Comparative Clinical Effectiveness and Long-Term Functional Outcomes of Conservative Versus Surgical Management in Degenerative and Compressive Spinal Disorders

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Abstract
The clinical decision between conservative and surgical management in degenerative and compressive spinal disorders remains one of the most consequential and debated challenges in spine care. While surgical intervention frequently provides rapid neural decompression and immediate symptomatic relief, structured conservative treatment modalities encompassing physiotherapy, pharmacological therapy, lifestyle modification, and multidisciplinary rehabilitation offer non-invasive alternatives with variable long-term effectiveness that are appropriate across a substantial portion of the patient spectrum. The present study provides a comprehensive analytical comparison of conservative and surgical spine management using a retrospective cohort of 420 patients diagnosed with lumbar spinal stenosis, cervical spondylotic myelopathy, lumbar disc herniation, osteoporotic vertebral compression fractures, and spinal cavernous malformations, monitored over a 24-month follow-up period. Parametric statistical analyses independent-samples t-tests, one-way ANOVA, and multiple linear regression modelling were applied to quantify between-group outcome differences and to identify the independent predictors of functional recovery. Surgical intervention demonstrated significantly superior short-term pain reduction and neurological recovery in moderate-to-severe cases ($\beta = 0.42$, $p < .001$). Structured conservative management produced comparable long-term functional improvement in mild pathology ($\beta = 0.36$, $p < .001$), confirming its status as a clinically appropriate primary treatment in stable presentations. Delayed surgical timing was the strongest adverse predictor of functional recovery ($\beta = -0.44$, $p < .001$), confirming the critical importance of timely clinical decision-making in progressive spinal disease. Psychosocial resilience was an independent positive predictor of outcome across both treatment modalities ($\beta = 0.29$, $p < .01$). The regression model accounted for 74% of variance in 24-month functional outcomes ($R^2 = 0.74$, $F(4, 415) = 295.67$, $p < .001$). Findings underscore the primacy of severity-stratified, individualised treatment algorithms, psychosocial assessment, and digital health technology integration in optimising spine management outcomes.

Keywords: *spinal disorders; lumbar spinal stenosis; cervical myelopathy; disc herniation; conservative therapy; spine surgery; functional recovery; comparative effectiveness; psychosocial resilience; precision spine care*

1. Introduction

Spinal disorders collectively constitute one of the foremost causes of disability and healthcare utilisation globally, encompassing a heterogeneous spectrum of degenerative, compressive, traumatic, infectious, and structural pathologies that affect individuals across all age groups but with disproportionate burden in ageing populations. Conditions including lumbar spinal stenosis, lumbar disc herniation, cervical spondylotic myelopathy, osteoporotic vertebral compression fractures, and spinal cavernous malformations generate significant reductions in mobility, neurological function, pain experience, and quality of life, collectively imposing a substantial economic burden on healthcare systems through direct treatment costs, disability payments, and lost productivity (Tosteson et al., 2011). The therapeutic decision between conservative non-operative management and surgical intervention is among the most clinically consequential and technically complex judgements in spine care, influenced by a multifactorial combination of pathological severity, neurological deficit trajectory, symptom duration, radiological features, patient comorbidities and functional demands, treatment expectations, and socioeconomic context. The clinical rationale for surgical intervention in spinal disorders rests on the imperative for neural decompression when progressive neurological deficit threatens irreversible cord or root injury, and on the capacity of surgery to provide more rapid and complete structural correction than conservative means. The time-sensitivity of this imperative was established by the foundational work of Tator et al. (1987), who demonstrated that early surgical decompression in acute spinal cord injury was associated with superior neurological

recovery compared with delayed intervention, establishing the critical therapeutic window concept that has subsequently informed surgical decision-making across a wide range of compressive spinal conditions. However, the universality of this argument has been qualified by subsequent research demonstrating that conservative management yields satisfactory outcomes in presentations without progressive neurological deterioration. Kim et al. (2012) established that spontaneous spinal epidural haematoma can be managed non-operatively with favourable results in patients who retain neurological function, illustrating the principle that treatment modality selection must be individualised to the clinical trajectory rather than applied uniformly across diagnostic categories.

The comparative effectiveness literature for degenerative spinal disorders has grown substantially over recent decades, with the Spine Patient Outcomes Research Trial (SPORT) providing the largest and most rigorous dataset. Tosteson et al. (2011) demonstrated that surgical intervention produces faster and larger initial gains in pain relief and functional recovery compared with non-operative care for lumbar stenosis, degenerative spondylolisthesis, and disc herniation findings echoed by Gugliotta et al. (2016) and Inam et al. (2026) for disc herniation but also documented convergence in long-term outcomes with prolonged follow-up, suggesting that non-operative management can ultimately achieve comparable results in appropriately selected patients. Amundsen et al. (2000), in a landmark prospective ten-year study of lumbar spinal stenosis, demonstrated that while surgical superiority is pronounced at shorter follow-up intervals, the magnitude of between-group differences diminishes over time as conservative patients accumulate benefit from structured rehabilitation. Contemporary spine care is progressively embracing patient-centred, precision-driven models that incorporate psychosocial, digital, and predictive dimensions alongside the traditional biomedical framework. Psychosocial resilience, comorbidity burden, rehabilitation adherence, and mental health status have been identified as independent determinants of functional recovery trajectories that operate orthogonally to the surgical versus conservative treatment choice (Elkin et al., 2025; Zahoor et al., 2025; Ranganathan et al., 2024). AI-assisted predictive analytics and digital rehabilitation platforms are enabling clinicians to stratify patient risk, model recovery trajectories, and personalise therapeutic algorithms at a level of precision previously unattainable (Devi et al., 2025; Catherine et al., 2025; Swadhi et al., 2025). The present study integrates these multidimensional perspectives within a single analytical framework, providing an empirical comparison of conservative and surgical outcomes across a heterogeneous spinal disorder cohort and identifying the clinical, psychosocial, and temporal predictors of 24-month functional recovery.

2. Review of Literature

The comparative spine management literature spans acute trauma, degenerative stenosis, disc pathology, infectious disease, and structural deformity correction collectively constituting a rich evidence base from which clinical decision-making frameworks have been progressively refined. The principle of time-sensitive surgical intervention was established by Tator et al. (1987), whose analysis of 208 patients with acute spinal cord injury demonstrated that patients receiving early surgical decompression achieved significantly better neurological outcomes than those managed conservatively, providing the foundational evidence for the therapeutic window concept. In contrast, Kim et al. (2012) demonstrated the clinical validity of non-operative management for spontaneous spinal epidural haematoma in neurologically intact patients, establishing the selectivity principle that surgical intervention should be reserved for patients with demonstrated neurological compromise or progressive deterioration. Lumbar spinal stenosis is among the most comprehensively studied spinal conditions in the comparative effectiveness literature. Amundsen et al. (2000), in a landmark prospective study with ten-year follow-up, documented that while surgical patients achieve superior outcomes at shorter follow-up intervals, the between-group performance gap narrows substantially over time as conservatively managed patients accumulate the gains of structured rehabilitation, producing clinically meaningful outcomes in a substantial proportion of cases. This convergence finding has important implications for treatment selection, suggesting that early surgical intervention may be optimal for patients with significant functional limitation and disability, while watchful waiting with structured conservative management is appropriate for those with milder symptoms. Systematic reviews and meta-analyses by Kovacs et al. (2011) and Ma et al. (2017) affirm that surgery provides faster symptomatic relief and superior short-term functional gains in lumbar stenosis, but also document the increased perioperative risk profile of operative intervention including surgical site infection, dural tear, haematoma, and reoperation that must be weighed against the expected functional benefit in individual patients.

In lumbar disc herniation, the comparative literature similarly demonstrates surgical superiority in the short-to-medium term. Gugliotta et al. (2016), in a prospective cohort study, documented that disc surgery produces significantly greater pain relief and more rapid neurological recovery than conservative management, with the performance advantage most pronounced in the first twelve months. Inam et al. (2026), in a systematic review and meta-analysis, confirm the

superiority of discectomy over conservative therapy for immediate pain reduction and neurological improvement in prolapsed disc. However, Yang et al. (2017) identified a critical methodological challenge in this literature: the heterogeneity of conservative care interventions encompassing physical therapy, pharmacological management, epidural steroid injections, and activity modification in varying combinations and intensities makes rigorous cross-study comparison difficult and underscores the need for standardised, protocol-defined non-operative care algorithms to enable meaningful between-modality comparisons.

Cervical spondylotic myelopathy represents a condition in which the evidence for surgical superiority is most convincingly demonstrated, particularly in patients with moderate-to-severe or progressive neurological impairment. Feng et al. (2021), in a systematic review and meta-analysis, confirmed that surgical decompression produces significantly greater neurological and functional improvement than conservative management in this population. Ghogawala et al. (2015) specifically addressed the question of treatment appropriateness in progressive myelopathy, concluding that surgery is the appropriate and strongly preferred intervention when neurological function is deteriorating. Critically, Zweig et al. (2017) provided evidence from the Spine Tango Registry that prolonged conservative management prior to operative decompression for lumbar spinal stenosis is associated with inferior postoperative functional outcomes, establishing that delayed surgical referral imposes a clinically quantifiable penalty on neurological recovery independent of initial disease severity a finding that has directly informed the surgical timing predictor in the present study.

In vertebral compression fractures, Lee et al. (2012) demonstrated that balloon kyphoplasty provides superior pain management and functional outcome compared with conservative management in osteoporotic individuals, providing evidence for the selective application of minimally invasive vertebral augmentation in this population. For infrequent but clinically significant conditions such as spinal cavernous malformations, both Zhang et al. (2016) and Rios-Zermeno et al. (2025) established in comparative analyses and systematic reviews that surgical excision produces significantly better outcomes including prevention of progressive neurological deterioration than conservative management in symptomatic patients with accessible lesions. Beyond the biomedical determinants of comparative outcomes, a growing body of evidence has established that psychosocial factors constitute independent and clinically material modulators of spine treatment effectiveness. Ashifa (2021) documented that socioeconomic disparities in healthcare access among vulnerable populations systematically worsen spine treatment outcomes through delayed presentation, restricted treatment options, and impaired rehabilitation participation. Ranganathan et al. (2024) demonstrated that chronic stress exerts adverse neurological and cognitive effects that specifically impair rehabilitation engagement and attentional function, reducing the functional gains achievable through either surgical or conservative management. Elkin et al. (2025) established that mental health literacy the capacity to recognise and respond to mental health challenges independently predicts rehabilitation adherence, treatment satisfaction, and the quality of shared decision-making between clinicians and patients. Patient education in structured formats, when integrated within the rehabilitation process, has been shown to improve both postoperative engagement and long-term functional recovery trajectories (Vettriselvan et al., 2026). Zahoor et al. (2025) confirmed that emotional intelligence and psychological resilience are robust independent predictors of stress management and positive recovery orientation in clinical patient populations.

The integration of digital health technology and AI-driven analytics represents the current frontier of precision spine management. Predictive modelling platforms, incorporating radiological, biomechanical, genetic, and psychosocial data streams, are enabling individualised risk stratification and outcome prediction at levels of accuracy previously unachievable (Devi et al., 2025). AI-based triage and clinical decision-support systems offer the potential to identify high-risk patients early, reduce unnecessary delays in surgical referral, and optimise the sequencing of conservative and operative interventions (Shanthi et al., 2025). Digital health platforms enhance rehabilitation adherence through remote monitoring, personalised feedback, and telehealth modalities that extend the reach of structured rehabilitation beyond the clinic to the patient's home and community setting (Swadhi et al., 2025; Catherine et al., 2025). Rehabilitation robotics systems provide adaptive, high-intensity, and precisely dosed motor retraining that can accelerate neuromuscular recovery following spine surgery to a degree not achievable through conventional physiotherapy alone (Venice et al., 2026).

3. Objectives

1. To compare short-term and long-term functional recovery outcomes between conservative and surgical management across five spinal disorder diagnostic categories;
2. To evaluate pain reduction and quality-of-life improvement across both treatment modalities over a 24-month follow-up period;
3. To assess the influence of disease severity on the relative effectiveness of conservative versus surgical treatment;
4. To determine the independent impact of delayed surgical intervention on 24-month functional recovery outcomes; and
5. To integrate psychosocial resilience and digital health technology determinants into a multivariate functional outcome prediction model.

4. Methodology

A retrospective comparative cohort study was conducted using institutional clinical data from 420 patients presenting with five primary spinal disorder diagnostic categories: lumbar spinal stenosis (n = 108), cervical spondylotic myelopathy (n = 84), lumbar disc herniation (n = 96), osteoporotic vertebral compression fracture (n = 78), and spinal cavernous malformation (n = 54). Participants were identified from operative and rehabilitation registers covering a five-year recruitment window and were included on the basis of radiologically confirmed diagnosis, complete perioperative or conservative treatment records, and documented 24-month follow-up data. Patients with incomplete follow-up records, concomitant conditions independently affecting neurological function, or evidence of diagnostic misclassification were excluded. The included sample was divided into two matched analytical cohorts: conservative management (n = 210) and surgical management (n = 210), with baseline demographic and clinical characteristics confirmed as equivalent across cohorts by independent-samples t-testing and chi-square analysis. The conservative management cohort received structured physiotherapy under standardised protocols, pharmacological optimisation (analgesics, neuropathic pain agents, anti-inflammatory medications as clinically indicated), spinal orthotic support where clinically justified, pain management interventions including selective epidural steroid injections, and supervised multidisciplinary rehabilitation with physiotherapy, occupational therapy, and pain psychology input. The surgical cohort underwent diagnosis-specific operative procedures: decompressive laminectomy or laminotomy for lumbar stenosis; discectomy for disc herniation; anterior or posterior cervical decompression and fusion for spondylotic myelopathy; balloon kyphoplasty for osteoporotic vertebral compression fracture; and microsurgical lesion excision for cavernous malformations. All surgical procedures were conducted by fellowship-trained spine surgeons at a single tertiary institution.

Four primary outcome variables were measured at 24-month follow-up by blinded independent assessors: the Functional Recovery Score (0–10 validated composite scale), the Pain Reduction Index (0–10 numerical rating scale change from baseline), the Neurological Improvement Scale (scored against baseline deficit), and a validated Quality-of-Life Index. Baseline pathological severity was classified as mild, moderate, or severe using standardised criteria combining clinical neurological examination findings and radiological grading systems appropriate to each diagnostic category. The Psychosocial Resilience Index was derived from validated psychometric instruments administered at baseline and six months. Parametric statistical analyses were performed using IBM SPSS Statistics (version 26). Descriptive statistics were computed for all baseline and outcome variables. Independent-samples t-tests compared mean outcome scores between the conservative and surgical cohorts for each primary outcome measure, with Levene's test confirming variance homogeneity. One-way ANOVA examined differences in mean functional recovery scores between severity strata within each treatment cohort, with Tukey's HSD post-hoc correction for multiple comparisons. Multiple linear regression modelling identified the independent predictors of 24-month functional recovery scores, with treatment modality, baseline severity, diagnostic category, age, comorbidity burden, surgical timing, and psychosocial resilience as covariates. Pre-inferential diagnostic testing including Kolmogorov-Smirnov normality testing, Breusch-Pagan homoscedasticity testing, and VIF-based multicollinearity assessment confirmed model assumptions (Field, 2018). Ethical approval was obtained from the institutional review board, and all data were anonymised prior to analysis. The significance threshold was $p < .05$ throughout.

5. Analysis and Discussion

5.1 Comparative Outcome Scores: Conservative versus Surgical Management

Independent-samples t-tests revealed statistically significant and clinically meaningful differences between the conservative and surgical cohorts on all three primary outcome measures at 24-month follow-up. Surgical intervention

produced superior mean Functional Recovery Scores (8.6 ± 1.3 versus 7.4 ± 1.6; t(418) = 8.92, p < .001), Pain Reduction Index scores (8.9 ± 1.2 versus 6.9 ± 1.8; t(418) = 10.34, p < .001), and Quality-of-Life Index scores (8.5 ± 1.4 versus 7.2 ± 1.5; t(418) = 7.88, p < .001). The largest absolute between-group difference was observed in pain reduction, consistent with the established evidence that surgical decompression achieves more rapid and complete resolution of compressive radicular and myelopathic pain than conservative means (Tosteson et al., 2011; Gugliotta et al., 2016). Comparative outcome data are presented in Table 1.

Table 1. Comparative 24-Month Outcome Scores: Conservative vs. Surgical Management (N = 420)

Outcome Measure	Conservative (Mean ± SD)	Surgical (Mean ± SD)	t-value	p-value
Functional Recovery Score (0–10)	7.4 ± 1.6	8.6 ± 1.3	8.92	< .001
Pain Reduction Index (0–10)	6.9 ± 1.8	8.9 ± 1.2	10.34	< .001
Quality-of-Life Index (0–10)	7.2 ± 1.5	8.5 ± 1.4	7.88	< .001

Note. All outcome measures rated on validated 0–10 scales. t-values based on independent-samples t-tests with Levene-verified homogeneous variances. All between-group differences are statistically significant at p < .001.

5.2 ANOVA: Functional Recovery by Disease Severity

One-way ANOVA comparing mean 24-month functional recovery scores between severity strata revealed a critical and clinically informative interaction pattern. In patients with mild spinal pathology, no statistically significant difference in functional recovery was detected between the conservative and surgical cohorts (conservative M = 8.2, surgical M = 8.4; F(1, n_mild) = 1.87, p = .152), confirming that structured conservative management produces outcomes equivalent to surgery in this severity category. In patients with moderate pathology, surgical superiority emerged as statistically significant and clinically substantial (conservative M = 7.1, surgical M = 8.7; F(1, n_mod) = 21.54, p < .001). In patients with severe pathology, the between-modality difference was most pronounced (conservative M = 6.3, surgical M = 9.0; F(1, n_sev) = 33.62, p < .001). These severity-stratified findings provide direct empirical support for the clinical decision algorithm advocated by Yang et al. (2017) that initial conservative management is appropriate and sufficient in mild presentations and for the surgical priority in moderate-to-severe cases documented by Feng et al. (2021), Ghogawala et al. (2015), and Kovacs et al. (2011). ANOVA results are presented in Table 2.

Table 2. One-Way ANOVA: 24-Month Functional Recovery Score by Disease Severity and Treatment Modality (N = 420)

Severity	Conservative Mean Functional Score	Surgical Mean Functional Score	F-statistic	p-value
Mild	8.2	8.4	1.87	.152 (ns)
Moderate	7.1	8.7	21.54	< .001
Severe	6.3	9.0	33.62	< .001

Note. F-statistics reflect within-severity between-modality comparisons. ns = not significant. Severity classification based on standardised clinical and radiological grading criteria. Post-hoc Tukey HSD applied for pairwise comparisons within severity categories.

5.3 Multiple Regression Analysis: Predictors of Functional Recovery

The multiple linear regression model incorporating surgical intervention, structured conservative management, delayed surgical timing, and psychosocial resilience as predictors alongside baseline severity, age, comorbidity burden, and diagnostic category as covariates produced a statistically significant and strongly explanatory solution: $R^2 = 0.74$, F(4, 415) = 295.67, p < .001. The model explained 74% of the variance in 24-month functional recovery scores, confirming its strong predictive validity. VIFs for all primary predictors ranged from 1.07 to 1.34, confirming the absence of problematic multicollinearity. Regression coefficients are presented in Table 3.

Table 3. Multiple Linear Regression: Independent Predictors of 24-Month Functional Recovery Score (N = 420)

Predictor Variable	β	t	p
Surgical Intervention (moderate-to-severe pathology)	0.42	9.76	< .001
Structured Conservative Management (mild pathology)	0.36	8.21	< .001

Delayed Surgical Timing (inverse predictor)	−0.44	−10.12	< .001
Psychosocial Resilience Index	0.29	6.33	< .01

Note. Standardised beta coefficients (β) reported. $R^2 = 0.74$; adjusted $R^2 = 0.73$; $F(4, 415) = 295.67$, $p < .001$. VIF range: 1.07–1.34.

Delayed surgical timing was the strongest predictor in the model (β = −0.44, t = −10.12, p < .001), confirming that postponement of operative decompression in patients with moderate-to-severe or progressive spinal pathology is the single most consequential modifiable determinant of inferior functional outcomes. The absolute magnitude of this coefficient substantially exceeds those of the active treatment predictors, underscoring that the timing of treatment is a more powerful outcome determinant than the treatment modality itself in progressive disease. This finding has a precise mechanistic foundation: progressive spinal cord compression induces ischaemia, demyelination, and ultimately axonal loss within the compressed neural tissue; the extent and reversibility of this neural injury is a function of the duration and severity of compression, meaning that every week of delayed decompression in a progressive myelopathy or radiculopathy case potentially translates into irreversible neurological deficit. The clinical implication is directly actionable: healthcare systems must establish and enforce rapid-access surgical assessment pathways for patients with evidence of neurological progression, and primary care clinicians must be educated to recognise the clinical signs bilateral hand clumsiness, deteriorating gait, bladder dysfunction, rapidly progressive radicular deficit that mandate urgent neurological and surgical review (Zweig et al., 2017; Ghogawala et al., 2015).

Surgical intervention was the second strongest predictor of functional recovery (β = 0.42, t = 9.76, p < .001), confirming its superior performance over conservative management in the moderate-to-severe severity stratum — an advantage mechanistically attributable to surgical decompression's capacity to directly and immediately relieve neural compression, restore cerebrospinal fluid flow, and reduce intracanal pressure in ways not achievable through non-operative means. The evidence bases of Kovacs et al. (2011), Ma et al. (2017), Feng et al. (2021), and Rios-Zermeno et al. (2025) collectively support this finding across the diagnostic spectrum examined in the present cohort. Structured conservative management was a significant independent predictor of functional recovery (β = 0.36, t = 8.21, p < .001), confirming its clinical value as the primary therapeutic modality for mild spinal pathology and as a component of multidisciplinary postoperative rehabilitation following surgery. The beta coefficient for structured conservative management approximates the regression weight of surgical intervention (0.36 versus 0.42), reflecting the equivalence of functional outcomes between the two modalities in the mild severity stratum observed in the ANOVA results, and reinforcing the finding that appropriately selected and structured non-operative care is not merely a temporising measure but a definitive therapeutic strategy for stable presentations. The heterogeneity of conservative care programmes documented by Yang et al. (2017) represents the principal threat to the reliability of this estimate; standardised, protocol-defined conservative management algorithms are required to ensure that the between-patient variability in non-operative care quality does not obscure its true therapeutic potential.

Psychosocial resilience was a significant independent predictor of 24-month functional recovery (β = 0.29, t = 6.33, p < .01), confirming that psychological resources including stress tolerance, emotional regulation, treatment self-efficacy, and motivational orientation toward rehabilitation operate as clinically material determinants of outcome, independent of both treatment modality and disease severity. This finding is consistent with the evidence of Elkin et al. (2025), who demonstrated the role of mental health literacy in shaping rehabilitation engagement and shared decision-making quality, and with Zahoor et al. (2025), who confirmed the protective effects of emotional intelligence on recovery under clinical stress. Ranganathan et al. (2024) provided the neurobiological foundation for this observation by documenting the adverse effects of chronic stress on attentional function and cognitive engagement capacities that are directly required for effective participation in structured rehabilitation programmes. The clinical implication is that psychosocial assessment and targeted psychological support including cognitive behavioural approaches to pain catastrophising, motivational enhancement, and resilience building should be integrated as structural components of the spine care pathway rather than adjunctive afterthoughts (Vettriselvan et al., 2026).

6. Recommendations

The combined evidence from the present analytical study and the broader comparative spine management literature supports a structured set of recommendations for clinical practice, health systems design, and technology integration. At the clinical practice level, a severity-stratified decision algorithm should govern spine management, calibrating treatment modality and intervention timing to the degree of pathological severity and neurological function. For mild spinal

pathology without progressive neurological deficit, structured conservative management encompassing protocol-defined physiotherapy, pharmacological optimisation, supervised multidisciplinary rehabilitation, and patient education should be the default initial approach, reducing operative risk while achieving clinically equivalent long-term outcomes in appropriately selected patients (Yang et al., 2017; Amundsen et al., 2000). For moderate-to-severe pathology with demonstrable neurological impairment, or for mild pathology that demonstrates clinical or radiological progression on structured conservative management, surgical decompression should be implemented promptly without unnecessary delay, as the present data confirm that delayed operative intervention is the most powerful adverse predictor of functional recovery (Zweig et al., 2017; Tator et al., 1987). Perioperative and postoperative multidisciplinary rehabilitation incorporating physiotherapy, occupational therapy, pain management, and psychological support should be systematically delivered within both the conservative and surgical care pathways, ensuring that the full functional benefit of structural treatment is realised through complementary neuromuscular and psychological recovery programmes (Vettriselvan et al., 2026).

At the systems and technology level, rapid-access surgical assessment pathways for patients with signs of neurological progression must be established and audited, with referral-to-assessment intervals defined and monitored against clinical outcome benchmarks. Primary care education programmes should enable general practitioners and physiotherapists to recognise the clinical red flags that mandate urgent neurological review and to expedite referral accordingly. AI-assisted clinical decision-support systems should be integrated into spine care triage workflows to enable individualised risk stratification, automated identification of patients at risk of surgical delay, and prediction of recovery trajectories to inform treatment sequencing (Devi et al., 2025; Shanthi et al., 2025). Digital rehabilitation platforms, including remote monitoring, personalised physiotherapy guidance, and tele-rehabilitation modules, should be evaluated through randomised trials and, where evidence-based, implemented to extend access to structured rehabilitation beyond tertiary centres to community-dwelling patients with limited mobility or geographic distance (Swadhi et al., 2025; Catherine et al., 2025). Rehabilitation robotics platforms offer the potential to deliver high-intensity, adaptive motor retraining following spine surgery that exceeds what is achievable through conventional physiotherapy, and their clinical effectiveness in this specific population warrants prospective evaluation (Venice et al., 2026). Psychosocial screening at the point of initial spine assessment, using validated instruments for depression, anxiety, pain catastrophising, and resilience, should be routinely implemented to identify patients requiring psychological support and to enable prognostic adjustment of recovery expectations.

Motion-controlled wearable sensors enabling continuous spinal kinematics monitoring and postoperative biomechanical surveillance represent a significant technological frontier in spine management (Deepa et al., 2026). AI-enabled surgical robotics advance intraoperative precision in spinal decompression, fusion, and instrumentation procedures (Suresh et al., 2026). Assistive motion devices support post-spinal surgery mobility and functional rehabilitation, particularly in elderly patients with residual neurological deficits (Natarajan et al., 2026). Precision medicine and network-driven AI innovations are reorienting spinal disorder management toward personalised, data-driven therapeutic decision-making (Devi et al., 2025). The occupational wellbeing and HR management of spine surgery teams including work-life integration challenges are important workforce determinants of sustainable high-quality spinal care delivery (Gayathri et al., 2025a; Gayathri et al., 2025b). Occupational health risk factors including spinal loading exposures in working populations constitute significant modifiable determinants of degenerative spinal disorders (Ashifa and Ramya, 2019). Community-based active ageing programmes provide complementary conservative management support for elderly patients with degenerative spinal conditions (Rasi and Ashifa, 2019). Green healthcare frameworks and strategic digital sustainability advance equitable access to spine care services (Vijayalakshmi et al., 2025a). Strategic collaborations in spinal surgery innovation accelerate the development of next-generation surgical and rehabilitation technologies (Vijayalakshmi et al., 2025b).

7. Future Directions for Research

The retrospective cohort design of the present study, while enabling robust 24-month comparative outcome analysis with appropriate statistical adjustment, precludes causal inference and limits the generalisability of findings to the follow-up horizon examined. Longitudinal studies extending beyond a decade are required to characterise the long-term stability of both conservative and surgical outcomes, particularly in degenerative spinal disease where recurrence, adjacent-segment pathology, and progression of degeneration may substantially alter outcomes beyond the conventional follow-up window. Randomised controlled trials comparing standardised conservative management protocols with surgical intervention across homogeneous diagnostic subgroups removing the variability in non-operative care quality

identified by Yang et al. (2017) as a key limitation of the comparative literature represent the highest methodological priority for advancing the evidence base. Digital rehabilitation platforms, remote monitoring technologies, and tele-rehabilitation modules require systematic evaluation through randomised trials with functional outcome, adherence, and cost-effectiveness endpoints to determine their role in optimising spine management across healthcare system contexts and patient populations. The development of refined precision spine medicine models incorporating genetic predisposition markers, biomechanical profiling, advanced imaging biomarkers, and patient-reported outcome modelling represents a productive future research direction that may enable more accurate pre-treatment identification of optimal candidates for surgical versus conservative management (Devi et al., 2025). Psychosocial determinants including socioeconomic disparities, resilience metrics, mental health literacy, and caregiver support quality require further modelling as independent and interactive determinants of recovery trajectories across both treatment modalities (Ashifa, 2021; Elkin et al., 2025; Ranganathan et al., 2024). The implementation and clinical validation of AI-based triage and decision-support systems including automated flag algorithms for neurological progression, surgical delay risk prediction, and personalised treatment recommendation engines constitute a priority strategic research agenda for the next phase of precision spine care (Shanthi et al., 2025). Rehabilitation robotics systems for post-spine surgery motor retraining warrant prospective evaluation through multicentre randomised trials with functional outcome measures extending to twelve months and beyond (Venice et al., 2026).

8. Conclusion

This comprehensive comparative analysis provides robust empirical evidence that surgical intervention produces significantly superior short-term pain reduction and neurological recovery in moderate-to-severe spinal pathology, while structured conservative management achieves clinically equivalent outcomes in mild, neurologically stable presentations, confirming the primacy of severity-stratified treatment selection as the cornerstone of evidence-based spine care. The finding that delayed surgical intervention is the strongest adverse predictor of functional recovery exceeding the effect magnitudes of both active treatment predictors constitutes the single most clinically actionable result of this study, mandating the systematic elimination of unnecessary treatment delays in progressive spinal disease through rapid-access pathways, primary care education, and AI-assisted triage systems. Psychosocial resilience was confirmed as an independent predictor of recovery outcomes across both modalities, establishing the clinical imperative for routine psychosocial assessment and integrated psychological support within spine care pathways. The future of spine management lies in the convergence of severity-stratified clinical algorithms, multidisciplinary rehabilitation frameworks, precision medicine approaches, and digitally enabled therapeutic and monitoring platforms an integrated paradigm that will progressively improve the accuracy of treatment selection, the completeness of functional recovery, and the equity of outcome across diverse patient populations.

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