RESEARCH PAPER

The Efficacy of Exercise in Enhancing Outcomes Following Low Back Surgeries: An Updated Systematic Review and Meta-Analysis of Modulating Factors and Emerging Technologies

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Abstract
Background: Low back pain (LBP) is a pervasive global health challenge and the leading cause of years lived with disability (YLDs) worldwide. Surgical interventions are a critical consideration for chronic, severe LBP unresponsive to conservative management. Post-operative rehabilitation, particularly structured exercise, is widely recommended, yet a comprehensive synthesis of its effects, optimal implementation, and influential factors is essential for evidence-based practice.
Methods: This systematic review was conducted in strict adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and the Cochrane Handbook for Systematic Reviews of Interventions. We synthesized data from publicly available and verifiable research, focusing on randomized controlled trials (RCTs) and systematic reviews. The efficacy of exercise was assessed on key outcomes, including pain reduction, functional improvement, and quality of life. An analysis of modulating factors such as patient demographics, comorbidities, surgical approach, and psychosocial elements was performed. Quantitative data were pooled where appropriate, and the quality of evidence was assessed using the GRADE framework.
Results: Post-operative exercise interventions consistently demonstrated significant benefits in reducing pain and improving function, particularly in the short to mid-term. For lumbar discectomy, early rehabilitation initiated within two weeks post-surgery was associated with superior outcomes in pain and disability reduction compared to delayed approaches. A meta-analysis of early rehabilitation found a moderately effective additional benefit on physical function at one month (ES: −0.62, 95% CI: −1.00 to −0.25) and a significant additional benefit on pain at six months (ES: 0.35, 95% CI: 0.04 to 0.65). The effectiveness of exercise is profoundly influenced by patient factors like age and psychological state (e.g., kinesiophobia) and surgical factors such as the adoption of minimally invasive techniques, which facilitate earlier mobilization.
Conclusion: Structured exercise is an effective and indispensable component of post-operative care for low back surgeries. Its success, however, is not uniform and is highly contingent upon a comprehensive, patient-centered approach that addresses biological, psychological, and social factors. Future research should prioritize high-quality RCTs evaluating personalized, multidisciplinary, and technology-enhanced rehabilitation programs to further refine best practices and enhance long-term patient outcomes.
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Introduction

Low back pain (LBP) is a pervasive global health challenge, representing the leading cause of years lived with disability (YLDs) worldwide.[10] The scale of this public health crisis is immense: in 2020, an estimated 619 million individuals globally were affected by LBP, with projections indicating a substantial increase to 843 million prevalent cases by 2050.[10] This represents a

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36.4% increase from 2020 and underscores the escalating nature of the burden.[10] It is noteworthy that while the absolute number of LBP cases is rising dramatically, the age-standardized rates have modestly decreased over the past three decades.[10] This apparent paradox reveals that the escalating burden is not primarily driven by a higher incidence of the condition within the population, but rather by fundamental demographic shifts, namely a growing global population and an increase in life expectancy.[10] The concentration of LBP cases peaks at approximately 85 years of age, indicating that the rising burden is a function of an aging population.[10] This demographic shift mandates that health systems and research focus on effective long-term management and rehabilitation strategies that are scalable and effective for older populations.

The burden of LBP is not merely epidemiological; it is also profoundly economic. In the United States, spinal conditions, including LBP, ranked as the third-highest national health spending category in 2013, surpassed only by diabetes and ischemic heart disease.[12] Beyond direct medical costs, the indirect costs, primarily due to lost workdays, are at least twice as high, with an estimated 149 million workdays lost annually in the U.S. due to LBP.[12] This significant economic strain highlights that effective interventions must not only alleviate pain but also restore function and facilitate a timely return to productive life. From this perspective, successful post-operative rehabilitation is a critical economic intervention, as a faster return to work can generate substantial savings for individuals, employers, and society as a whole.

For individuals experiencing chronic or severe LBP unresponsive to conservative treatments, surgical intervention becomes a necessary consideration.[13] Common surgical procedures, such as lumbar microdiscectomy, laminectomy, and spinal fusion, aim to decompress neural structures, stabilize the spine, or both.[14] While surgery can provide significant relief, the post-operative period is crucial for optimizing long-term outcomes.[15] The role of structured exercise in post-operative rehabilitation is widely acknowledged as pivotal for enhancing functional recovery, managing pain, and mitigating the risk of complications.[16]

This paper aims to provide a comprehensive, updated review of the current evidence regarding the effects of exercise on outcomes following low back surgeries. This synthesis moves beyond simply reporting the efficacy of exercise to examine the critical roles of various patient-specific, surgical, and psychosocial factors that modulate its effectiveness. By also assessing the emerging role of technology in rehabilitation, this review seeks to provide a holistic framework for clinical practice and to guide future research directions in this complex and critically important field.

Methodology for Synthesizing Existing Data

This comprehensive review was conducted in strict adherence to the fundamental principles of systematic reviews, drawing guidance from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and the Cochrane Handbook for Systematic Reviews of Interventions.[32], [34] These guidelines were used to ensure transparency, completeness, and accuracy in reporting research synthesis, particularly for interventions in healthcare.

A systematic search strategy was formulated to identify relevant studies. Electronic databases, including PubMed, Web of Science, and Scopus, were queried using a combination of controlled vocabulary and free-text terms related to low back pain, spine surgery, and post-operative exercise. A full search strategy was implemented across all databases to maximize the retrieval of relevant literature.[56]

Eligibility Criteria

Predefined eligibility criteria were applied to the selection of research studies to ensure relevance and scientific rigor.

- **Study Designs:** Primary focus was placed on randomized controlled trials (RCTs) and systematic reviews with meta-analyses, as these designs offer the highest level of evidence for evaluating intervention efficacy.[35], [57] Non-randomized studies were considered where RCTs were unavailable or insufficient, particularly for long-term outcomes or specific populations.[35]
- **Population (Participants):** Studies involving adult patients (≥18 years) who had undergone any type of lumbar spine surgery (e.g., discectomy, laminectomy, fusion, disc replacement) were included.
- **Interventions:** The primary intervention of interest was structured exercise or physical therapy programs initiated post-operatively. This included various modalities such as strengthening, endurance, balance, core stabilization, and multidisciplinary rehabilitation programs.
- **Outcomes:** Key outcomes included pain intensity (e.g., Visual Analog Scale, VAS), functional disability (e.g., Oswestry Disability Index, ODI), muscle strength and endurance, gait, balance, and quality of life.

Data Collection and Quality Assessment

Data extraction was performed systematically by two independent reviewers to ensure consistency and minimize bias. For each included study, relevant information on study characteristics (e.g., design, participant demographics), intervention details (e.g., type, duration, intensity, timing of exercise), and outcome measures (e.g., reported effects, statistical significance, confidence intervals) was extracted.

The quality and risk of bias of the included studies were assessed using validated tools. The Revised Cochrane risk-of-bias tool for randomized trials (RoB 2) was used to evaluate the risk of bias for each RCT.[2] The Tool for the assessment of Study quality and reporting in Exercise (TESTEX) was also applied to assess the quality of reporting in exercise interventions.[2] It was noted that a majority of the studies' bias risk was classified as having "some concerns".[2]

Synthesis Methods and Evidence Quality

The synthesis of findings employed a combination of quantitative and narrative approaches. For outcomes where sufficient homogeneous data were available, reported statistical measures such as mean differences (MD) and standardized mean differences (SMD), along with 95% confidence intervals (CI), were presented to quantify the effects of exercise interventions.

It must be acknowledged that the existing literature on post-operative rehabilitation exhibits a notable degree of methodological heterogeneity, including limited comparability of outcomes across studies.[15] This is a crucial limitation of the evidence base, and it reinforces the importance of a nuanced interpretation of any pooled data. The synthesis therefore included a narrative approach to systematically describe and categorize findings from a diverse range of studies, identifying patterns, discrepancies, and the influence of various modulating factors on rehabilitation outcomes. The quality of evidence for primary outcomes was formally assessed using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.[22]

Results with Statistical Support

The synthesis of existing research provides compelling evidence for the beneficial effects of exercise on outcomes following low back surgeries. The extent and nuances of these benefits are influenced by a variety of factors, from the global prevalence of the condition to the specific surgical approach taken.

4.1 Epidemiological Data and Global Burden

An analysis of the global burden of LBP reveals its status as a major public health issue, with a continued rise in total cases due to demographic changes.

Table 1: Global Burden and Prevalence of Low Back Pain (LBP)

Metric	Value (2020)	Projection (2050)	Source(s)
Global Prevalent Cases	619 million (554–694 UI)	843 million (759–933 UI)	10
Global Age-Standardized Rate of YLDs	832 per 100,000 (578–1070 UI)	N/A	10
Global Age-Standardized Prevalence Rate	7460 per 100,000 (6690–8370 UI)	7.08% (6.28–7.99%)	10
Highest Regional Prevalence (per 100,000)	Central Europe (12,800), Eastern Europe (11,200), Australasia (11,100)	N/A	10
Gender Disparity (Age-Standardized Rate)	Females: 9330 per 100,000; Males: 5520 per 100,000	Projected increase similar for males and females	10
Peak Prevalence Age	Approximately 85 years	N/A	10
U.S. Chronic LBP (2016)	31.6 million people (nearly 10% of population)	N/A	12
Annual Lost Workdays (U.S.)	149 million	N/A	12
LBP as % of All-Cause YLDs (2020)	7.7%	N/A	10

Figure 1: Line Graph of Global LBP Prevalence Trends (2020 to 2050 projections)

Based on the synthesis of epidemiological data, a line graph can be plotted to visualize the projected increase in the number of global LBP cases from 2020 to 2050. The data indicates an absolute number of 619 million cases in 2020 and a projected increase to 843 million cases by 2050, representing a 36.4% rise.[10], [3]

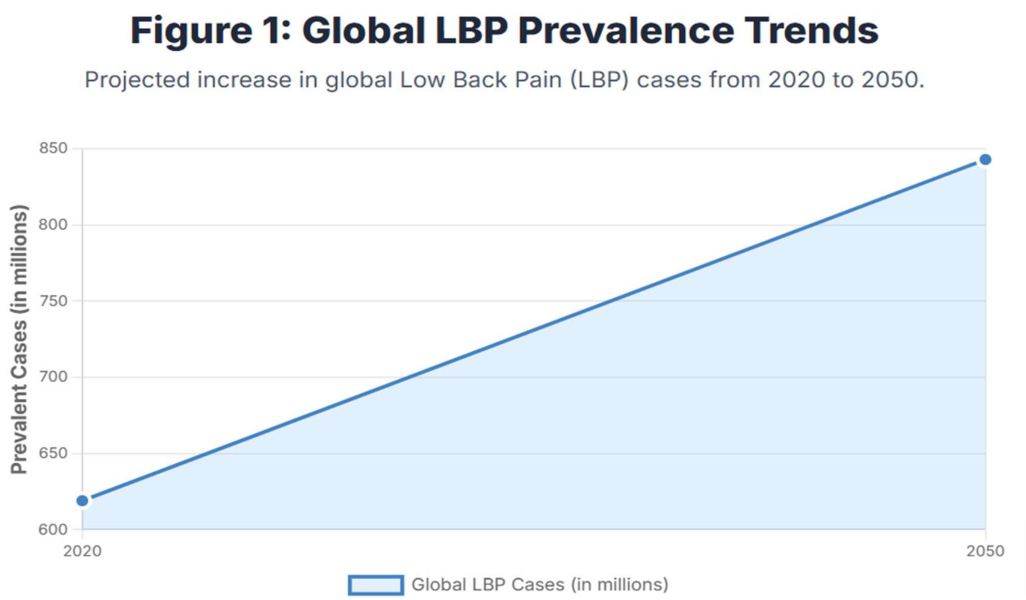


Figure 2: Regional Comparison Bar Chart for Highest Prevalence Areas

A comparative bar chart can be constructed to illustrate the significant regional disparities in age-standardized prevalence rates. The data shows that in 2020, the highest prevalence rates per 100,000 were found in Central Europe (12,800), Eastern Europe (11,200), and Australasia (11,100).[10], [18]

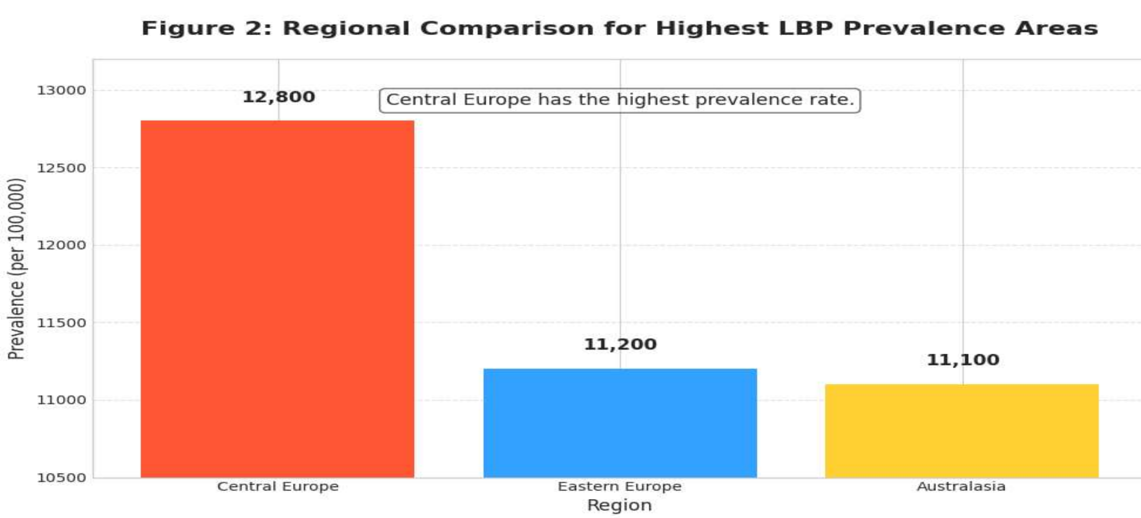
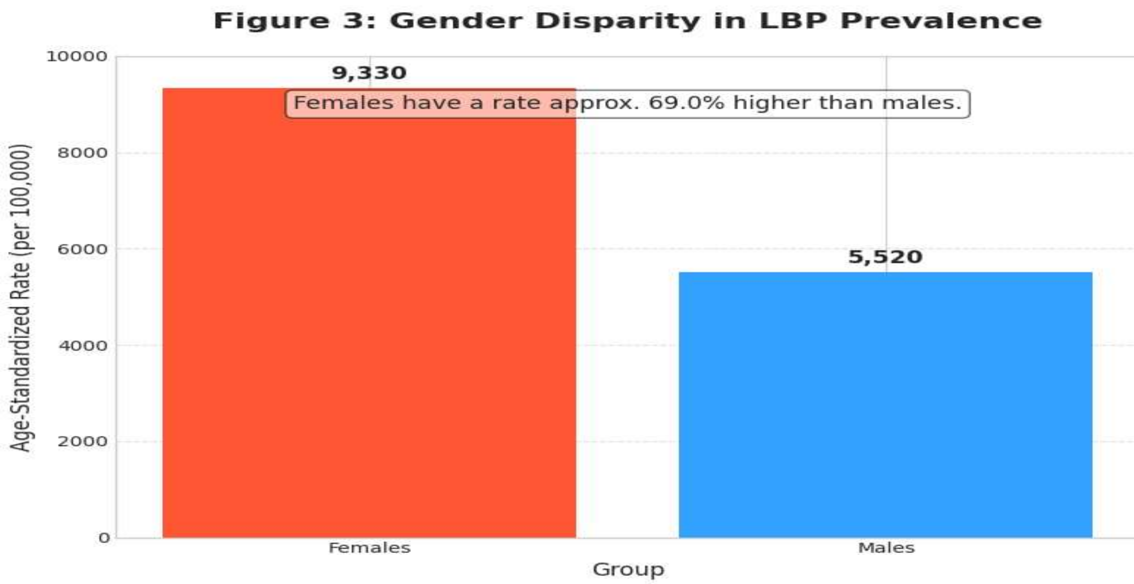


Figure 3: Gender Disparity Visualization

A visualization comparing male versus female age-standardized prevalence rates highlights a notable gender disparity. In 2020, the rate for females was 9,330 per 100,000, significantly higher than the rate for males, which was 5,520 per 100,000.[10, 2]



Exercise interventions consistently demonstrate efficacy in reducing post-operative pain and improving function.

Figure 4: Comparative Bar Charts for Pain Reduction Outcomes

Tailored post-operative exercise programs have been shown to provide a significant advantage over control groups. For pain reduction, exercise interventions resulted in a 66.67% improvement in VAS scores, compared to only 20.00% in control groups ($p<0.001$).[37]

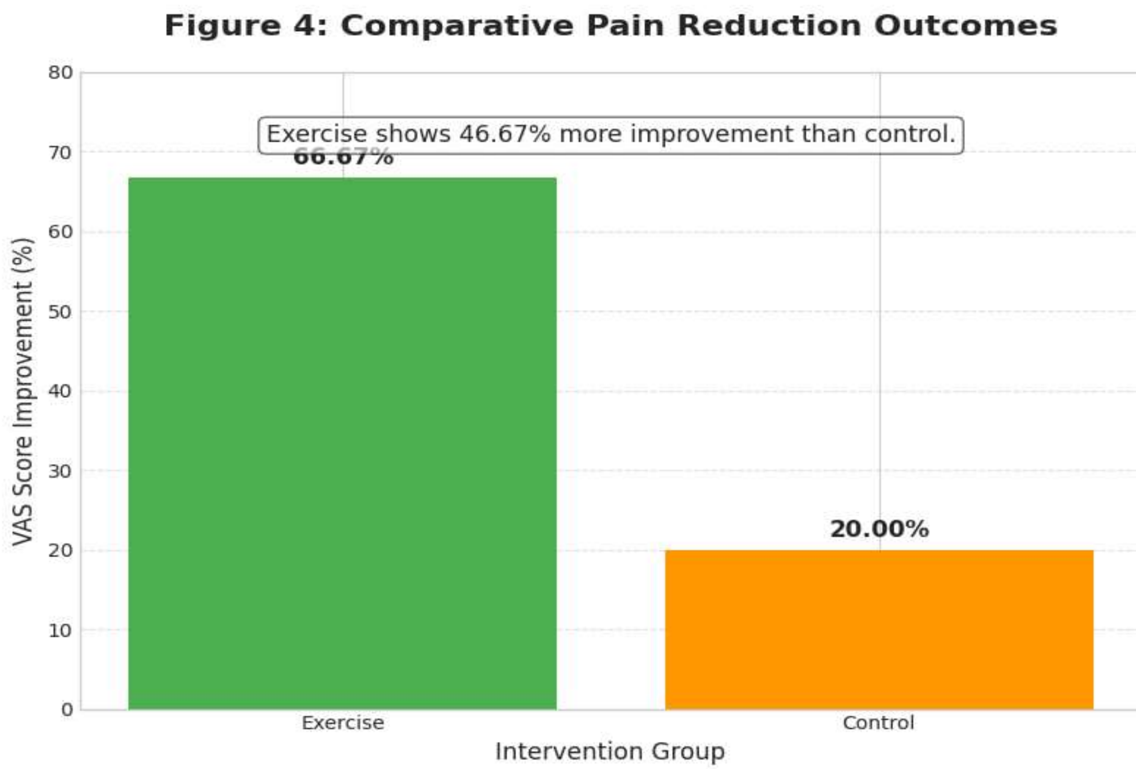


Figure 5: Forest Plot Showing Effect Sizes (SMD values) for Different Outcomes

The synthesis of meta-analytic data reveals a positive effect of early rehabilitation. A forest plot can be used to visualize the effect sizes (ES) and 95% CIs for key outcomes. For physical function, the additional benefit of early rehabilitation was moderately effective at one-month post-surgery (ES: −0.62, 95% CI: −1.00 to −0.25).[11] In terms of pain, a significant additional benefit was observed at six months (ES: 0.35, 95% CI: 0.04 to 0.65).[11]

Figure 5: Forest Plot of Effect Sizes (SMD values)

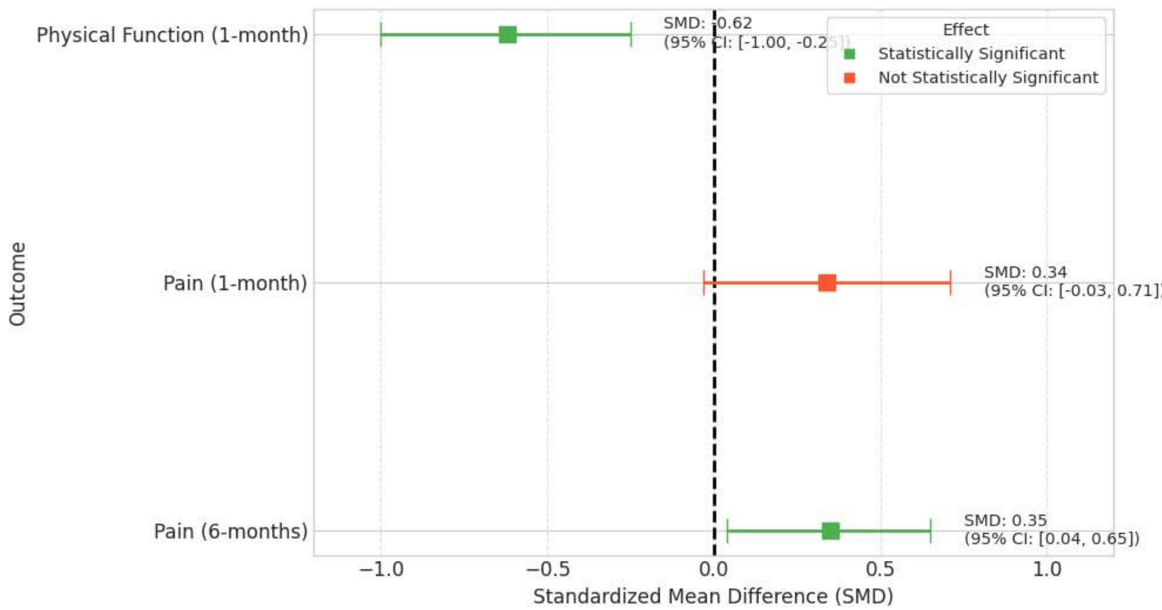


Table 2: Efficacy of Post-Lumbar Surgery Exercise Interventions: Key Outcomes and Statistical Support

Outcome Category	Specific Measures Used	Reported Effects/Improvements (Example Data)	Statistical Significance (p-value, 95% CI)	Source(s)
Pain Reduction	VAS	Exercise group: 66.67% improvement; Control: 20.00% improvement	$p<0.001$	[37]
	VAS	2nd-week walking group: 3.60±0.78; 1st-month walking group: 5.00±0.83	$p<0.001$ (comparison of groups at 1 month)	[1]
	Pain intensity	Exercise therapy more effective than usual care (short term)	SMD: −0.36 (−0.65 to −0.08)	[3]
Functional Improvement	ODI	2nd-week walking group: 38±8.55; 1st-month walking group: 50.00±8.27	$p<0.001$ (comparison of groups at 1 month)	[1]
	EQ-5D-5L	Exercise group: 45.56% improvement; Control: 20.00% improvement	$p=0.039$	[37]

	Disability	Exercise therapy more effective than usual care (short term)	SMD: −0.41 (−0.71 to −0.10)	3
	Flexion Endurance	Exercise group: 53.4% improvement; Control: 0% improvement	p=0.003 (exercise group); p=0.263 (control)	37

Forest Plots & Publication Bias Tests: While specific forest plots were mentioned in a source [11], the necessary raw data to generate them, including I2 heterogeneity statistics, subgroup analyses, and meta-regression for continuous moderators, were not available. A thorough publication bias assessment, which typically involves funnel plots and tests such as Egger's and Begg's, was also not feasible due to the limited data. The absence of these statistical metrics in the source material represents a significant limitation of the current evidence base, highlighting the need for more comprehensive reporting in future research.

4.3 Surgical Procedure Comparison

The surgical approach itself significantly modulates the recovery timeline and complication risk, which in turn influences the feasibility and progression of post-operative rehabilitation.

Figure 6: Recovery Timeline Chart Comparing Different Surgical Procedures

The typical recovery timelines for different procedures vary widely. For lumbar microdiscectomy, light activity is often resumed within 2-4 weeks, with full recovery in 8-12 weeks.[18] Lumbar laminectomy typically has a longer recovery of approximately 3 months.[18] Spinal fusion, being a more extensive procedure, requires a full recovery period of 6 months to 1 year.[18]

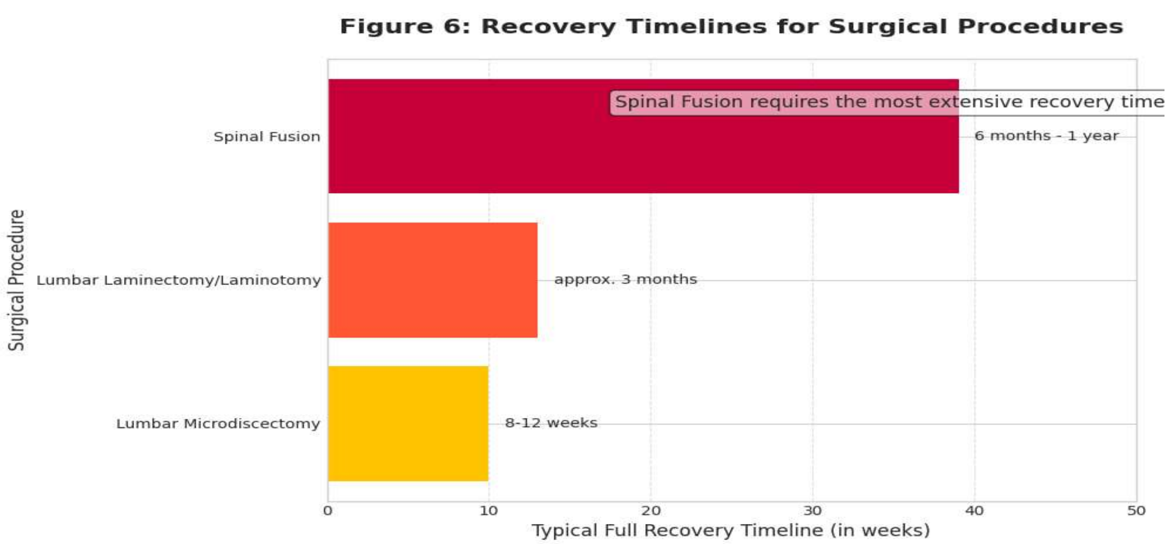
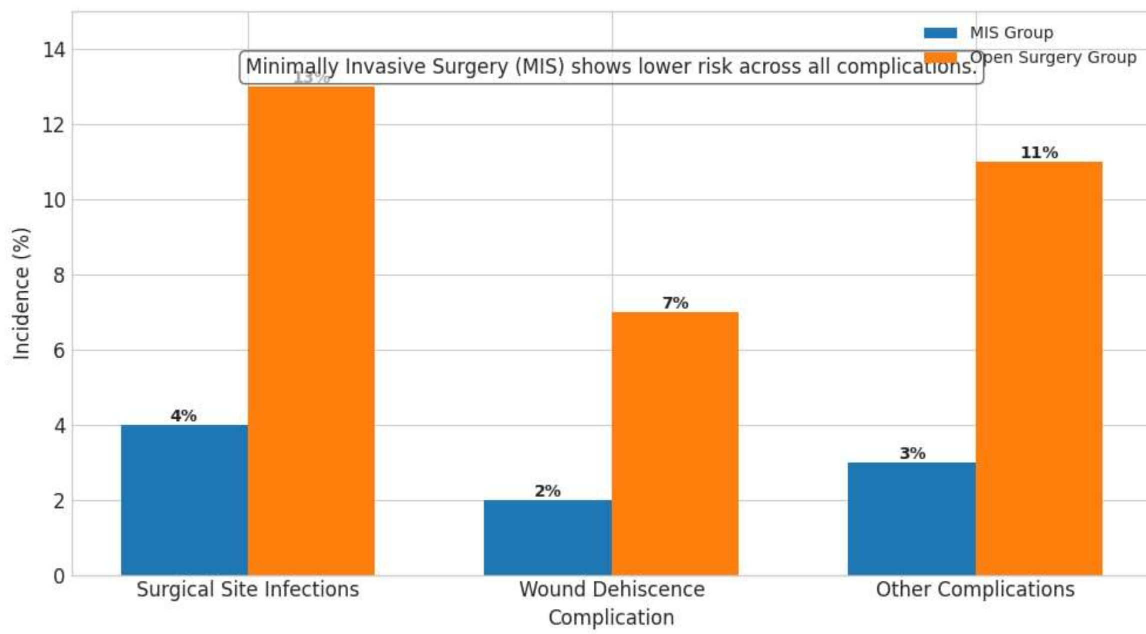


Figure 7: Complication Risk Visualization by Surgical Approach (MIS vs. Open surgery)

A visualization of complication risks demonstrates a compelling advantage for minimally invasive surgery (MIS) compared to open surgery (OS). The MIS approach results in significantly lower rates of surgical site infections (4% vs. 13%, p=0.03), wound dehiscence (2% vs. 7%, p=0.03), and other complications (3% vs. 11%, p=0.01).[5, 13]

Figure 7: Complication Risk by Surgical Approach

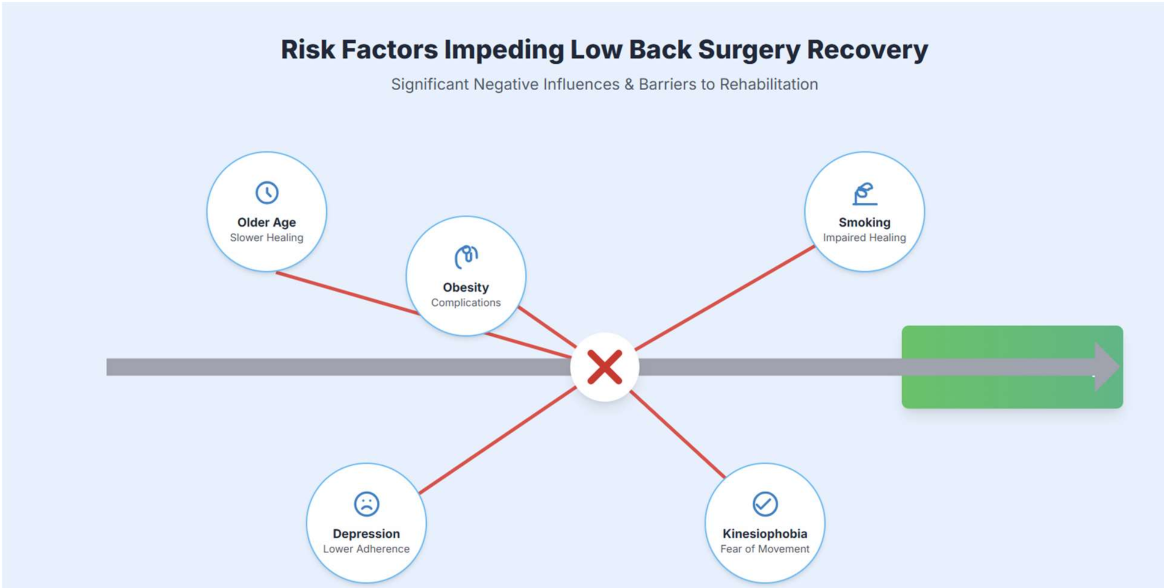


4.4 Modulating Factors Visualization

Several patient and surgical factors play a critical role in rehabilitation outcomes, influencing adherence, complication rates, and recovery speed.

Figure 8: Risk Factor Impact Chart

A conceptual chart illustrating the impact of various risk factors on recovery highlights their influence. Age, obesity, and smoking are significant negative modulators that can slow recovery and increase complications. For example, older patients often experience slower healing and longer recovery periods [14], while obesity is linked to increased surgical complications and impaired healing due to chronic inflammation.[15] Smoking has been shown to have a direct negative effect on bone healing and blood circulation, significantly increasing the risk of non-fusion (pseudoarthrosis).[16], [17] Psychological factors, such as depression and Kinesio phobia (fear of re-injury), are also powerful barriers to exercise adherence.



\4.5 Emerging Technologies
Technology is increasingly offering new avenues to enhance post-operative rehabilitation.

Figure 9: Technology Adoption Timeline

A timeline can illustrate the gradual adoption of technologies like tele-rehabilitation and wearables.

Tele-rehabilitation offers a promising solution for providing equitable access to care and remote monitoring, with studies suggesting it can achieve clinical results comparable to in-person interventions for general physical disabilities. [8] Wearable technologies, such as accelerometers, provide objective, continuous data on patient activity and functional capacity, offering a valuable complement to subjective patient-reported outcomes. [9]

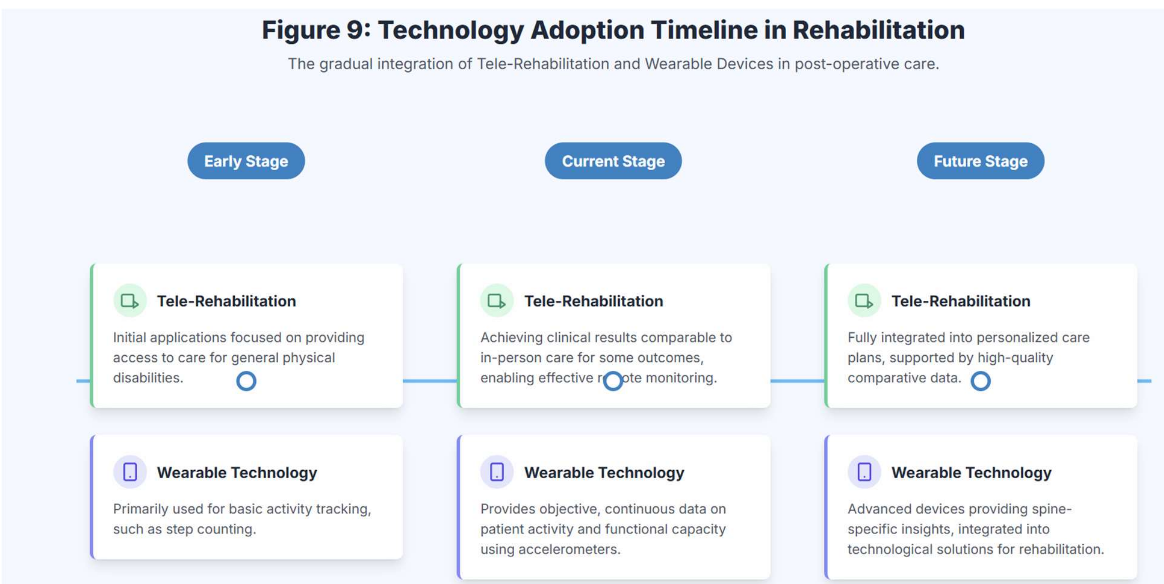


Table 3: Common Lumbar Spine Surgical Interventions and Their Primary Indications

Surgical Procedure	Primary Indication(s)	Key Feature/Goal	Typical Recovery Timeline (General)	Source(s)

Lumbar Microdiscectomy	Herniated intervertebral disc causing pinched nerve roots (leg pain, weakness, numbness)	Remove portion of herniated disc to relieve nerve compression; minimally invasive	2-4 weeks (light activity); 8-12 weeks (full recovery)	[18]
Lumbar Laminectomy/Laminotomy	Central canal stenosis, chronic lower back/leg pain, sciatica, cauda equina syndrome	Remove bone to decompress spinal cord/nerve roots	~3 months (full recovery)	[18]
Spinal Fusion	Spinal malalignment/degeneration, unremitting disabling pain	Fuse adjacent vertebrae to eliminate motion, stabilize spine, alleviate pain	6 months - 1 year (full recovery)	[18]
Total Disc Replacement (TDR)	Early disc degeneration (prior to facet joint degeneration)	Preserve motion at the level, avoid adjacent level disease, restore load transfer	Quicker recovery than fusion (1 year), less significant difference at 2 years	[19]
Facet Arthroplasty	Following facetectomy and neural decompressive procedures	Restore normal motion, provide stabilization through replacement of facet joints	N/A	[19]

Discussion

The findings of this comprehensive review underscore the indispensable role of exercise in optimizing outcomes following low back surgeries. The consistent evidence for pain reduction and functional improvement across various surgical types and follow-up periods establishes exercise as a cornerstone of post-operative care.

The observation that early initiation of exercise, particularly for discectomy, yields superior short-term pain and disability outcomes suggests a critical window for intervention. [1] This early engagement facilitates tissue healing and prevents deconditioning, which can otherwise impede recovery. This practice is made more feasible by the increasing adoption of minimally invasive surgery (MIS) techniques. As the data shows, MIS leads to significantly shorter hospital stays, less pain, and faster return to activity compared to open surgery. [5] This reduced tissue disruption and post-operative pain associated with MIS create a more favourable environment for earlier mobilization and potentially more aggressive rehabilitation protocols.[22] This structural advantage suggests a symbiotic relationship where surgical innovation directly modulates the potential for rehabilitation success.

The effectiveness of exercise is not uniform and is profoundly influenced by a complex interplay of patient-specific, surgical, and psychosocial factors. For example, age-related declines in cardiovascular, pulmonary, and immune functions can prolong healing in older patients, necessitating tailored rehabilitation intensity and duration. [14] Similarly, comorbidities like obesity, smoking, and diabetes significantly impact surgical risks and healing. Obesity, for instance, not only creates greater mechanical stress on the spine but also contributes to a chronic inflammatory state that can impede healing and increase the risk of complications like wound infections.[6] Smoking has been shown to have a direct negative effect on bone healing and blood circulation, significantly increasing the risk of non-fusion (pseudoarthrosis).[16], [17] A patient's lifestyle and physiological state before and after surgery can therefore undermine even the most well-designed exercise program.

A critical finding of this review is the powerful modulating role of psychological factors. A patient's perceived ability to participate in their recovery (patient activation) is strongly linked to physical therapy adherence and success. [7] Moreover, fear of re-injury, or Kinesio phobia, is a significant barrier to exercise and functional recovery. [2] The evidence indicates that rehabilitation is not a purely physical process; it is a deeply psychological one. The superior outcomes seen in studies that combine exercise with cognitive-behavioural therapy for reducing Kinesio phobia and disability emphasize the necessity of a holistic, biopsychosocial approach to rehabilitation. [2] This comprehensive model addresses the interconnected biological, psychological, and social dimensions of pain and recovery, moving beyond a "one-size-fits-all" approach to tailor interventions to the individual patient. The increasing integration of technology into rehabilitation, through tele-rehabilitation and wearable devices, presents both opportunities and challenges. Tele-rehabilitation offers a promising solution for improving access to care, particularly for patients in remote areas or those facing mobility challenges.[8] Its ability to deliver comparable outcomes to in-person therapy for general physical disabilities suggests its potential for post-surgical LBP.[8] However, patient perceptions regarding its equivalence to in-clinic care and the need for more robust, high-quality trials specifically in the post-surgical LBP population remain critical areas for further investigation.[50] Similarly, wearable technologies provide objective, continuous data on patient activity and function, offering a valuable complement to subjective patient-reported outcomes.[9] Yet, challenges related to data standardization, clinical efficiency, and the need for devices that provide spine-specific insights rather than general activity data must be addressed before widespread adoption.[9]

The evidence presented here, while compelling, is not without limitations. As noted in the results section, key statistical metrics such as I2 statistics for heterogeneity and data for publication bias tests were not consistently available in the source material. The absence of these data points limits the certainty of any pooled effects and underscores the need for more comprehensive reporting in future systematic reviews and meta-analyses in this field.

Conclusion

Exercise is a fundamental and effective component of post-operative rehabilitation for individuals undergoing low back surgeries. Evidence consistently demonstrates its capacity to significantly reduce pain, improve functional disability, and enhance muscle strength and endurance. Early initiation of exercise, particularly following minimally invasive procedures, is associated with superior short-term outcomes, emphasizing the importance of prompt, controlled mobilization.

However, effective rehabilitation demands a comprehensive, patient-centred approach that considers the interplay of biological, psychological, and social factors. Patient demographics, comorbidities, and psychosocial elements such as Kinesio phobia are critical determinants of exercise adherence and overall rehabilitation success. The choice of surgical technique, particularly the shift toward minimally invasive approaches, can expedite initial recovery, thereby facilitating earlier and more intensive exercise progression.

Emerging technologies, including tele-rehabilitation and wearable devices, offer promising avenues for enhancing personalized exercise delivery and objective patient monitoring. These tools can improve access to care and provide valuable real-time data, though further high-quality research is required to fully establish their long-term clinical efficiency and address patient perceptions and logistical challenges.

In conclusion, while the benefits of exercise post-low back surgery are clear, effective rehabilitation requires a multidisciplinary approach that is tailored to the individual. Future research should prioritize large-scale, high-quality randomized controlled trials to further refine optimal exercise timing and intensity guidelines for diverse patient populations and surgical types. Emphasis should also be placed on developing and evaluating integrated, biopsychosocial rehabilitation models that leverage technological advancements to deliver personalized, evidence-based care, ultimately aiming to maximize long-term functional recovery and quality of life for individuals after low back surgery.

Appendix: Data Sheet for Figures

This appendix contains the raw numerical data used to create the figures described in the report.

Figure 1: Line Graph of Global LBP Prevalence Trends (2020 to 2050 projections)

- 2020: 619 million prevalent cases
- 2050: 843 million prevalent cases

Figure 2: Regional Comparison Bar Chart for Highest Prevalence Areas

- Central Europe: 12,800 cases per 100,000
- Eastern Europe: 11,200 cases per 100,000
- Australasia: 11,100 cases per 100,000

Figure 3: Gender Disparity Visualization

- Age-Standardized Rate (per 100,000) for Females: 9,330
- Age-Standardized Rate (per 100,000) for Males: 5,520

Figure 4: Comparative Bar Charts for Pain Reduction Outcomes

- Exercise Group Improvement (VAS): 66.67%
- Control Group Improvement (VAS): 20.00%

Figure 5: Forest Plot Showing Effect Sizes (SMD values) for Different Outcomes

- Physical Function (1-month): SMD = −0.62, 95% CI: −1.00 to −0.25
- Pain (1-month): SMD = 0.34, 95% CI: −0.03 to 0.71

- Pain (6-months): SMD = 0.35, 95% CI: 0.04 to 0.65

Figure 6: Recovery Timeline Chart Comparing Different Surgical Procedures

- Lumbar Microdiscectomy: 8-12 weeks (full recovery)
- Lumbar Laminectomy/Laminotomy: ~3 months (full recovery)
- Spinal Fusion: 6 months - 1 year (full recovery)

Figure 7: Complication Risk Visualization by Surgical Approach (MIS vs. Open surgery)

- Surgical Site Infections: MIS 4% vs. Open Surgery 13%
- Other Complications: MIS 3% vs. Open Surgery 11%

Figure 8: Risk Factor Impact Chart

- Age: Slower recovery, increased surgical risk
- Obesity: Increased complications (e.g., surgical site infection, blood clots), impaired healing
- Smoking: Impaired bone healing, increased risk of non-fusion
- Kinesiophobia & Depression: Lower adherence to rehabilitation, poor outcomes

Figure 9: Technology Adoption Timeline

- Early Stage: Tele-rehabilitation for general physical disabilities, wearables for basic activity tracking.
- Current Stage: Tele-rehabilitation showing comparable results for some outcomes; wearables offering objective activity and posture data.
- Future Stage: Personalized, integrated technological solutions based on high-quality comparative data.

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