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ORIGINAL RESEARCH

Long-Term Refined Paraspinal Muscle Exercises Combined with ERAS Protocol Enhance Postoperative Recovery Following Lumbar Fusion Surgery

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Objective: This study assesses the impact of long-term refined paraspinal muscle exercises on clinical outcomes in patients undergoing posterior lumbar interbody fusion (PLIF) surgery. We hypothesize that the integration of long-term refined paraspinal muscle exercises with ERAS short-term rehabilitation will result in superior musculoskeletal and psychological recovery compared to ERAS short-term exercises alone.

Methods: A total of 298 patients who underwent PLIF surgery between January 2020 and September 2023 were included. Of these, 198 patients (118 males, 80 females) followed the ERAS protocol for short-term recovery, with early mobilization and basic exercises starting within 24 hours post-surgery (ERAS-ST Group). The remaining 100 patients (55 males, 45 females) adhered to ERAS combined with long-term refined paraspinal muscle exercises, beginning within the first week post-surgery and continuing for at least 12 months (ERAS-LT Group). These exercises aimed to strengthen the lumbar and paraspinal muscles, promote long-term functional recovery, and prevent muscle atrophy and related complications. Clinical outcomes were assessed using the Visual Analogue Scale (VAS) for pain, the Oswestry Disability Index (ODI) for functional recovery, and PHQ-9 and GAD-7 to measure depression and anxiety symptoms. Muscle strength was evaluated using hand-held dynamometry (HHD), with measurements taken at baseline, 3 months, 6 months, and 12 months post-surgery.

Results: The ERAS-LT group showed significantly better outcomes in pain reduction (VAS), functional recovery (ODI), and psychological well-being (lower PHQ-9 and GAD-7 scores) compared to the ERAS-ST group. Notably, patients in the ERAS-LT Group demonstrated faster recovery in both physical and psychological domains. Key paraspinal muscles showed significantly improved muscle strength in the ERAS-LT Group.

Conclusion: Combining ERAS short-term functional exercises with long-term refined paraspinal muscle exercises significantly improves postoperative recovery in PLIF patients. The long-term exercise regimen enhanced pain management, functional recovery, muscle strength, and psychological well-being, supporting its incorporation into clinical rehabilitation protocols.

Keywords: lumbar fusion, refined paraspinal muscle exercises, postoperative rehabilitation, pain management, functional recovery, psychological well-being

Introduction

Lumbar degenerative diseases are among the most prevalent musculoskeletal conditions, affecting approximately 5% to 6% of the population.[1,2] These conditions are a leading cause of low back pain and are frequently associated with

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symptoms such as difficulty in standing or walking, restricted spinal mobility, and, in more severe cases, numbness or paralysis in the lower limbs.[3] Consequently, lumbar degenerative diseases can significantly impact both the physical and mental health of affected individuals, substantially reducing their overall quality of life.

While mild cases of lumbar degenerative diseases are typically managed with conservative treatments, moderate to severe cases often necessitate surgical intervention. Posterior lumbar interbody fusion (PLIF) is one of the most commonly performed surgical procedures for treating these diseases.[3] However, PLIF surgery presents several challenges,[4] including increased muscle trauma, postoperative complications, and delayed recovery, particularly in older patients. Moreover, psychological factors such as depression and anxiety are often overlooked during the recovery process, despite their critical role in exacerbating postoperative pain and hindering recovery.[5,6]

Active rehabilitation training has been shown to alleviate physical pain and improve psychological outcomes, such as depression and anxiety, in patients with spinal disorders.[7–9] A key component of spinal rehabilitation is strengthening the paraspinal muscles, which are essential for maintaining spinal stability.[10] Functional training targeting these muscles, particularly early lumbar and back muscle exercises, has demonstrated significant benefits in managing conditions like low back pain,[11] ankylosing spondylitis,[11] and stroke.[12] However, many patients remain unaware of the importance of these exercises, which often leads to poor adherence to rehabilitation programs.

Enhanced Recovery After Surgery (ERAS) protocols, which emphasize early mobilization and perioperative care, are designed to minimize surgical trauma and stress responses, thus promoting faster recovery.[13] While short-term rehabilitation under the ERAS protocol has demonstrated benefits in early recovery,[14] there is a lack of research on long-term exercise interventions, which aim to prevent muscle atrophy, enhance muscle strength, and reduce postoperative pain in the months following lumbar surgery.

In our center, the integration of rehabilitation therapy, nursing measures, and surgical treatment through multidisciplinary collaboration has facilitated the implementation of this long-term, structured paraspinal muscle exercise program.

This study hypothesizes that long-term, refined paraspinal muscle exercises, when combined with early postoperative rehabilitation, will significantly enhance recovery outcomes in patients undergoing PLIF surgery. The aim is to evaluate the comprehensive impact of structured, long-term paraspinal muscle exercises on pain relief, functional recovery, psychological well-being, and flexion/extension muscle strength in PLIF patients, thereby providing practical rehabilitation guidance for clinical practice.

Clinical Data

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Ethics Committee of Qinghai Provincial People's Hospital (2024073). All participants provided written informed consent after receiving detailed information about the study objectives and procedures. The study population comprised patients who underwent posterior lumbar interbody fusion (PLIF) surgery between January 2020 and September 2023. Patients were divided into two groups based on postoperative rehabilitation preferences and family support capacity: the ERAS-ST group (short-term ERAS rehabilitation only) and the ERAS-LT group (ERAS combined with long-term paraspinal muscle training). Propensity score matching was applied to control for confounders such as age, sex, and baseline pain scores.

Study Population

This study included 298 patients who underwent PLIF surgery between January 2020 and September 2023. The cohort consisted of 173 males and 125 females. Patients were divided into two groups based on the rehabilitation protocol they followed:ERAS Short-Term Functional Exercise Group (ERAS-ST): 198 patients (118 males, 80 females), aged 56–75 years (mean age: 58.42 ± 6.67 years), who adhered to the ERAS protocol with short-term postoperative functional exercises, including early mobilization, pain management, and basic exercises starting within 24 hours after surgery; ERAS + Long-Term Paraspinal Muscle Exercise Group (ERAS-LT): 100 patients (55 males, 45 females), aged 57–78 years (mean age: 60.15 ± 7.53 years), who followed the ERAS protocol and also engaged in long-term, refined paraspinal muscle exercises (starting within the first week post-surgery and continuing for at least 12 months) to enhance muscle strength, improve mobility, and support long-term functional recovery.

Inclusion and Exclusion Criteria

Inclusion criteria for PLIF surgery: 1) Imaging-confirmed diagnoses of disc herniation, degeneration, spondylolisthesis, or spinal stenosis causing nerve root compression. 2) Symptoms that failed to improve or worsened after three months of conservative treatment. 3) No contraindications for surgery.

Exclusion criteria for PLIF surgery: 1) History of prior spinal surgery. 2) Presence of infections, tumors, or severe systemic diseases. 3) Incomplete clinical data.

Inclusion criteria for the back muscle exercise program: 1) Patients fully informed and aware of the rehabilitation process. 2) Ability and willingness to comply with the prescribed exercise regimen.

Exclusion criteria for the back muscle exercise program: 1) Inability to adhere to medical advice or tolerate rehabilitation exercises. 2) Presence of mental or cognitive impairments that hinder cooperation with investigators.

Surgical Procedure and Intervention

Both groups underwent posterior lumbar interbody fusion (PLIF) with a standardized surgical approach.

ERAS Short-Term Functional Exercise Group (ERAS-ST):

Patients in this group followed the Enhanced Recovery After Surgery (ERAS) protocol, which focuses on early mobilization, minimizing surgical trauma, and reducing perioperative stress to promote early recovery.[14] Postoperative functional exercises commencedwithin 24 hours after surgery, focusing primarily on pain management, basic mobility, and strengthening exercises to assist patients in regaining functional abilities in the immediate postoperative period.

ERAS + Long-Term Paraspinal Muscle Exercise Group (ERAS-LT):

In addition to adhering to the standard ERAS protocol, patients in this group participated in structured, long-term paraspinal muscle exercises, which began 2–4 weeks post-surgery and continued for at least 12 months. Before discharge, patients were assessed by a rehabilitation therapist, and after discharge, exercises were performed under family supervision. Regular follow-up through phone calls was conducted by nursing staff to monitor progress and address any issues encountered during the training. To ensure adherence to the long-term exercise regimen, ERAS-LT patients received personalized guidance from rehabilitation therapists at discharge, with daily supervision by family members. A rehabilitation log was maintained to record exercise details (eg, type, duration, and perceived exertion using the Borg Scale). The research team conducted monthly telephone follow-ups to verify logs and address training issues. Only patients who completed ≥80% of the exercise plan (ie, ≥38 weeks/year) were included in the final analysis; non-compliant cases (n=12) were excluded.

Paraspinal Muscle Exercise Details

The lumbar spine functions through the coordinated action of multiple muscle groups. Various exercises target specific muscles to achieve comprehensive rehabilitation, such as:[15]

Five-Point Support and Four-Point Kneeling Alternating to Two-Point Kneeling

This exercise targets the multifidus muscle, crucial for stabilizing the lumbar spine and improving posture. Begin in a quadruped position (hands and knees) and alternate lifting the opposite arm and leg, holding each position briefly before switching sides. This controlled movement enhances spinal stability and balance.

Flying Swallow (Small Swallow Exercise) and Back Extension (Goat Back Lift)

These exercises focus on the erector spinae muscles, which support spinal extension and upright posture. For the Flying Swallow, lie prone and lift the right arm and left leg simultaneously, holding for a few seconds before alternating. In the Back Extension, gently lift the upper torso off the ground while keeping the legs and arms grounded, strengthening spinal muscles.

Pull-Ups and Latissimus Dorsi Stretch

Pull-ups strengthen the latissimus dorsi, a key muscle for spinal stabilization. The Latissimus Dorsi Stretch involves raising both arms overhead and gently leaning to one side, stretching the muscles along the back. Together, these exercises build upper body strength and enhance spinal support.

Supine Alternating Leg Raises

This exercise targets the psoas major, essential for lumbar flexion and core stability. Lie on your back with legs extended, then lift one leg while keeping the other grounded. Alternate between legs to strengthen the core and support lower back stability.

Quadratus Lumborum Stretch

Stretching the quadratus lumborum can alleviate muscle-induced low back pain, as this muscle is often involved in chronic lumbar discomfort. Stand upright, raise one arm overhead, and gently lean to the opposite side to feel the stretch along the lower back.

Recommended Frequency (for all exercises): Perform 3–5 sets of each exercise, with 10–15 repetitions per set; Aim to complete exercises 3–4 times per week for optimal results; For stretching exercises (Latissimus Dorsi Stretch and Quadratus Lumborum Stretch), hold each stretch for 20–30 seconds per side, repeating 3–4 times per week.

Evaluation Indicators

The Visual Analogue Scale (VAS) for low back pain and Oswestry Disability Index (ODI) were used to evaluate clinical outcomes.

PHQ-9 and GAD-7 were utilized to assess depressive and anxiety symptoms.[16] The Patient Health Questionnaire-9 (PHQ-9) is a 9-item self-administered tool designed to assess depression, with scores ranging from 0 to 27. Higher scores indicate more severe depression.

The GAD-7 assesses anxiety symptoms through seven questions aimed at identifying the presence of anxiety. Each item is scored from 0 to 3, with a total score ranging from 0 to 21. Higher scores indicate more severe anxiety.

Hand-Held Dynamometry (HHD): to evaluate the strength of paraspinal muscles.[17] This method provided objective measurements of muscle strength at various time points post-surgery, specifically for the lumbar and paraspinal regions. The measurements were taken preoperatively and at 3, 6, and 12 months post-surgery to track the improvement in muscle strength.

Statistical Methods

To minimize measurement bias, all outcomes were assessed by evaluators blinded to group allocation. Statistical analysis was performed using SPSS 26.0 software Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$). For normally distributed data, independent sample *t*-tests were used for comparisons between the two groups, while paired *t*-tests were applied for within-group comparisons at two time points. For non-normally distributed data, rank-sum tests and Mann–Whitney *U*-tests were used. Categorical data were analyzed using the chi-square test or Fisher's exact test. A p-value of less than 0.05 was considered statistically significant.

Results

Basic Characteristics

Baseline comparisons revealed no significant differences between the two groups in terms of demographic characteristics, including age, sex, disease duration, occupation, household income, insurance status, and surgical segments ($P > 0.05$). In the ERAS-LT group, 88% of patients (88/100) completed ≥90% of the exercise plan without encountering significant difficulties. Additionally, 12 patients completed 80–90% of the training program. The 12 dropouts were primarily attributed to insufficient family support (n=7) or health-related issues (n=5, eg, cardiovascular events), none of which resulted in significant adverse effects or complications. Baseline medication use (eg, NSAIDs, antidepressants) showed no significant differences between the two groups ($P > 0.05$).

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Pain and Lumbar Function

Regarding functional recovery, there were no differences in VAS scores between the two groups preoperatively and at 1 and 6 months; however, at 3 months, group LT's pain scores were higher than those of group ST. A At 12 months postoperatively, the score in group LT was 1.74 ± 1.50, significantly lower than that in group ST (2.19 ± 1.58, P = 0.011). ODI scores showed no statistically significant differences between group LT and group ST preoperatively and at 1 month postoperatively. Group LT significantly outperformed group ST at 3 months (P = 0.007), 6 months (P = 0.002), and 12 months (P = 0.031), with scores of 17.76 ± 7.81, 16.52 ± 8.46, and 18.65 ± 11.14, respectively, compared to group B's scores of 22.47 ± 8.08, 20.84 ± 5.63, and 23.81 ± 10.42. Figure 1 illustrates representative preoperative and postoperative

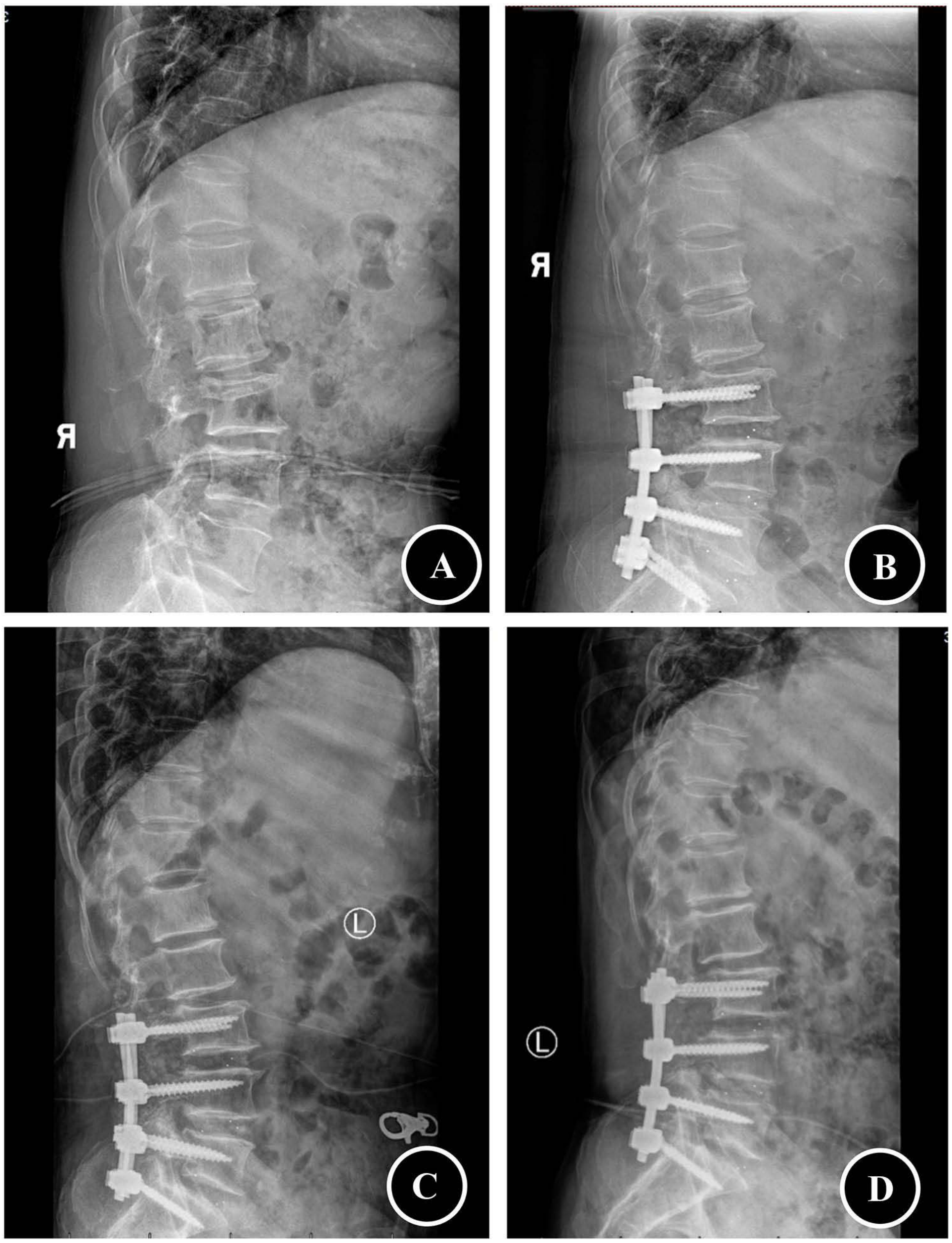

Figure 1 Preoperative and Postoperative Imaging of a Patient Undergoing PLIF. (**A**) Preoperative lateral radiograph showing degenerative changes and spinal instability. (**B**) Postoperative lateral radiograph at 1 month, demonstrating the initial placement of interbody fusion hardware and spinal alignment. (**C**) Postoperative lateral radiograph at 6 months, showing early signs of fusion and improved spinal alignment. (**D**) Final follow-up lateral radiograph, confirming successful fusion, stable hardware, and maintained spinal alignment. This figure illustrates the radiographic progression of a patient who underwent posterior lumbar interbody fusion (PLIF) surgery, highlighting the structural improvements achieved through the procedure and postoperative rehabilitation.

radiographic findings in a patient undergoing PLIF surgery, demonstrating degenerative changes preoperatively (A), initial hardware placement at 1 month (B), early fusion signs at 6 months (C), and confirmed successful fusion at final follow-up (D).

Depression and Anxiety

In terms of emotional state, the comparison of PHQ-9 scores showed no differences between the two groups preoperatively. There was no statistically significant difference between the two groups at 6 months postoperatively; however, group LT had scores of 4.74 ± 3.93 and 2.39 ± 1.86 at 3 and 12 months postoperatively, respectively, which were significantly lower than group ST's scores of 6.97 ± 4.19 and 4.28 ± 3.07 ($P = 0.009$ and $P = 0.001$). This indicates significant improvement in depressive symptoms for group LT, emphasizing the beneficial effect of consistent exercise on mental health. Although early GAD-7 scores showed no statistical differences, at 12 months postoperatively, group LT's score was 3.08 ± 1.80, significantly lower than group ST's score of 4.13 ± 2.08 ($P = 0.012$), further supporting the role of exercise in alleviating anxiety.

Muscle Strength

The results indicated that between 3 and 6 months postoperatively, patients showed a gradual recovery of both flexor and extensor muscle strength, although these values remained lower than preoperative levels. At 6 months post-surgery, the LT group demonstrated a statistically significant improvement in extensor muscle strength compared to the ST group ($P < 0.05$). By 12 months, the LT group exhibited more substantial recovery in both extensor and flexor muscle strength ($P < 0.05$).

Long-Term Complications

Fewer patients in the ERAS-LT group experienced long-term complications such as muscle atrophy and chronic back pain. Only 8% of patients in the ERAS-LT group reported persistent back pain at 12 months, compared to 20% in the ERAS-ST group ($P < 0.05$).

Discussion

Lumbar degenerative diseases, a leading cause of low back pain, significantly impact patients' physical and mental health.[18] These conditions often lead to reduced spinal mobility, muscle atrophy, and psychological distress, which can significantly impair the quality of life. Posterior lumbar interbody fusion (PLIF) surgery is commonly performed to restore spinal stability, but it presents challenges, including muscle trauma, postoperative complications, and delayed recovery. In this context, enhancing the rehabilitation process, particularly through muscle-strengthening exercises, can play a crucial role in mitigating these challenges.[19]

This study underscores the significant benefits of incorporating long-term, refined paraspinal muscle exercises into the postoperative rehabilitation of patients undergoing lumbar fusion surgery. Evidence demonstrates that targeted interventions, such as isolated lumbar extension resistance exercises (ILEX), effectively recondition lumbar extensor strength and improve functional outcomes in chronic low back pain populations, with MRI and T2 mapping confirming enhanced paraspinal muscle endurance and morphology after exercise programs.[20,21] Our findings align with studies showing that postoperative rehabilitation not only accelerates physical recovery but also reduces pain and improves patient satisfaction by restoring flexor-extensor muscle balance.[22,23] For instance, a 12-month home-based exercise program post-lumbar fusion significantly improved trunk muscle strength, with back-specific exercises yielding greater functional gains compared to general rehabilitation protocols.[24,25] Furthermore, multidisciplinary collaboration among surgical, rehabilitation, and nursing teams has enabled the development of comprehensive approaches addressing muscle asymmetry and fatty infiltration—key predictors of mechanical complications and reoperation risks.[26] This integration is critical, as preoperative paraspinal muscle assessments (eg, cross-sectional area, fat infiltration) have emerged as prognostic indicators for postoperative outcomes, emphasizing the need for tailored rehabilitation.[27] Notably, interventions combining motor control training with isolated lumbar strengthening (MC + ILEX) outperformed general exercise in enhancing upper lumbar paraspinal muscle volume and patient-reported outcomes, underscoring the value of biomechanically optimized regimens.[28] Psychological well-being improvements are further amplified by addressing muscle strength imbalances, such as reduced extensor/flexor ratios linked to disability indices, which correlate with better Oswestry scores and reduced pain intensity.[29] Collectively, these findings validate the necessity of sustained, structured paraspinal exercise programs supported by multidisciplinary strategies to optimize both physiological and psychological recovery trajectories.

Muscle Strength and Recovery Outcomes

A central aspect of this study was the objective measurement of muscle strength using hand-held dynamometry (HHD), a reliable tool validated for assessing isometric strength in both acute and subacute rehabilitation phases. We observed significant improvements in muscle strength across key paraspinal muscle groups such as the multifidus, erector spinae, and psoas major in the ERAS-LT group at both 6 and 12 months post-surgery. Notably, the slower strength gains in extensors compared to flexors may reflect differential biomechanical demands during early spinal stabilization, as the multifidus and erector spinae exhibit higher susceptibility to atrophy and fatty infiltration in degenerative conditions. These improvements were associated with better pain management, as evidenced by lower Visual Analog Scale (VAS) scores, and enhanced functional recovery, reflected by improved Oswestry Disability Index (ODI) scores, consistent with studies linking paraspinal muscle quality (eg, reduced fatty infiltration and increased functional cross-sectional area) to postoperative pain/disability outcomes.[30,31]

Paraspinal muscle strengthening provides multifaceted biomechanical advantages. Enhanced paraspinal muscles reduce pain related to spinal instability by improving load distribution, as evidenced by the inverse association between psoas mass and mechanical stress in degenerative lumbar conditions.[32] Additionally, increased erector spinae muscle quantity correlates with diminished mechanical stress on spinal structures, contributing to sustained pain reduction and disability mitigation.[33,34] This aligns with evidence that preserved multifidus integrity decreases dural sac compression and enhances lumbar flexibility, thereby slowing disability progression in degenerative spinal disorders.[34] The delayed recovery of extensor strength relative to flexors may reflect distinct neuromuscular activation patterns, with extensors such as the multifidus playing a crucial role in segmental stabilization during dynamic motion.[35] This differential underscores the importance of targeted rehabilitation protocols, particularly given the link between early postoperative paraspinal strengthening and reduced complications, including pedicle screw loosening.[36] These findings extend prior observations by demonstrating that systematic muscle strengthening not only improves spinal stability but also optimizes force absorption during functional movements, addressing both pain pathogenesis and mechanical overload.[37]

Psychological Well-Being and Recovery

In addition to physical benefits, our study also underscores the psychological advantages of long-term muscle rehabilitation. We found that patients in the ERAS-LT group showed significant reductions in depression (PHQ-9 scores) and anxiety (GAD-7 scores) over time. These psychological improvements were particularly notable at 12 months post-surgery. The relationship between muscle strength and psychological well-being can be understood through the concept of self-efficacy, where stronger muscles contribute to a sense of control over one's physical state.[38] This sense of control, in turn, enhances psychological resilience, helping to reduce anxiety and depression associated with postoperative recovery.

Our findings corroborate existing evidence emphasizing that enhanced physical strength fosters psychological resilience through improved functional capacity and reduced disability-related distress.[39,40] Robust physical function enhances self-esteem and mitigates mental health decline, particularly in chronic pain contexts where pain self-efficacy plays a pivotal role in reducing anxiety.[41–43] Since pain and psychological distress often exhibit bidirectional interactions, the concurrent reduction in both domains observed in the ERAS-LT group highlights the critical need for integrated biopsychosocial rehabilitation approaches that address somatic and affective components holistically. Notably, at 3 months postoperatively, the ERAS-LT group displayed higher Visual Analogue Scale (VAS) scores than the ERAS-ST group, followed by a marked decline. This transient pain elevation likely reflects initial muscle adaptation responses involving microtrauma and delayed-onset muscle soreness (DOMS), which resembles exercise-induced discomfort in healthy individuals and may originate from fascial sources rather than muscle tissues.[44] Concurrently, psychological barriers or suboptimal exercise technique during early rehabilitation may exacerbate transient pain through increased distress.[42,45]

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As rehabilitation progressed, however, enhanced neuromuscular coordination—facilitated by motor skill adaptation—mediated pain tolerance and score reduction.[46] These dynamics underscore the imperative for tailored patient education in early-phase rehabilitation to alleviate anxiety and bolster adherence.[39] The psychological benefits of long-term exercise may be mediated through multiple pathways. First, physical activity upregulates brain-derived neurotrophic factor (BDNF), enhancing neuroplasticity and alleviating depressive symptoms.[47] Second, improved muscle strength fosters self-efficacy—patients' confidence in their ability to recover—which reduces helplessness and psychological distress.[48] Third, regular exercise modulates the hypothalamic-pituitary-adrenal (HPA) axis, lowering cortisol levels and stabilizing mood.[49] These mechanisms synergistically create a "biopsychological positive feedback loop", amplifying rehabilitation outcomes. Future studies should incorporate biomarkers (eg, serum BDNF, cortisol) to validate these hypotheses.

Muscle Soreness and Adaptation

Our study findings reveal that, although flexor and extensor muscle strength progressively increased postoperatively, the average muscle strength remained lower than preoperative levels due to various factors, such as pain, fear, and stress, as well as the lack of long-term exercise. In the context of long-term back muscle exercises, we observed that extensor muscle strength showed significant improvement at 6 months and may even recover to a level higher than preoperative strength. In contrast, flexor muscle strength only exhibited notable differences at 12 months and ultimately recovered to levels comparable to preoperative strength.

It is also important to note the temporary discomfort and muscle soreness experienced by patients in the ERAS-LT group at the 3-month follow-up. This discomfort, likely stemming from muscle adaptation to the strengthening regimen, was transient and should not be interpreted as a failure of the rehabilitation protocol. On the contrary, this short-term discomfort reflects the necessary adjustments the body makes as muscles strengthen, ultimately contributing to long-term recovery. The absence of significant muscle strength improvements in the ERAS-ST group further underscores the pivotal role that sustained, structured rehabilitation exercises play in enhancing postoperative recovery.

Long-Term Outcomes and Complications

In terms of long-term outcomes, patients in the ERAS-LT group reported fewer complications, such as chronic back pain, compared to those in the ERAS-ST group. Only 8% of patients in the ERAS-LT group experienced persistent back pain at 12 months, whereas 18.2% of patients in the ERAS-ST group reported the same. This finding suggests that the long-term rehabilitation protocol not only promotes functional recovery but also helps prevent long-term complications that could potentially undermine the success of PLIF surgery. However, it is important to acknowledge that the relatively long duration of our study and the exclusion of patients who were unable to adhere to the exercise regimen may limit the comparison of certain long-term complications, particularly severe complications such as reoperation, adjacent segment degeneration, and nerve compression resulting from these conditions.

Study Limitations and Future Directions

Despite the promising findings, this study has some limitations. The observational design and lack of randomization introduce potential selection bias, and the sample size, though adequate, may not fully account for all potential confounding variables. Although propensity score matching controlled for baseline confounders (eg, age, sex), self-selection bias may persist due to patient preferences for long-term exercise. Future randomized controlled trials with larger cohorts and longer follow-up periods are necessary to validate these findings and further explore the mechanisms underlying muscle strength improvements, including neuroplasticity and muscle remodeling.

Additionally, it would be beneficial to investigate the specific biological mechanisms that mediate the improvements in muscle strength and psychological outcomes, potentially leading to more targeted rehabilitation strategies. Understanding these pathways could further optimize rehabilitation protocols for PLIF patients and extend the benefits of muscle training to other spinal conditions.

Conclusion

In conclusion, our study demonstrates that integrating long-term refined paraspinal muscle exercises with the ERAS short-term rehabilitation protocol significantly improves postoperative recovery in PLIF patients. This long-term exercise regimen not only enhances pain management, functional recovery, and muscle strength but also contributes to better psychological well-being. These findings underscore the importance of incorporating long-term, structured muscle exercises into clinical rehabilitation protocols, offering a holistic approach to optimizing recovery outcomes and improving the overall quality of life for PLIF patients. Future research should focus on refining these rehabilitation strategies and exploring the underlying mechanisms to further enhance recovery and long-term health outcomes for this patient population.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request. Restrictions may apply to the availability of some data due to privacy or ethical considerations.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Ethics Committee of Qinghai Provincial People's Hospital. Written informed consent was obtained from all participants prior to their inclusion in the study. Participants were fully informed about the study objectives, procedures, potential risks, and benefits.

Consent for Publication

All authors have provided their consent for the publication of this manuscript. The manuscript does not contain any individual person's data in any form (including images, videos, or other identifiable information).

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Author Contributions

All authors made a significant contribution to the work reported, whether in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests. No financial or non-financial conflicts of interest influenced the design, execution, or reporting of this study.

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