al. 2019_A	6.4	0.83	45	1.84	0.46	45	5.0%	4.56 [4.28, 4.84]
Wei et al. 2024_A	7.88	0.8	60	0.62	0.65	60	5.0%	7.26 [7.00, 7.52]
Wu et al. 2019_A	7.4	1.9	14	1.5	0.8	14	4.6%	5.90 [4.82, 6.98]
Wu et al. 2019_B	6.9	1.7	26	1.7	0.8	26	4.8%	5.20 [4.48, 5.92]
Subtotal (95% CI)			**484**			**478**	**53.7%**	**4.73 [3.70, 5.77]**
Heterogeneity: Tau² = 2.94; Chi² = 551.45, df = 10 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 8.99 (P < 0.00001)								
1.3.2 Lumbar Open Microdiscectomy (LOM)								
Cristante et al. 2016_A	6.3	3	20	4.06	3.54	20	3.7%	2.24 [0.21, 4.27]
Kandeel et al. 2024_B	5.42	0.88	33	2.09	0.73	33	5.0%	3.33 [2.94, 3.72]
Liu et al. 2021_B	2.88	1.95	60	0.87	0.75	60	4.9%	2.01 [1.48, 2.54]
Meyer et al. 2020_B	8.7	1.7	24	3	3.6	24	4.1%	5.70 [4.11, 7.29]
Sonawane et al. 2024_A	4.71	1.19	32	0.63	0.76	32	5.0%	4.08 [3.59, 4.57]
Sonawane et al. 2024_B	5.22	1.17	31	0.87	0.76	31	5.0%	4.35 [3.86, 4.84]
Subtotal (95% CI)			**200**			**200**	**27.7%**	**3.60 [2.74, 4.47]**
Heterogeneity: Tau² = 0.94; Chi² = 56.95, df = 5 (P < 0.00001); I² = 91%								
Test for overall effect: Z = 8.15 (P < 0.00001)								
1.3.3 Microendoscopic Discectomy (MED)								
Chen et al. 2018_B	3.7	2.6	73	0.4	0.8	63	4.9%	3.30 [2.67, 3.93]
Subtotal (95% CI)			**73**			**63**	**4.9%**	**3.30 [2.67, 3.93]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 10.29 (P < 0.00001)								
1.3.4 Visualization of PELD with annular suture								
Shi et al. 2023_B	6.07	1	33	1	0.97	33	5.0%	5.07 [4.59, 5.55]
Subtotal (95% CI)			**33**			**33**	**5.0%**	**5.07 [4.59, 5.55]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 20.91 (P < 0.00001)								
1.3.5 Lumbar Percutaneous Hydrodiscectomy								
Cristante et al. 2016_B	6.3	3	20	3.03	3.32	20	3.8%	3.27 [1.31, 5.23]
Subtotal (95% CI)			**20**			**20**	**3.8%**	**3.27 [1.31, 5.23]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.27 (P = 0.001)								
1.3.6 Unilateral Biportal Endoscopic (UBE)								
Wei et al. 2024_B	7.67	0.79	55	0.68	0.59	55	5.0%	6.99 [6.73, 7.25]
Subtotal (95% CI)			**55**			**55**	**5.0%**	**6.99 [6.73, 7.25]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 52.58 (P < 0.00001)								
Total (95% CI)			**865**			**849**	**100.0%**	**4.43 [3.67, 5.19]**
Heterogeneity: Tau² = 2.94; Chi² = 1031.03, df = 20 (P < 0.00001); I² = 98%								
Test for overall effect: Z = 11.48 (P < 0.00001)								
Test for subgroup differences: Chi² = 183.33, df = 5 (P < 0.00001), I² = 97.3%								

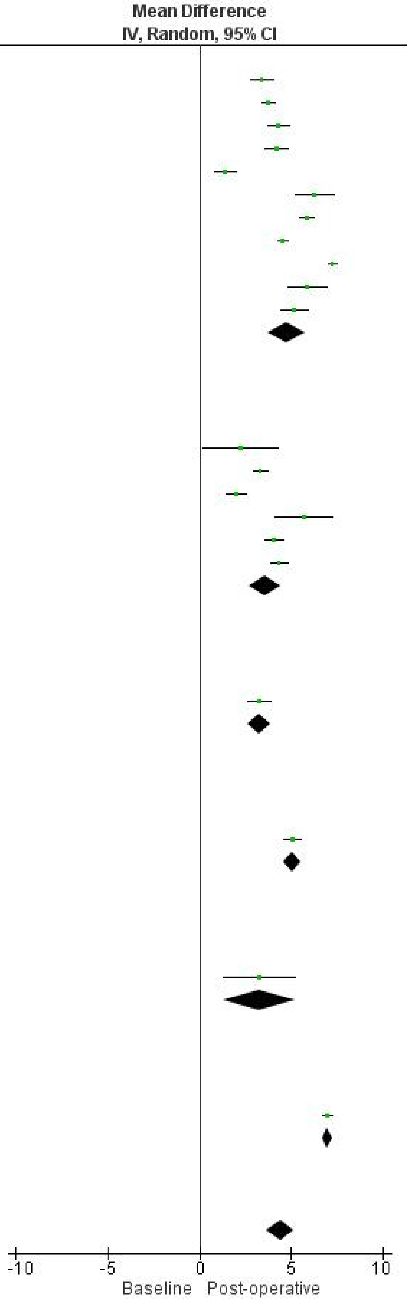


Figure 4: Lower back pain changes from baseline after different surgeries.

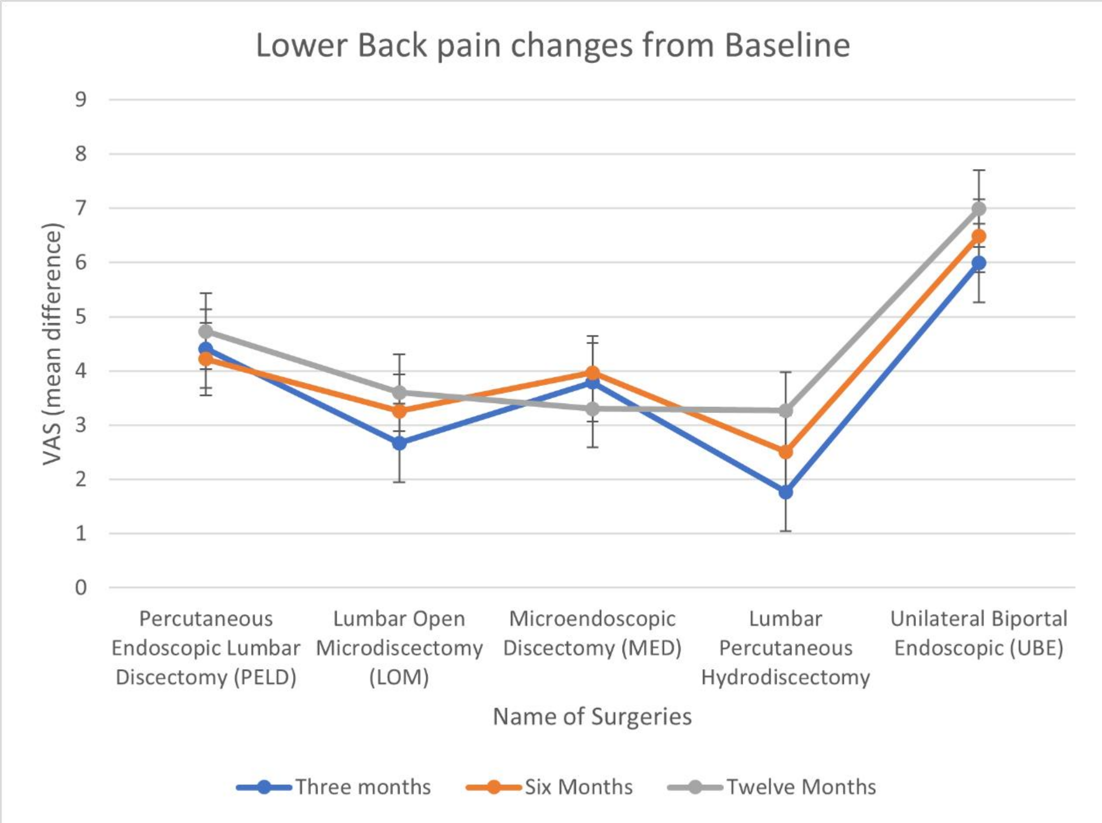


Figure 5: Recurrence of lumber disc Herniation after PELD and MELD surgery.

Study or Subgroup	MELD Events	MELD Total	PELD Events	PELD Total	Weight	Odds Ratio M-H, Random, 95% CI
Chen et al. 2018_A	3	73	5	80	37.8%	0.64 [0.15, 2.79]
Li et al. 2020_A	1	31	3	36	15.2%	0.37 [0.04, 3.72]
Lin et al. 2023_A	4	60	2	60	27.0%	2.07 [0.36, 11.76]
Sonawane et al. 2024_A	2	32	2	35	20.0%	1.10 [0.15, 8.30]
Total (95% CI)		**196**		**211**	**100.0%**	**0.90 [0.37, 2.22]**
Total events	10		12			

Heterogeneity: Tau² = 0.00; Chi² = 1.70, df = 3 (P = 0.64); I² = 0%

Test for overall effect: Z = 0.23 (P = 0.82)