Research Square

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Comparison of Local, Epidural, and Combined Spinal-Epidural Anesthesia in Percutaneous Transforaminal Endoscopic Discectomy: A Focus on Perioperative Efficiency and Early Recovery

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Abstract

Objective

To comprehensively compare the effects of local anesthesia (LA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) on perioperative efficiency and early recovery in patients undergoing single-level percutaneous transforaminal endoscopic discectomy (PTED).

Methods

In this retrospective cohort study, clinical data of patients who underwent PTED between February 2023 to August 2024 were reviewed and categorized into three groups based on anesthetic technique: LA group, EA group, and CSEA group. Primary outcomes included operative time and intraoperative blood loss. Secondary outcomes encompassed hospitalization costs, pain intensity assessed by the Visual Analogue Scale (VAS), functional status evaluated by the Oswestry Disability Index (ODI) at preoperative, 3-day, and 3-month intervals, surgical experience measured by a Likert scale, and the success rate according to the modified MacNab criteria at 6 months.

Results

A total of 120 patients were included (n = 40 per group). The three groups were comparable in baseline demographics. The CSEA group demonstrated superior perioperative efficiency, exhibiting the shortest operative time and the least intraoperative blood loss among the three groups ($P < 0.05$), followed by the EA group. Patients in the CSEA group reported the most favorable intraoperative experience ($P < 0.001$). While pain and function improved significantly in all groups after surgery, the CSEA group achieved significantly lower VAS and ODI scores at the 3-month follow-up compared to both the EA and LA groups ($P < 0.05$), with the EA group showing better scores than the LA group. All three techniques resulted in similarly high success rates at 6 months with no statistically significant difference.

Conclusion

For PTED, the choice of anesthesia significantly impacts perioperative course and early recovery. CSEA is associated with the greatest advantages in operative efficiency, patient comfort, and the speed of pain relief and functional recovery within the first 3 months, likely attributable to its unique mechanism of rapid and dense sensory blockade. EA offers an intermediate benefit profile compared to LA. These findings provide evidence for refining anesthesia protocols within an enhanced recovery after surgery (ERAS) framework for spinal endoscopic procedures.

1.Introduction

Lumbar disc herniation (LDH) remains a predominant cause of chronic low back pain and radiculopathy, imposing a substantial burden on healthcare systems and patient quality of life globally[1]. For patient's refractory to conservative management, surgical decompression is the definitive treatment. The evolution of spine surgery has been profoundly shaped by minimally invasive philosophies, with percutaneous transforaminal endoscopic discectomy (PTED) emerging as a cornerstone technique[2, 3]. PTED offers distinct advantages over traditional open surgery, including minimal muscular disruption, reduced blood loss, and the potential for accelerated postoperative recovery, often enabling same-day ambulation[4] .

Within this technically precise procedure, the choice of anesthesia is not merely supportive but is a critical determinant of procedural success, patient safety, and satisfaction. The ideal anesthetic must achieve a delicate balance: providing profound intraoperative analgesia, maintaining hemodynamic stability, and preserving the ability for immediate neurological assessment, particularly in an aging population with elevated risks for general anesthesia[5]. To this end, regional anesthesia techniques have become central to PTED protocols.

Local anesthesia (LA), involving direct infiltration along the surgical trajectory, is the most basic form. Its principal merits are the preservation of real-time patient feedback—theoretically enhancing safety by alerting the surgeon to nerve root contact—and its applicability to high-risk patients[3]. However, its fundamental limitation is frequently inadequate analgesia for the profound manipulation of peri-neural tissues, often necessitating significant supplemental sedation which can compromise airway security and patient cooperation[6]. Epidural anesthesia (EA) represents a significant advancement, delivering a more reliable and bilateral sensory block by depositing local anesthetics within the epidural space. This results in superior intraoperative pain control compared to LA[7]. Nonetheless, EA has inherent constraints. Its onset is relatively slower, and the block density and distribution can be inconsistent, sometimes failing to fully suppress the intense, focused nociception generated during foraminal preparation[8]. Combined spinal-epidural anesthesia (CSEA) is an integrative technique designed to overcome these limitations. It synergistically combines the rapid-onset, dense, and reliable sensory blockade of intrathecal spinal anesthesia (SA) with the flexibility and extended duration provided by an epidural catheter[9]. The spinal component is particularly crucial, as it can produce a superior differential or dissociative block. This refers to the preferential inhibition of small-diameter A-delta and C pain fibers, while better preserving motor and proprioceptive function compared to EA alone[10]. Mechanistically, this suggests CSEA could provide the optimal triad for PTED: impeccable intraoperative analgesia, excellent surgical conditions via patient immobility and muscle relaxation, and a foundation for smoother early mobilization.

Despite these distinct mechanistic profiles, high-quality direct comparisons of all three techniques are scarce. Recent analyses, including a 2024 network meta-analysis, have concluded that while LA may expedite surgery, EA provides better anesthesia satisfaction and postoperative pain control. This analysis explicitly identified the need for more robust studies comparing regional techniques. Another study highlighted the effective analgesic role of epidural anesthesia via the intervertebral foramen

approach in PTED, further underscoring the importance of the topic[2, 11]. The specific value proposition of CSEA—whether its theoretical benefits translate into measurable superior outcomes in PTED—remains largely unquantified, creating a significant gap in evidence-based clinical decision-making.

Therefore, this three-arm retrospective cohort study was designed to conduct a comprehensive, hierarchical comparison of LA, EA, and CSEA in patients undergoing single-level PTED. We hypothesize that CSEA will be associated with superior perioperative efficiency (shorter operative time, reduced blood loss) and accelerated early functional recovery compared to both EA and LA, and that EA will demonstrate a favorable intermediate profile over LA. Our findings aim to deliver actionable evidence for optimizing anesthesia protocols within Enhanced Recovery After Surgery (ERAS) pathways for spinal endoscopic surgery.

2. Materials and Methods

2.1. General Information

This single-center, retrospective cohort study was conducted after obtaining approval from the Ethics Committee of Guangzhou Hospital of Integrated Traditional and Western Medicine (GZTCWM2025261). The requirement for written informed consent was waived due to the retrospective nature of the analysis. We systematically reviewed the electronic medical records and a prospectively maintained spine surgery database to identify all consecutive patients who underwent single-level percutaneous transforaminal endoscopic discectomy (PTED) for symptomatic lumbar disc herniation between February 2023 and August 2024. The data collection was concluded in August 2024 to ensure that all included patients had completed a minimum of 6 months of postoperative follow-up, thereby guaranteeing the integrity of the primary outcome assessment. Patients were categorized into three groups based on the anesthetic technique employed: the Local Anesthesia (LA) group, the Epidural Anesthesia (EA) group, and the Combined Spinal-Epidural Anesthesia (CSEA) group. The choice of anesthesia was made preoperatively through a shared decision-making process involving the anesthesiologist, surgeon, and patient, based on clinical assessment and patient preference.

Inclusion criteria were: (1) age between 18 and 75 years; (2) single-level, unilateral lumbar disc herniation (L3/4, L4/5, or L5/S1) confirmed by magnetic resonance imaging (MRI), with clinical symptoms and signs consistent with the radiological findings; (3) failure of at least 6 weeks of structured conservative treatment; (4) complete clinical and follow-up data records. Exclusion criteria included: (1) multi-level disc herniation, spinal stenosis, spondylolisthesis (> Grade I), or segmental instability; (2) previous lumbar spine surgery; (3) concurrent severe cardiopulmonary, hepatic, or renal dysfunction; (4) contraindications to regional anesthesia (e.g., coagulopathy, local infection, severe allergy to local anesthetics); (5) conversion to general anesthesia during the procedure; (6) pregnancy.

2.2 Surgical and Anesthetic Procedure

All surgical procedures were performed by the same senior endoscopic spine surgeon with extensive experience in PTED, using a standardized technique to minimize inter-operator variability.

Anesthetic Techniques: Local Anesthesia (LA) Group: Patients were placed in a prone position on a radiolucent spinal table. Under fluoroscopic guidance, a local infiltration block was performed along the planned surgical trajectory using 1% lidocaine. The infiltration targeted the skin, subcutaneous tissue, thoracolumbar fascia, and the periarticular region of the facet joint.

Epidural Anesthesia (EA) Group: Patients received epidural anesthesia in the lateral decubitus position. After identifying the L2/3 or L3/4 interspace, an 18-gauge Tuohy needle was advanced into the epidural space using the loss-of-resistance technique. A test dose was administered, followed by 8–12 mL of 0.5% ropivacaine to establish a sensory block level between T10 and S1. An epidural catheter was inserted for potential intraoperative supplementation.

Combined Spinal-Epidural Anesthesia (CSEA) Group: Using the needle-through-needle technique at the L2/3 or L3/4 interspace, a 27-gauge pencil-point spinal needle was passed through the Tuohy epidural needle. After confirming free flow of cerebrospinal fluid, 1.8-2.2mL of 0.5% ropivacaine was injected intrathecally. The spinal needle was withdrawn, and an epidural catheter was threaded into the epidural space for postoperative analgesia.

Surgical Technique (TESSYS): Following successful anesthesia, all patients were positioned prone. Under real-time C-arm fluoroscopy, the target intervertebral foramen was identified. A guidewire was introduced poster laterally, approximately 10–12 cm from the midline, and advanced to the foramen. Sequential dilators were used to create a working channel, followed by placement of a beveled working cannula. A high-resolution endoscope was introduced. Under continuous saline irrigation, adequate foraminoplasty was performed using endoscopic reamers when necessary. The herniated disc fragment was meticulously identified, decompressed, and removed with endoscopic forceps, ensuring complete liberation of the traversing and exiting nerve roots. Hemostasis was achieved endoscopically, and the incision was closed with a single suture.

2.3. Clinical Evaluation

Demographic data (age, gender, body mass index), operative level, and American Society of Anesthesiologists (ASA) physical status classification were recorded.

Outcome measures were categorized as follows:

Primary Outcomes (Perioperative Efficiency):

Operative Time: Defined as the interval from skin incision to skin closure.

Intraoperative Blood Loss: Estimated by summing the volume in the suction canister and the weight increase of surgical gauzes.

Secondary Outcomes:

Pain Intensity: Assessed using the Visual Analogue Scale (VAS, range 0–10, where 0 = no pain and 10 = worst imaginable pain) for lower back and leg pain.

Functional Status: Evaluated using the Oswestry Disability Index (ODI, version 2.0, expressed as a percentage from 0% to 100%, with higher scores indicating greater disability).

Surgical Experience: Measured on the first postoperative day using a 5-point Likert scale (1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = excellent). The proportion of patients reporting a "good" or "excellent" experience (score ≥ 4) was calculated.

Global Outcome: Assessed at 6 months postoperatively using the modified MacNab criteria, categorized as "excellent," "good," "fair," or "poor." An "excellent" or "good" rating was considered a successful outcome.

Economic Indicator: Total hospitalization costs (in local currency) were recorded.

VAS and ODI scores were collected preoperatively (baseline), at postoperative day 3 (during hospitalization), and at the 3-month outpatient follow-up. Modified MacNab evaluation was conducted at the 6-month follow-up via clinic visit or structured telephone interview.

2.4. Statistical Assessments

Statistical analysis was performed using SPSS software (version 26.0, IBM Corp.). Continuous variables were tested for normality with the Shapiro-Wilk test. Normally distributed data are presented as mean ± standard deviation (SD) and were compared among the three groups using one-way analysis of variance (ANOVA), followed by the Bonferroni post-hoc test for pairwise comparisons. Non-normally distributed data are presented as median (interquartile range) and were compared using the Kruskal-Wallis H test, with Dunn's test for post-hoc analysis. Categorical variables are presented as counts (percentages) and were compared using the chi-square test or Fisher's exact test, as appropriate. Repeated-measures ANOVA was used to analyze the changes in VAS and ODI scores over time within and between groups. A two-tailed P-value of less than 0.05 was considered statistically significant for all tests.

3.Results

3.1 Baseline Demographic and Clinical Characteristics

A total of 120 patients who met the inclusion criteria were enrolled in the final analysis, with 40 patients in each of the three anesthetic groups: Local Anesthesia (LA), Epidural Anesthesia (EA), and Combined Spinal-Epidural Anesthesia (CSEA). The study population comprised 68 male and 52 female patients. As detailed in Table 1, the three groups were well-matched at baseline. There were no statistically significant differences in age, gender distribution, body mass index (BMI), American Society of

Anesthesiologists (ASA) physical status classification, or the distribution of operative levels (all $P > 0.05$). Preoperative Visual Analogue Scale (VAS) scores for leg pain and Oswestry Disability Index (ODI) scores were also comparable across groups, confirming the homogeneity of the cohort prior to intervention.

Table 1
Baseline Demographic and Clinical Characteristics of the Patients(n = 40, mean ± SD)

Characteristic	LA Group	EA Group	CSEA Group	P-Value
Age(years)	46.2 ± 11.5	47.8 ± 10.3	45.9 ± 12.1	0.742
Gender	24 (60.0)	22 (55.0)	22 (55.0)	0.887
BMI	24.5 ± 3.2	25.1 ± 3.6	24.8 ± 3.4	0.721
ASA Grade I/II	32/8	30/10	33/7	0.741
Operative Level				
L4/5	32 (80.0)	31 (77.5)	33 (82.5)	0.902
L5/S1	8 (20.0)	9 (22.5)	7 (17.5)	
Preoperative VAS (leg)	7.8 ± 1.2	7.9 ± 1.1	8.0 ± 1.3	0.815
Preoperative ODI	66.5 ± 7.8	67.2 ± 8.1	65.8 ± 7.5	0.768

3.2 Primary Outcomes: Perioperative Efficiency

A significant difference was observed among the three groups in the primary efficiency metrics (Table 2). The CSEA group demonstrated the shortest mean operative time (65.3 ± 12.1minutes), which was significantly less than both the EA group (78.5 ± 15.4minutes, $P = 0.001$) and the LA group (92.7 ± 18.6 minutes, $P < 0.001$). The EA group also had a significantly shorter operative time compared to the LA group ($P = 0.012$). Similarly, for intraoperative blood loss, the CSEA group had the lowest volume (18.5 ± 8.7mL), significantly lower than the EA group (25.1 ± 10.2mL, $P = 0.018$) and the LA group (35.8 ± 15.3mL, $P < 0.001$). The EA group, in turn, showed significantly less blood loss than the LA group *(*$P = 0.009$).

Table 2
Comparison of Primary Perioperative Outcomes(n = 40, mean ± SD)

Outcome	LA Group	EA Group	CSEA Group	P-Value
Operative Time (min)	92.7 ± 18.6	78.5 ± 15.4[a]	65.3 ± 12.1[ab]	< 0.001
Blood Loss (mL)	35.8 ± 15.3	25.1 ± 10.2[a]	18.5 ± 8.7[ab]	< 0.001
Note: Data presented as mean ± SD. $P < 0.05$ vs. LA group (a); $P < 0.05$ vs. EA group (b); $P < 0.05$ vs. CSEA group (c).				

3.3 Secondary Outcomes

Hospitalization Costs

Total hospitalization costs differed significantly among groups ($P = 0.003$). The CSEA group incurred the highest costs, followed by the EA group, with the LA group having the lowest costs. Pairwise comparisons showed the difference was significant between the CSEA and LA groups ($P = 0.001$).

Postoperative Pain and Function: Repeated-measures ANOVA revealed significant effects of time and group, as well as a significant time-by-group interaction for both VAS and ODI scores (all $P < 0.01$), indicating different recovery trajectories. At postoperative day 3, all groups showed a significant reduction from baseline ($P < 0.001$), with no significant inter-group differences ($P > 0.05$). By the 3-month follow-up, the CSEA group achieved the lowest VAS and ODI scores (VAS: 1.3 ± 0.7;ODI:11.5 ± 3.8%), which were significantly better than both the EA group (VAS: 1.9 ± 0.8, $P = 0.007$; ODI: 15.2 ± 4.1%, $P = 0.002$) and the LA group (VAS: 2.4 ± 0.9,$P < 0.001$; ODI:18.6 ± 5.2%, $P < 0.001$). The EA group's scores at 3 months were also significantly better than the LA group's ($P = 0.018$ for VAS; $P = 0.011$ for ODI).

Patient Experience and Long-term Success: The proportion of patients rating their surgical experience as "good" or "excellent" (Likert score ≥ 4) was highest in the CSEA group (92.5%, 37/40), compared to 72.5% (29/40) in the EA group and 62.5% (25/40) in the LA group ($P = 0.003$). At the 6-month follow-up, the modified MacNab success rate (excellent/good outcomes) was similarly high across all groups: 90.0% (36/40) in the LA group, 92.5% (37/40) in the EA group, and 95.0% (38/40) in the CSEA group, with no statistically significant difference ($P = 0.724$).

Table 3
Comparison of Hospitalization Costs, Patient Experience, and Long-term Success

Outcome Measure	LA Group	EA Group	CSEA Group	*P*
Total Hospitalization Cost (¥)	20,562 ± 4,268	23,184 ± 5,771	24,795 ± 6,123	0.003
Satisfactory Surgical Experience	25 (62.5%)	29 (72.5%)	37 (92.5%)	0.003
6-month MacNab Success Rate	36 (90.0%)	37 (92.5%)	38 (95.0%)	0.724

3.4 Complications

No major complications, such as nerve root injury, dural tear, postoperative hematoma, or surgical site infection, were recorded in any group. Minor complications included transient hypotension in 2 patients in the CSEA group, which was promptly managed with vasopressors, and postoperative urinary retention in 1 patient in the EA group.

4.Discussion

This three-arm retrospective cohort study elucidates a clear performance hierarchy among regional anesthetic techniques for single-level PTED. While local anesthesia (LA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) all enabled effective neural decompression with equivalent long-term success, they dictated substantially different perioperative pathways. CSEA was consistently associated with the most favorable outcomes, achieving superior intraoperative efficiency, the highest patient comfort, and the most rapid functional recovery in the first three months. EA offered a significant intermediate benefit over LA. Our findings posit that anesthetic selection in PTED is a strategic decision balancing procedural resource intensity against the quality of early recovery, with CSEA presenting the optimal profile for integrating into ERAS protocols.

The established gradient—CSEA > EA > LA—in operative time and blood loss is pivotal and best explained by the quality of neuraxial blockade[12, 13]. The rapid-onset, dense sensory-motor block from the spinal component of CSEA creates an ideal surgical field of profound analgesia and muscle relaxation [14]. This minimizes patient discomfort and movement during critical steps like foraminoplasty, directly enhancing surgical precision and flow. In contrast, surgery under LA can be disrupted by the need to manage procedural pain. Although EA provides more substantial analgesia than LA, its reliance on epidural diffusion can lead to a slower onset and less predictable block density than the intrathecal block of CSEA, resulting in intermediate efficiency. This finding extends the literature where comparisons of only LA and EA showed no operative time difference, highlighting the unique incremental benefit of the spinal component in CSEA[15, 16].

Beyond technical efficiency, anesthesia choice profoundly impacted patient-centered outcomes. The highest satisfaction in the CSEA group, followed by EA, correlates directly with superior intraoperative comfort, aligning with meta-analytic evidence that EA provides better satisfaction and analgesia than LA[17–19]. Mechanistically, the rapid and complete abolition of procedural pain with CSEA reduces anxiety and establishes an optimal psychological state for surgery. More importantly, the accelerated early recovery, evidenced by superior VAS and ODI scores at three months in the CSEA group, suggests benefits extending far beyond the operating room. We propose a multifactorial mechanism: the superior intraoperative conditions likely attenuate surgical stress and local tissue trauma; the epidural catheter enables seamless postoperative analgesia, preventing severe breakthrough pain; and the rapid pain relief with relative preservation of motor function encourages earlier ambulation and physiotherapy. This accelerated functional restoration is a core patient-centric advantage and a principal goal of ERAS[20] [21] [22, 23].

A fundamental and reassuring finding is the convergence of excellent and equivalent long-term success rates at six months across all groups. This conclusively demonstrates that the ultimate success of PTED depends on adequate neural decompression, not the anesthetic modality[24]. Therefore, the clinical decision pivots from efficacy to a value-based consideration of recovery quality versus resource allocation. The observation that the advantages of CSEA and EA come with higher direct costs introduces a necessary pragmatic dimension. It prompts a critical assessment of whether the

investment in more sophisticated anesthesia is justified by the returns in operative efficiency, patient satisfaction, and reduced convalescence, meriting formal cost-effectiveness analysis[25].

The excellent safety profile across all groups is noteworthy. Minor complications were manageable and consistent with known side-effect profiles, reinforcing evidence that EA and CSEA are as safe as LA for PTED when performed by experienced practitioners. The absence of nerve injuries in our series suggests that the theoretical safety advantage of patient feedback under LA may be less critical with surgical expertise and precise endoscopic visualization, which are well-maintained under the more comfortable neuraxial blocks.[16, 26, 27]. The absence of nerve injuries in our series suggests that the theoretical safety advantage of patient feedback under LA may be less critical with surgical expertise and precise endoscopic visualization, which are well-maintained under the more comfortable neuraxial blocks.

This study has limitations inherent to its retrospective, single-center design, including potential unmeasured confounding and selection bias. The sample size, while adequate for primary outcomes, may be underpowered for rare adverse events. The follow-up period is sufficient for early and medium-term outcomes but does not inform on long-term recurrence. Future prospective, randomized controlled trials with larger, multicenter cohorts are warranted. Such studies should incorporate detailed health-economic analyses and biomarkers of surgical stress to fully elucidate the comprehensive impact of anesthetic choice on the PTED recovery trajectory.

Conclusion

In conclusion, this three-arm comparative study establishes a clear clinical hierarchy in the perioperative performance of regional anesthetic techniques for PTED. CSEA emerges as the most comprehensive option, conferring the greatest advantages in surgical efficiency, patient intraoperative comfort, and the pace of early functional recovery. EA presents a highly effective and reliable intermediate alternative, offering substantial improvements over LA. LA remains a safe and cost-effective cornerstone of practice, indispensable for patients with specific contraindications or preferences.

These findings collectively provide an evidence-based framework to guide the collaborative refinement of anesthesia protocols by spine surgeons and anesthesiologists. They advocate for a paradigm shift from a uniform approach towards a tailored, patient-centered strategy. By aligning the choice of anesthesia with individual patient profiles, comorbidities, and surgical goals, clinicians can optimize the entire perioperative journey within an ERAS framework. This personalized approach ultimately seeks to enhance the overall value of care—balancing clinical outcomes, patient experience, and resource utilization—in spinal endoscopic surgery. Future prospective studies incorporating detailed cost-effectiveness analyses are warranted to further solidify these clinical and economic recommendations.

Declarations

Ethics approval and consent to participate

This single-center, retrospective cohort study was conducted after obtaining approval from the Ethics Committee of Guangzhou Hospital of Integrated Traditional and Western Medicine (GZTCWM2025261).

Consent for publication

This retrospective study was approved by the Ethics Committee of Guangzhou Hospital of Integrated Traditional and Western Medicine (Approval No.: GZTCWM2025261). The need for written informed consent from participants was waived by the ethics committee due to the retrospective nature of the study. All patient data were anonymized and de-identified prior to analysis. The manuscript does not contain any individual person's data in any form.

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Author Contribution

Wang Tang, Donghua Liu, Jiaqi Li,and Heying Zhong wrote the main manuscript text. Yu Dai Lei Wan prepared figures. All authors reviewed the manuscript.

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Data Availability

The data used to support the findings of this study are available from the first author upon request.

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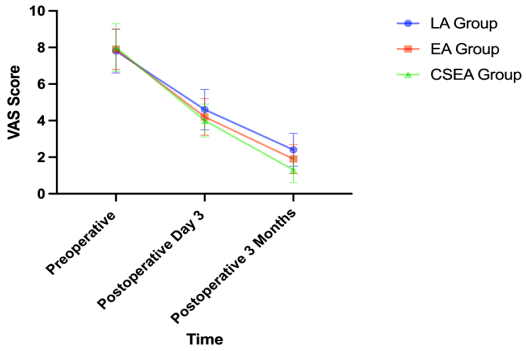
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Figures

A

Group	Assessment Point	VAS Score	ODI Score
LA Group	Preoperative	7.8 ± 1.2	66.5 ± 7.8
	Postoperative Day 3	4.6 ± 1.1$^{\#}$	38.2 ± 7.5$^{\#}$
	Postoperative 3 Months	2.4 ± 0.9$^{\#}$	18.6 ± 5.2$^{\#}$
EA Group	Preoperative	7.9 ± 1.1	67.2 ± 8.1
	Postoperative Day 3	4.2 ± 1.0$^{\#}$	35.0 ± 6.8$^{\#}$
	Postoperative 3 Months	1.9 ± 0.8$^{\#a}$	15.2 ± 4.1$^{\#a}$
CSEA Group	Preoperative	8.0 ± 1.3	65.8 ± 7.5
	Postoperative Day 3	4.0 ± 0.9$^{\#}$	33.5 ± 6.2$^{\#}$
	Postoperative 3 Months	1.3 ± 0.7$^{\#ab}$	11.5 ± 3.8$^{\#ab}$
P-value (Interaction: Time × Group)		< 0.001	< 0.001

B



C

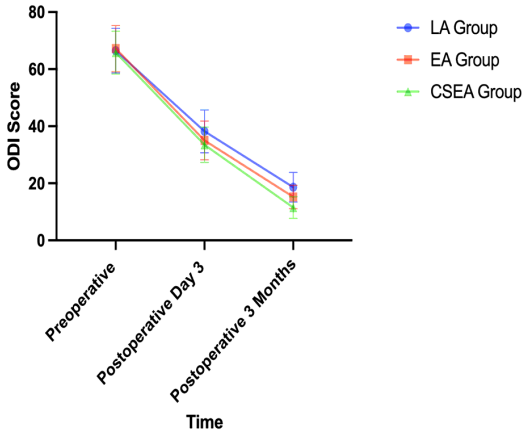


Figure 1

Dynamic Changes in Pain (VAS) and Functional (ODI) Scores Across Time. Data presented as Mean ± Standard Deviation. $^{\#}$Indicates a significant improvement compared to the preoperative baseline within the same group (*P*<0.001). Superscript letters denote significant differences in pairwise post-hoc comparisons at the 3-month time point (P < 0.05): ^{a} Significant difference compared to the LA Group. ^{b} Significant difference compared to the EA Group. ^{c} Significant difference compared to the CSEA Group.