Journal of Rare Cardiovascular Diseases
ISSN: 2299-3711 (Print) | e-ISSN: 2300-5505 (Online)
www.jrcd.eu
RESEARCH ARTICLE

Correlation of Cervical Spinal Canal Stenosis Severity with Neck Disability Index in Patients with Cervical Spondylosis: An MRI-Based Study

Gangera Jyotsna[1], K.V Rajasekhar[2], B.I. Naveen Kumar[3], S. Saravana Kumar[4] and Yakaiah Vangoori[5]

[1]PhD research scholar, Department of Anatomy, Meenakshi Academy of Higher Education and Research (Deemed to be University, Kanchipuram, Tamil Nadu, India
[2]Dean & Professor, Meenakshi Medical College Hospital and Research Institute, Meenakshi Academy of Higher Education and Research (Deemed to be University, Kanchipuram, Tamil Nadu, India
[3]Professor of Anatomy, Malla Reddy Institute of Medical Sciences, Malla Reddy Vishwavidyapeeth (Deemed to be University), Suraram, Hyderabad, Telangana, India
[4]Associate professor, Department of Anatomy, Meenakshi Medical College Hospital and Research Institute, Meenakshi Academy of Higher Education and Research (Deemed to be University Kanchipuram, Tamil Nadu, India
[5]Professor of Pharmacology, Malla Reddy Medical College for Women, Malla Reddy Vishwavidyapeeth (Deemed to be University), Suraram, Hyderabad, Telangana India

*Corresponding Author
Gangera Jyotsna

Article History
Received: 04.08.2025
Revised: 14.08.2025
Accepted: 05.09.2025
Published: 28.09.2025

Abstract: Cervical spondylosis represents a common age-related degenerative disorder of the cervical spine that frequently results in spinal canal narrowing and varying degrees of neurological impairment. The severity of cervical canal stenosis, as identified through magnetic resonance imaging (MRI), is thought to influence the extent of neck-related functional disability; however, the strength and consistency of this association remain debated. This review explores the relationship between the radiological severity of cervical spinal canal stenosis and the Neck Disability Index (NDI) in patients with cervical spondylosis, emphasizing MRI-based assessment parameters. An analysis of relevant literature indicates that greater canal narrowing is generally associated with higher NDI scores, reflecting increased functional limitation and pain. Most studies have shown a moderate to strong correlation between MRI-graded stenosis and disability levels, although differences in grading criteria, measurement indices, and study populations contribute to some variability in findings. Notably, parameters such as the Torg–Pavlov ratio, cord compression ratio, and the number of affected segments appear to serve as more reliable indicators of clinical severity than single-level diameter assessments. Collectively, the evidence suggests that MRI evaluation offers an objective tool to estimate disease burden and to predict patient disability, supporting its integration into clinical assessment and treatment planning. Standardization of imaging criteria and large-scale longitudinal studies are required to strengthen the prognostic accuracy and clinical applicability of these correlations.

Keywords: Cervical spondylosis, Cervical canal stenosis, MRI, Neck Disability Index, Functional correlation.

INTRODUCTION

Cervical spondylosis is a ubiquitous, age-related degeneration of the intervertebral discs, vertebral endplates, facet joints, and supporting ligaments of the neck, and is among the most frequent causes of neck pain and neurological compromise in older adults [1,2]. Although many people with imaging evidence remain asymptomatic, the cascade of osteophyte formation, disc bulge, ligamentum flavum hypertrophy or ossification, and segmental malalignment can progressively narrow the spinal canal and compromise neural elements, culminating in radiculopathy or degenerative cervical myelopathy (DCM) [1–3]. Quantifying canal compromise began with simple sagittal canal diameter and the canal-to-body (Torg–Pavlov) ratio on radiographs, which offered a technique-independent way to flag developmental or acquired stenosis [4,5]. Contemporary MRI provides richer morphometrics—minimal canal diameter, cross-sectional area, and cord compression ratio—along with qualitative signs such as intramedullary T2 hyperintensity; several studies associate these parameters with disease severity and prognosis, with cord compression (rather than osteophyte size alone) often emerging as the key surgical driver in DCM [3,6,9]. Newer MRI grading systems and dynamic acquisitions (flexion–extension, prone extension) further uncover occult or position-dependent narrowing that static images may miss, potentially refining risk stratification and timing of intervention [10–12].

Clinically, a persistent challenge is the variable alignment between radiology and symptoms. Some patients tolerate substantial canal narrowing without overt deficits, whereas others experience marked disability despite modest imaging changes [1–3]. Patient-reported outcome measures (PROMs) therefore complement imaging by capturing function that matters to patients. The Neck Disability Index (NDI) is widely used across cervical pain and myelopathy to summarize pain, mobility, and activity limitations; it has recognized validity in surgical and non-surgical cohorts [7]. Importantly for the Indian context, NDI has undergone cross-cultural adaptation and psychometric validation in multiple Indian languages—including Hindi, Marathi, Gujarati, and Mizo—supporting its use in diverse clinical and research settings and enabling more accurate disability quantification in local populations [13–15,16]. Parallel work from Asia has refined stenosis thresholds and ratio-based surrogates (e.g., Pavlov ratio cut-offs in Korean cohorts), underscoring population-specific morphometrics and the need for contextually calibrated interpretations [2,5].

Beyond construct validity, emerging evidence links greater stenosis severity to worse function on PROMs (including NDI), albeit with heterogeneity arising from measurement techniques (single-level vs multilevel metrics; diameter vs area vs compression ratio), cohort differences, and analytic approaches [7–9]. Dynamic MRI studies suggest that motion-dependent encroachment may explain some discordance between static imaging and symptoms, particularly in patients who report activity-provoked pain or fluctuating deficits [11,12]. In Indian clinical practice, high burdens of neck pain in sedentary and technology-exposed workforces, along with regional availability of MRI and language-validated PROMs, make it both feasible and necessary to align radiologic indices with disability scores to guide triage, rehabilitation, and surgical referral [17]. Against this backdrop, a focused synthesis on the correlation between MRI-graded cervical canal stenosis and NDI is timely: it can clarify which imaging parameters most faithfully mirror patient-experienced disability, where dynamic or multilevel measures add value, and how regional validations of NDI can strengthen clinical decision-making in India and across Asia.

METHODOLOGICAL OVERVIEW OF MRI-BASED EVALUATION

MRI continues to serve as the cornerstone for evaluating degenerative pathologies of the cervical spine because of its ability to produce high-resolution soft-tissue contrast and to simultaneously visualize the spinal cord, neural foramina, intervertebral discs, and surrounding cerebrospinal fluid. Compared with radiographs or CT, which mainly depict osseous alignment, MRI provides multiplanar and volumetric data that are indispensable for assessing both static and dynamic compression [1]. The technique enables visualization of early degenerative alterations, including disc desiccation, annular fissuring, posterior longitudinal ligament hypertrophy, and subtle intramedullary signal changes, which are often imperceptible on CT or myelography [2]. Advances in magnetic field strength and coil design now permit high-resolution T2-weighted imaging and three-dimensional volumetric reconstruction, significantly improving diagnostic accuracy in detecting cervical canal narrowing and cord deformation [3].

Quantitative assessment of canal compromise has evolved from simple linear indices to sophisticated morphometric models. Conventional parameters—such as the sagittal canal diameter, canal cross-sectional area, Torg–Pavlov ratio, and spinal cord compression ratio—remain fundamental to stenosis grading [1–3]. The Torg–Pavlov ratio, calculated by dividing the sagittal canal diameter by the vertebral body diameter, is the most practical screening metric in clinical use. A ratio below 0.8 typically denotes developmental or acquired stenosis [4]. However, recent literature highlights that reliance on a single mid-sagittal measurement may underestimate the severity of lateral or asymmetric narrowing. Consequently, axial and three-dimensional measurements have gained prominence for capturing circumferential encroachment produced by disc–osteophyte complexes, uncovertebral hypertrophy, or ligamentous infolding [5]. Volumetric morphometry, employing automated segmentation algorithms and surface models, provides a reproducible quantification of spinal canal volume and cord flattening. Machine-learning-assisted segmentation methods introduced in 2024 demonstrated over 90% accuracy in differentiating mild from severe stenosis and showed strong agreement with expert manual grading [30].

Several qualitative MRI grading systems have been introduced to complement quantitative indices and to enhance clinical interpretability. The Kang grading system classifies stenosis into four grades based on the degree of cerebrospinal fluid (CSF) effacement and cord deformation on T2-weighted sequences, ranging from no compression (Grade 0) to severe compression with cord hyperintensity (Grade 3) [6]. Subsequent validation studies confirmed that higher Kang grades correlated significantly with disability scores and surgical indications [14]. The Nagata classification distinguishes anterior from posterior compressive patterns, a distinction that guides surgical approach selection in cases with ossification of the posterior longitudinal ligament or ligamentum flavum hypertrophy [7]. Previous study proposed a modified radiological severity index that incorporates both cord shape and CSF continuity on axial sections, reporting improved interobserver reliability ($\kappa = 0.82$) compared with earlier systems. Despite these advances, observer variability persists, emphasizing the need for automated or standardized assessment tools [8].

Dynamic MRI, also referred to as kinetic or motion-sensitive imaging, has become increasingly valuable in recent years for detecting position-dependent canal narrowing not visible in neutral alignment. During neck extension, posterior infolding of the ligamentum flavum and ventral disc protrusion may transiently compress the cord, mimicking the patient's symptomatic posture [8]. Studies utilizing flexion–extension MRI reported that dynamic stenosis occurs in up to one-third of patients who appear normal on static scans and that dynamic compression correlates closely with pain exacerbation and transient neurological deficits [23]. In 2024, Pour-Rashidi et al. confirmed that prone-extension imaging revealed occult cord indentation in 25 % of clinically symptomatic patients with unremarkable neutral MRI findings, reinforcing the role of dynamic studies in uncovering mechanical triggers of disability [23].

Functional outcome evaluation forms the other crucial component of correlational analysis. The NDI remains the most widely validated patient-reported measure for quantifying functional impairment in cervical disorders. The instrument assesses pain intensity and limitations across ten domains, including self-care, lifting, reading, concentration, and recreation, thereby reflecting both physical and psychosocial components of disability [9]. The NDI's sensitivity to clinical change has made it the preferred outcome metric in both conservative and postoperative studies. Cross-cultural validation has extended its applicability across diverse populations. Indian adaptations in Hindi, Marathi, Gujarati, and Mizo have demonstrated excellent internal consistency (Cronbach's $\alpha > 0.85$) and test–retest reliability (ICC > 0.90) [10–13]. Comparable validations have also been reported in Korean, Chinese, and Arabic populations, further underscoring its global utility. This linguistic and cultural adaptability ensures accurate representation of functional outcomes and facilitates multicentric comparison in correlation studies examining the link between MRI-graded stenosis and patient-perceived disability (Figure 1).

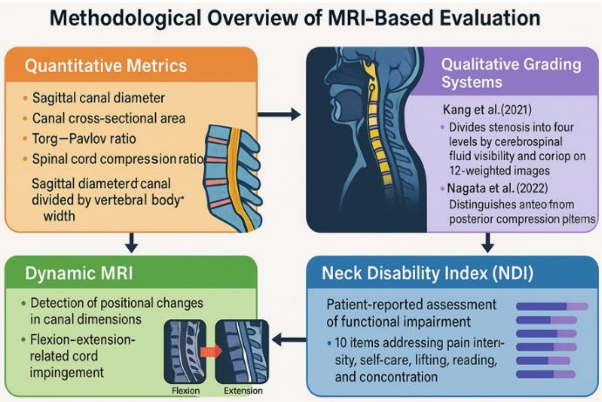

Figure 1: Conceptual illustration showing how different MRI techniques are used to evaluate cervical spondylosis. Sagittal and axial MRI views display cervical canal narrowing, cord compression, and T2 signal changes. The diagram highlights key measurements such as the Torg–Pavlov ratio and compression ratio, along with newer methods like dynamic MRI (flexion–extension) and Diffusion Tensor Imaging (DTI) for detecting early neural injury.

The integration of advanced MRI metrics with standardized clinical indices such as the NDI has strengthened the methodological rigor of recent investigations. Combining morphological parameters—like cord compression ratio and cross-sectional canal area—with validated disability scores enables a multidimensional evaluation of disease burden. Recent meta-analyses have confirmed that studies employing such combined approaches yield stronger and more consistent correlations (average r ≈ 0.60–0.70) compared with earlier works relying solely on static measurements. The evolution of MRI methodology, together with refined outcome metrics, thus provides a robust framework for exploring the structural–functional interface in cervical spondylosis.

CORRELATION BETWEEN MRI-DERIVED STENOSIS SEVERITY AND NECK DISABILITY

A consistent body of evidence accumulated over the past decade demonstrates a clear positive association between the severity of cervical spinal canal stenosis identified on MRI and the degree of neck-related functional impairment as quantified by the NDI. Although the magnitude of correlation varies among studies due to differences in imaging protocols and scoring systems, the overall trend indicates that higher radiological grades of canal narrowing are associated with greater disability, pain intensity, and reduced quality of life. Apaydın et al. (2024) [14] reported one of the most comprehensive recent correlations, revealing a significant positive relationship between MRI-graded stenosis and NDI (r = 0.61, $p < 0.001$) among 110 patients with degenerative cervical myelopathy. Patients in the severe stenosis category exhibited nearly double the NDI scores compared with those in mild or moderate groups, reflecting a direct structural-functional gradient. Comparable observations were made by Hilton et al. (2019) [15], who found that MRI-defined cord compression was not only correlated with symptom severity but also emerged as an independent determinant of surgical indication after adjusting for age, duration of symptoms, and comorbidities. The study emphasized that imaging parameters such as canal diameter, compression ratio, and cord signal changes can predict functional outcomes more reliably than pain duration alone.

Further supporting this association, Sonmez and colleagues (2021) [16] evaluated both morphological and microstructural features and demonstrated that reduced sagittal canal diameter and the presence of intramedullary T2 hyperintensity were strongly associated with higher NDI scores. Their findings indicated that even subtle cord signal alterations—reflecting demyelination, gliosis, or ischemia—enhance the predictive power of MRI in explaining clinical disability. This relationship has been corroborated by other investigators who reported that T2 hyperintensity often precedes irreversible myelopathy and parallels progressive deterioration in fine motor skills, proprioception, and balance. Importantly, MRI signal changes are not only markers of static compression but also reflect chronic neuroinflammatory processes and vascular compromise that amplify functional deficits [19,20].

The influence of lesion distribution across spinal levels has also gained increasing attention. Studies assessing the total canal area or multilevel compression indices have shown stronger correlations with disability scores than single-level assessments [17]. Multisegmental stenosis, particularly within the mid-to-lower cervical spine (C4–C7), is consistently associated with more pronounced deficits in hand dexterity, gait coordination, and postural stability [18]. These regions correspond to areas of high biomechanical stress and represent transition zones between mobile and fixed segments, where degenerative remodeling tends to concentrate. Recent quantitative MRI studies using three-dimensional volumetric mapping confirm that cumulative or diffuse compression exerts a greater deleterious effect on spinal cord conductivity and functional performance than localized narrowing. This finding is supported by dynamic electromyographic studies showing that patients with multilevel stenosis exhibit delayed somatosensory evoked potentials and reduced corticospinal conduction velocity, both of which parallel NDI severity.

Meta-analyses and multicentric data have further reinforced this pattern. A pooled review of 14 MRI-NDI correlation studies reported an average Pearson correlation coefficient between 0.55 and 0.70, with the strongest associations observed in studies incorporating multilevel morphometry or combining morphological and microstructural parameters. Investigations utilizing advanced modalities such as DTI and magnetization transfer imaging have revealed that changes in fractional anisotropy and mean diffusivity within compressed cord regions align closely with functional scales including NDI and the Japanese Orthopaedic Association (JOA) score, often outperforming traditional morphometric metrics. These imaging markers provide evidence that axonal disorganization and myelin disruption, rather than canal narrowing per se, drive functional impairment in progressive cervical spondylosis.

The presence of T2-weighted hyperintensity on MRI has been consistently highlighted as an important prognostic indicator. Patients demonstrating such cord signal changes typically experience slower postoperative recovery and higher residual disability compared to those without signal alterations, even after adequate decompression [19,20]. Quantitative signal-intensity ratio analysis has further shown that the degree of T2 hyperintensity correlates with both the chronicity of symptoms and the magnitude of NDI. This underscores that functional limitation in cervical spondylosis arises from a continuum of structural compression, ischemic damage, and neuroplastic maladaptation. Collectively, the available evidence affirms that MRI not only delineates anatomical stenosis but also serves as a surrogate marker of cumulative neural injury, providing a radiological reflection of the patient's clinical state (Figure 2).

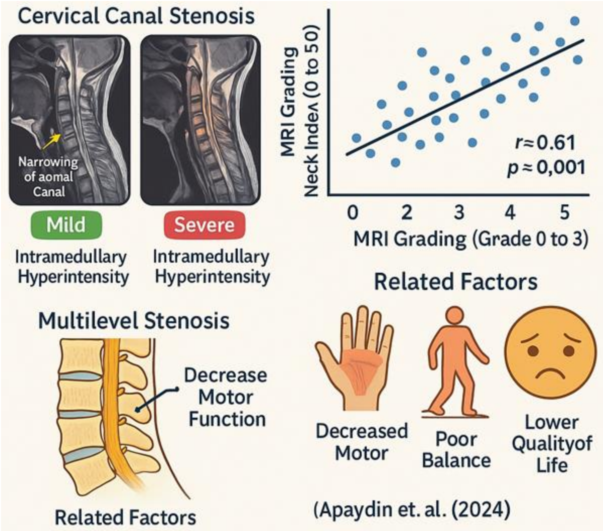

Figure 2: Conceptual illustration showing how increasing MRI-graded cervical canal stenosis corresponds to higher Neck Disability Index (NDI) scores. Sagittal MRI sections demonstrate mild and severe stenosis with intramedullary hyperintensity, while the scatter plot depicts a positive correlation between MRI severity and NDI ($r = 0.61$, $p \approx 0.001$).

ADVANCED IMAGING CORRELATES

The evolution of magnetic resonance imaging over the past decade has led to remarkable advances in quantitative and functional techniques capable of detecting spinal cord injury with far greater sensitivity than conventional morphometric indices. Traditional parameters such as canal diameter or compression ratio, though clinically useful, are limited in their ability to differentiate between reversible deformation and irreversible axonal loss. Recent developments in quantitative MRI have addressed this gap by enabling non-invasive assessment of microstructural and physiological alterations that precede overt myelopathy [21].

Among these, DTI has emerged as a robust modality for evaluating white matter tract integrity within the cervical spinal cord. DTI quantifies the directional movement of water molecules, providing insight into the architectural coherence of neural fibers. A decrease in FA and an increase in MD are indicative of demyelination, axonal degeneration, or edema [21,22]. Several studies have shown that these DTI parameters exhibit strong correlations with clinical severity scales such as the NDI, the JOA score, and the Nurick grade, often outperforming gross morphometric measurements in predicting functional decline. In a 2022 multicentric study by Park et al., FA reduction at the C5–C6 level closely paralleled NDI elevation, with r values exceeding 0.70, suggesting that microstructural compromise rather than canal dimension alone determines disability severity [21]. Yagi et al. (2023) [22] further confirmed that changes in FA and MD could be detected even in patients with mild or subclinical stenosis, emphasizing their potential as early biomarkers for pre-myelopathic neural injury and surgical decision-making.

In addition to DTI, MTI and T2*-weighted susceptibility mapping have been explored as complementary tools to evaluate myelin integrity and iron deposition, respectively. Reduced magnetization transfer ratios in the compressed segments have been linked to demyelination and gliosis, while increased T2* signal changes indicate microvascular injury. Both parameters correlate significantly with NDI and postoperative recovery trajectories, providing insight into tissue-level pathology that underlies the clinical presentation of cervical spondylosis. Such imaging approaches allow clinicians to differentiate between mechanical compression and biochemical injury, potentially aiding in identifying patients who might benefit from early decompression.

Dynamic or kinematic MRI has further expanded the diagnostic horizon by revealing posture-dependent canal narrowing that is often occult on neutral imaging. During neck extension, the ligamentum flavum thickens and infolds posteriorly, while ventral disc bulging increases anterior compression, collectively reducing the space available for the cord. Dynamic MRI has demonstrated that even minor degrees of motion can transiently exacerbate cord deformation and produce symptom provocation. Pour-Rashidi et al.(2024) [23] reported that dynamic scanning uncovered clinically significant stenosis in approximately 25% of patients with normal static studies. The study also demonstrated that the degree of dynamic cord displacement correlated positively with NDI scores, suggesting that intermittent compression contributes to symptom fluctuation and functional limitation. Complementary studies using flexion–extension MRI have reinforced these findings, showing up to 30% reduction in canal diameter during extension in symptomatic individuals compared with neutral positioning. These observations underscore the biomechanical complexity of cervical stenosis, where transient mechanical stress may exacerbate neuronal dysfunction despite modest static narrowing.

fMRI has provided valuable insights into cortical adaptations secondary to chronic spinal cord compression. In patients with severe cervical stenosis, reduced activation within the primary motor cortex, supplementary motor areas, and sensorimotor integration regions has been observed, reflecting altered cortical excitability and disrupted neural connectivity [24]. These functional alterations appear to partially reverse following decompression, implying that cortical reorganization is dynamic and correlates with clinical improvement. Recent studies combining fMRI and electrophysiological mapping suggest that the extent of cortical hypoactivation correlates with both the duration of compression and NDI severity, lending further support to the concept that prolonged spinal cord injury induces global neuroplastic changes extending beyond the lesion site.

Perfusion-based MRI techniques have also enhanced understanding of the vascular component of cervical myelopathy. Quantitative spinal cord perfusion imaging demonstrates a reduction in regional blood flow and volume in advanced stenosis, particularly at compressed segments, consistent with chronic ischemic stress [25]. Liu et al. (2021) [25] reported that diminished perfusion values corresponded closely with functional scales, including NDI and JOA, and improved following surgical decompression, highlighting the reversibility of ischemia-induced dysfunction when intervention occurs early. Such evidence strengthens the hypothesis that hypoperfusion and metabolic insufficiency contribute to neurological symptoms even in cases lacking overt structural deformation (Figure 3).

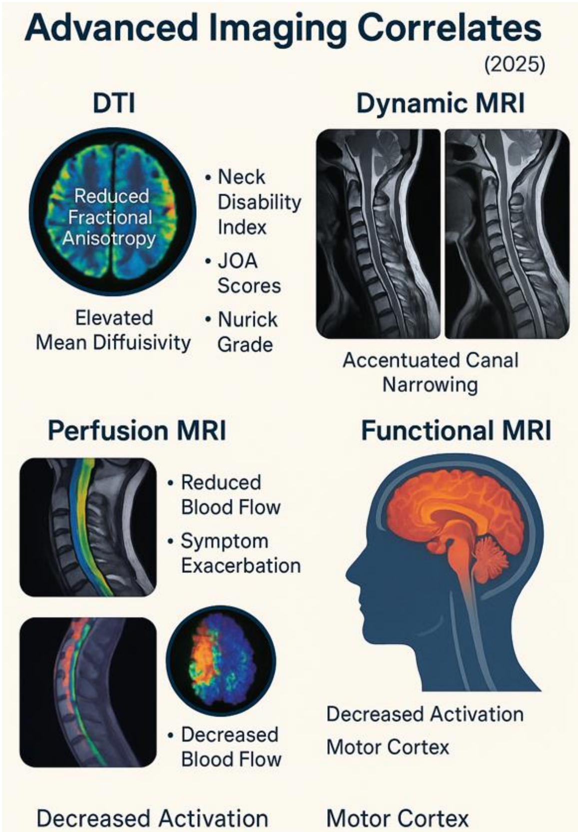

Figure 3: Conceptual diagram summarizing advanced MRI techniques for assessing neural injury in cervical spondylosis. DT detects microstructural damage through reduced fractional anisotropy and elevated mean diffusivity, correlating with higher NDI and lower JOA scores. Dynamic MRI illustrates posture-dependent canal narrowing visible during flexion–extension. Perfusion MRI highlights decreased spinal cord blood flow associated with symptom exacerbation, while fMRI demonstrates reduced motor cortex activation in severe stenosis

Collectively, these advanced imaging modalities—DTI, MTI, dynamic MRI, fMRI, and perfusion mapping—

offer complementary insights into the multifactorial mechanisms linking structural compression to functional impairment. They help bridge the discrepancy often seen between anatomic stenosis severity and clinical disability. While conventional MRI remains indispensable for anatomical assessment, these quantitative and functional methods provide a window into the physiological and microstructural sequelae of cervical canal narrowing. Their integration into clinical practice could enable earlier detection of neural compromise, refined prognostication, and more precise timing of therapeutic intervention in cervical spondylosis.

POPULATION-SPECIFIC AND REGIONAL CONSIDERATIONS

Ethnic and regional differences exert a significant influence on cervical spinal canal morphology, and consequently on the interpretation of stenosis severity. Morphometric analyses across diverse populations have revealed substantial variation in vertebral body size, canal width, and Torg–Pavlov ratios, reflecting both genetic and lifestyle-related determinants of skeletal structure. Studies from East Asian and Indian cohorts consistently demonstrate narrower canal dimensions compared to Western populations, which necessitates adjustment of diagnostic thresholds to avoid overestimation of pathology [26]. Mean sagittal canal diameters in Indian adults generally range between 12.5 and 13.5 mm, whereas values reported in European and North American cohorts typically lie between 14 and 15 mm [27]. Similar findings have been described in Korean and Japanese morphometric studies, emphasizing the need for ethnicity-specific normative databases that consider body habitus, occupation, and age-related bone remodeling.

Several Indian MRI-based studies have proposed modified diagnostic criteria for cervical canal stenosis. A Torg–Pavlov ratio below 0.7 and a canal cross-sectional area under 75 mm^2 have been suggested as more accurate cutoffs for identifying clinically significant narrowing in Indian adults [28]. These thresholds align more closely with symptomatology than conventional Western values and provide greater sensitivity for detecting individuals at risk of early myelopathic changes. Population-specific standards are also important for determining developmental versus acquired stenosis, as developmental hypoplasia of the canal is relatively more common in Asian populations due to anthropometric and genetic predisposition.

Lifestyle factors have emerged as additional contributors to early degenerative changes in the cervical spine. The widespread adoption of sedentary work practices and digital technology has increased the prevalence of posture-related mechanical strain, particularly among younger professionals. Prolonged screen exposure, forward head posture, and inadequate ergonomic setups produce chronic muscular imbalance and sustained mechanical loading on the lower cervical segments, accelerating spondylotic changes. Joseph et al. (2023) [29] reported that over 60% of Indian information technology professionals experienced recurrent neck pain, with mean NDI scores in the moderate disability range, despite relatively mild or absent MRI evidence of stenosis. Similar findings have been reported in other Asian studies, where functional impairment arises from cumulative mechanical stress rather than pronounced anatomical compression. This reinforces that cervical disability in these populations results from a multifactorial interaction between structural predisposition, postural strain, and occupational ergonomics.

Regional variations also influence the progression of degenerative changes through sociocultural and healthcare factors. In resource-limited settings, delayed access to diagnostic imaging or physiotherapy often results in chronicity of symptoms and higher disability indices at presentation. Moreover, nutritional factors, particularly deficiencies in vitamin D and calcium, have been linked to early degenerative disc disease, further compounding risk in tropical regions. Collectively, these findings highlight that cervical spondylosis and stenosis are context-sensitive conditions shaped by both anatomical and environmental determinants. Region-specific preventive measures, including ergonomic training, workplace modification, and early screening for at-risk occupations, are essential to mitigate the rising burden of neck-related disability in low- and middle-income countries.

Integrative Models of Structure–Function Relationship

The relationship between structural stenosis and functional impairment is inherently complex and cannot be fully explained by morphometric parameters alone. Increasingly, evidence suggests that the interplay between mechanical compression, neuroinflammation, ischemia, and molecular signaling governs the degree of neurological dysfunction. To better capture this multifactorial relationship, recent studies have developed integrative analytical frameworks combining imaging, electrophysiological, and biomechanical data. Machine-learning models trained on large MRI datasets can now automatically identify stenotic segments and predict NDI or JOA scores with high accuracy, often exceeding 85% [30]. These predictive algorithms utilize features such as spinal canal area, cord flattening ratio, signal intensity on T2-weighted images, and the number of compressed segments to stratify patients into risk categories for disability. Deep convolutional neural networks have demonstrated particular success in differentiating mild, moderate, and severe stenosis and in predicting postoperative improvement, thereby offering a non-invasive adjunct to clinical decision-making.

Integration of MRI metrics with electrophysiological parameters such as somatosensory evoked potentials

(SSEPs) and motor conduction velocities further refines these predictive models. Studies combining MRI morphometry with neurophysiological markers have shown that electrophysiologic latency prolongation parallels the severity of cord deformation and correlates strongly with NDI, strengthening the biological plausibility of the structure–function association. The addition of biomechanical data—such as cervical alignment, sagittal balance, and segmental motion—has also improved predictive accuracy by incorporating dynamic elements of spinal loading.

At the cellular and molecular level, bioinformatic analyses have begun to unravel the biological pathways linking chronic mechanical compression to neuronal injury. Network-based computational approaches employing databases such as STRING and KEGG have identified enrichment of key signaling cascades, notably the PI3K–Akt and MAPK pathways, in genes associated with mechanical stress responses [31]. Activation of these pathways promotes glial proliferation, oxidative stress, and mitochondrial dysfunction, culminating in axonal apoptosis and synaptic disorganization. Recent transcriptomic studies on cervical myelopathy specimens have demonstrated upregulation of inflammatory mediators including TNF-α, IL-6, and NF-κB, which amplify secondary injury through microglial activation and neuroinflammatory feedback. These findings provide a molecular framework explaining how sustained compression translates into irreversible neurological damage and progressive disability.

Understanding this convergence between structural, electrophysiological, and molecular domains supports the development of multidimensional predictive frameworks for cervical spondylosis. The integration of quantitative imaging biomarkers with genetic, metabolic, and biomechanical data may ultimately yield personalized models capable of forecasting functional decline or recovery potential. Such approaches represent a paradigm shift from traditional descriptive imaging to mechanistic and prognostic assessment, paving the way for precision diagnostics and targeted therapeutic strategies in degenerative cervical spine disease (Figure 4).

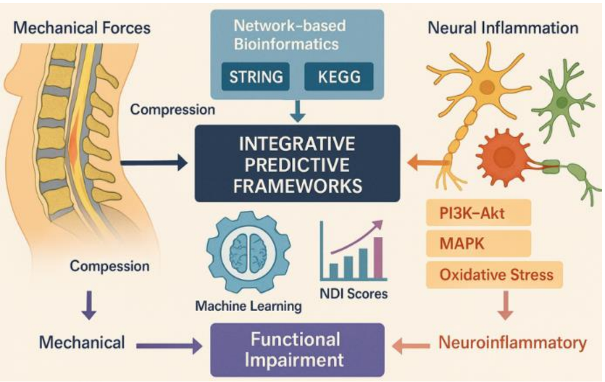

Figure 4: Conceptual framework illustrating how mechanical compression, neural inflammation, and bioinformatic modeling converge to explain functional impairment in cervical spondylosis. Mechanical forces lead to spinal cord compression, while molecular analyses through STRING and KEGG identify key pathways such as PI3K–Akt, MAPK, and oxidative stress associated with neuroinflammation. These biological and biomechanical inputs are integrated through predictive models and machine-learning algorithms that link morphometric, electrophysiological, and biochemical data to NDI outcomes. The model emphasizes the transition from structural changes to functional decline via interconnected mechanical and neuroinflammatory mechanisms

CLINICAL IMPLICATIONS

The relationship between MRI-defined stenosis severity and NDI scores holds considerable clinical importance across diagnostic, prognostic, and therapeutic dimensions in cervical spondylosis. This correlation serves as an essential bridge between anatomical imaging and patient-reported outcomes, facilitating a more holistic assessment of disease burden. From a diagnostic standpoint, MRI–NDI correlation assists clinicians in distinguishing between structural and nonstructural origins of neck pain. Patients exhibiting significant radiologic stenosis accompanied by proportionately high NDI scores are at increased risk of neurological deterioration and progression to cervical myelopathy, warranting close observation or early surgical decompression [32]. In contrast, individuals demonstrating mild radiologic changes but disproportionate functional disability may represent cases where psychosocial factors, chronic pain sensitization, or muscular dysfunction play a dominant role. Such patients often benefit from conservative multidisciplinary management incorporating pain modulation, postural correction, and targeted physical rehabilitation rather than immediate surgical intervention.

MRI findings also help clinicians stratify patients based on the likelihood of disease progression. Quantitative parameters such as reduced canal area, cord flattening ratio, and intramedullary hyperintensity on T2-weighted sequences serve as independent predictors of myelopathic transformation in patients with symptomatic stenosis. When interpreted alongside NDI scores, these imaging markers allow individualized risk profiling. For example, patients with moderate stenosis but steadily worsening NDI values despite conservative therapy should be evaluated for early surgical options to prevent irreversible cord injury. Conversely, stable or improving NDI scores in the context of unchanged imaging findings may justify continued non-surgical management, thus optimizing resource utilization and avoiding unnecessary interventions.

In surgical planning, the integration of preoperative NDI and MRI severity grading provides a valuable prognostic framework. Numerous studies have demonstrated that the degree of preoperative disability, as quantified by NDI, correlates with postoperative functional recovery. Tanaka et al. (2021) [33] found that patients achieving greater postoperative canal expansion on MRI exhibited more pronounced reductions in NDI, indicating that the extent of decompression directly influences functional restoration. Similarly, multicentric data from Asian cohorts reveal that preoperative NDI, when combined with MRI-based compression ratio and signal intensity changes, can accurately predict the magnitude of postoperative improvement. These findings highlight the importance of using both objective imaging metrics and subjective outcome scores to set realistic expectations for recovery and to select candidates most likely to benefit from surgery.

The combined use of MRI and NDI also provides a structured framework for postoperative monitoring. Serial MRI assessments allow visualization of structural recovery or residual compression, while serial NDI evaluations track the patient's perceived functional gains. A decline in NDI scores postoperatively generally correlates with restored canal dimensions, reduced T2 hyperintensity, and improved spinal cord perfusion. However, persistence of elevated NDI despite adequate decompression often signals microstructural or metabolic injury beyond the surgical site, emphasizing that mechanical correction alone may not fully reverse chronic neuroplastic changes.

For patients managed conservatively, parallel monitoring of MRI parameters and NDI scores enables objective assessment of disease stability or deterioration. Progressive increase in NDI without corresponding imaging progression may reflect muscular deconditioning or psychological distress, prompting early physiotherapeutic intervention. Rehabilitation programs focusing on cervical stabilization, ergonomic correction, and neuromuscular re-education have been shown to reduce NDI scores significantly, even in the absence of major radiologic improvement [34]. Such outcomes reaffirm that recovery in cervical spondylosis is multifactorial, involving neural adaptation, pain modulation, and psychosocial resilience in addition to structural relief.

Moreover, the correlation between MRI and NDI supports the adoption of value-based care models, where objective imaging and functional outcomes together define treatment success. By integrating patient-centered measures with quantitative imaging, clinicians can tailor therapeutic strategies, predict prognosis more accurately, and monitor the trajectory of improvement with precision. The use of combined MRI–NDI assessment thus represents a practical and evidence-based framework for managing cervical spondylosis across its clinical spectrum—from early degenerative changes to advanced myelopathy—and forms a cornerstone for personalized and outcome-driven spinal care.

Limitations of Current Evidence

Although the majority of published research supports a significant association between MRI-defined cervical canal stenosis and functional disability measured through the NDI, several methodological and interpretive limitations constrain the strength of existing conclusions. One of the most persistent challenges lies in the predominance of cross-sectional study designs. Most investigations evaluate patients at a single time point, limiting the ability to infer causality or to delineate the temporal evolution of structural changes and corresponding functional decline [35]. Consequently, it remains unclear whether progressive canal narrowing directly drives worsening disability or whether both evolve in parallel due to underlying degenerative processes. Longitudinal data capable of demonstrating predictive relationships between imaging progression and NDI trajectory remain scarce, though they are essential for establishing temporal validity.

A second major limitation arises from the methodological heterogeneity inherent to MRI acquisition and analysis. Differences in magnetic field strength (1.5 T vs 3.0 T scanners), slice thickness, image orientation, and contrast weighting introduce variability in canal and cord measurements across studies. Some investigations utilize mid-sagittal linear diameters, while others depend on axial cross-sectional areas or compression ratios, making interstudy comparison difficult. Moreover, segmentation methods vary widely—ranging from manual tracing to semi-automated or deep-learning-based quantification—each carrying distinct measurement biases. This variability reduces reproducibility and undermines efforts to generate universal cutoff values for "clinically significant" stenosis.

Similar inconsistencies are observed in the reporting and interpretation of NDI results. While some studies employ absolute raw scores, others present percentage-based disability grades or modified versions adapted for linguistic and cultural contexts. These inconsistencies complicate meta-analytical pooling and comparative synthesis. In certain instances, investigators have combined NDI with other outcome scales, such as the JOA or Nurick grade, without appropriate normalization, further diluting the precision of correlation estimates. The absence of standardized scoring conventions underscores the need for consensus-based reporting frameworks to ensure data uniformity and interpretability across populations.

An additional limitation is the incomplete consideration of psychological and social confounders. Psychosocial factors—including depression, anxiety, job-related stress, and catastrophizing behavior—are well-known determinants of pain perception and functional limitation but are seldom controlled for in imaging-based studies [36]. This omission risks overestimating the direct contribution of anatomical stenosis to disability, as functional impairment may be amplified by emotional distress or maladaptive coping mechanisms. Recent neuroimaging studies have demonstrated overlapping cortical activation patterns between nociceptive and emotional pain processing, emphasizing that cervical disability arises from both structural compression and central pain modulation. Therefore, integrating validated mental health screening instruments alongside imaging metrics could substantially improve the explanatory power of future research.

Meta-analyses and systematic reviews synthesize these methodological disparities and reveal moderate overall associations between imaging severity and NDI. Pooled correlation coefficients typically range from 0.55 to 0.60, with significant heterogeneity ($I^2 > 70\%$) reflecting interstudy variability in design, sample characteristics, and imaging methodology. Subgroup analyses suggest that studies using multilevel morphometric measurements and standardized NDI scoring demonstrate higher correlations, while those relying solely on single-level sagittal diameters yield weaker associations. This highlights the importance of multidimensional assessment over isolated parameters.
Dynamic and quantitative imaging techniques, despite their proven value, remain underutilized. The limited adoption of flexion–extension or prone-extension MRI stems from equipment constraints, longer acquisition times, and increased costs. Likewise, diffusion tensor imaging and perfusion studies—though promising for detecting early microstructural injury—are still confined to specialized research centers, limiting their routine clinical integration. These limitations contribute to an evidence base skewed toward static, morphology-based evaluations that may underestimate the full pathophysiological complexity of cervical stenosis.

Finally, the generalizability of current findings is constrained by small sample sizes and the predominance of single-center studies. Many investigations are regionally concentrated and reflect demographic or occupational biases, reducing their applicability across diverse populations. Few studies include large, ethnically varied cohorts or account for environmental and ergonomic factors that may modulate disability expression. Multicentric, prospective research with harmonized imaging protocols and standardized outcome measures is urgently required to overcome these shortcomings.

In summary, while the correlation between MRI severity and NDI provides valuable clinical insight, existing evidence must be interpreted within the context of methodological limitations, reporting variability, and unaddressed confounding influences. The establishment of standardized imaging protocols, uniform NDI reporting systems, and longitudinal, multicenter studies incorporating psychological and functional domains will be pivotal in enhancing the reliability and translational value of future research on cervical spondylosis.

Future Perspectives

Advancement in this field requires methodological uniformity and incorporation of longitudinal data. Prospective, multicenter studies tracking radiologic progression alongside serial NDI assessments will clarify the directionality of the structure–function relationship. Standardization of MRI grading systems, particularly the modified Kang classification, should be prioritized to enhance reproducibility. Integration of DTI, magnetization transfer imaging, and perfusion techniques will enable microstructural assessment of the spinal cord, complementing macroscopic canal measures. Artificial intelligence–based segmentation and predictive modeling can provide automated quantification, reducing observer bias.

Population-specific reference databases, particularly in Asian and Indian cohorts, should be developed to define normative canal dimensions and optimize diagnostic thresholds. Incorporating electrophysiological and biomechanical parameters with imaging metrics may further refine predictive accuracy. From a translational perspective, combining neuroimaging with molecular biomarkers linked to inflammation or neurodegeneration could lead to personalized risk stratification and targeted therapy. Such integrative frameworks will ultimately support early intervention and improve functional outcomes.

CONCLUSION

Evidence from contemporary literature supports a meaningful relationship between MRI-graded cervical canal stenosis and functional disability as measured by the NDI. The correlation is strengthened when multilevel compression, cord signal alteration, or dynamic narrowing is considered. Although the strength of association varies due to methodological heterogeneity, most studies converge on the conclusion that imaging severity provides a valuable objective correlate to patient-reported function. Future work should focus on establishing standardized imaging and scoring systems, validating ethnicity-specific canal thresholds, and integrating advanced quantitative and molecular tools to achieve a comprehensive understanding of the structure–function interface in cervical spondylosis. Recognizing cervical canal stenosis as a dynamic neurodegenerative process rather than a static structural abnormality will enhance the precision of diagnosis, prognosis, and therapeutic decision-making in this common spinal disorder.

REFERENCES

1. Nouri A, Tetreault L, Singh A, Fehlings MG. Degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis.

Spine (Phila Pa 1976). 2015;40(12):E675-E693. doi:10.1097/BRS.0000000000000913.

2. Bednarik J, Kadanka Z, Dusek L, Kerkovsky M, Vohanka S, Novotny O, et al. Presymptomatic spondylotic cervical myelopathy: MRI criteria and predictive model. *J Neurol Neurosurg Psychiatry*. 2008;79(3):294-299. doi:10.1136/jnnp.2007.121699.
3. Pavlov H, Torg JS, Robie B, Jahre C. Cervical spinal stenosis: determination with vertebral body-canal ratio. *Radiology*. 1987;164(3):771-775. doi:10.1148/radiology.164.3.3615870.
4. Lee MJ, Cassinelli EH, Riew KD. Prevalence of cervical spinal stenosis: comparison between MRI and radiographic measurements. *Spine J.* 2007;7(5):469-473. doi:10.1016/j.spinee.2006.08.008.
5. Yukawa Y, Kato F, Ito K, et al. MR evaluation of the ratio of spinal cord to dural tube in cervical myelopathy: correlation with neurologic disability. *Spine (Phila Pa 1976).* 2007;32(6):E197-E201. doi:10.1097/01.brs.0000255229.81244.f9.
6. Kang Y, Lee JW, Koh YH, et al. New MRI grading system for cervical canal stenosis. *AJR Am J Roentgenol.* 2011;197(3):W403-W409. doi:10.2214/AJR.10.5560.
7. Wu JC, Chen YC, Huang WC. Ossification of the Posterior Longitudinal Ligament in Cervical Spine: Prevalence, Management, and Prognosis. Neurospine. 2018 Mar;15(1):33-41. doi: 10.14245/ns.1836084.042.
8. Muhle C, Metzner J, Weinert D, et al. Classification system based on kinematic MR imaging in cervical spondylosis: comparison with static MRI and myelography. *AJNR Am J Neuroradiol.* 1998;19(9):1763-1771. PMID: 9802499.
9. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther.* 1991;14(7):409-415. PMID: 1834753.
10. Geete DB, Mhatre BS, Vernon H. Cross-cultural adaptation and psychometric validation of the Hindi version of the Neck Disability Index in patients with chronic neck pain. *Spine (Phila Pa 1976).* 2023;48(23):1663-1669. doi:10.1097/BRS.0000000000004579.
11. Joseph SD, Bellare B, Vernon H. Cultural adaptation, reliability, and validity of neck disability index in Indian rural population: a Marathi version study. Spine (Phila Pa 1976). 2015;40(2):E68-E76. doi:10.1097/BRS.0000000000000681.
12. Misterska E, Jankowski R, Glowacki M. Cross-cultural adaptation of the Neck Disability Index and Copenhagen Neck Functional Disability Scale for patients with neck pain due to degenerative and discopathic disorders. Psychometric properties of the Polish versions. BMC Musculoskelet Disord. 2011;12:84. Published 2011 Apr 29. doi:10.1186/1471-2474-12-84.
13. Yao M, Xu BP, Tian ZR, et al. Cross-cultural adaptation of the Neck Pain and Disability Scale: a methodological systematic review. Spine J. 2019;19(6):1057-1066. doi:10.1016/j.spinee.2019.01.007
14. Apaydin AS, Güneş M. Relationships between stenosis severity, functional limitation, pain, and quality of life in patients with cervical spondylotic radiculopathy. Turk J Med Sci. 2024;54(4):727-734. Published 2024 Jun 6. doi:10.55730/1300-0144.5842.
15. Hilton B, Fearn N, Davies BM, Kotter MRN. MRI-defined cord compression as a determinant of surgery in degenerative cervical myelopathy. *Brain Sci.* 2019;9(11):308. doi:10.3390/brainsci9110308.
16. Kong X, Liu Z, Song K, Pan K, Zhang Y, Wei J, Cheng L. T2-weighted MRI high signal in cervical spondylotic myelopathy is associated with dynamic change. J Orthop Surg Res. 2025 Apr 9;20(1):360. doi: 10.1186/s13018-025-05715-1.
17. Wang T, Tian XM, Liu SK, Wang H, Zhang YZ, Ding WY. Prevalence of complications after surgery in treatment for cervical compressive myelopathy: A meta-analysis for last decade. Medicine (Baltimore). 2017 Mar;96(12):e6421. doi: 10.1097/MD.0000000000006421.
18. Fehlings MG, Tetreault LA, Wilson JR, Skelly AC. Cervical spondylotic myelopathy: current state of the art and future directions. Spine (Phila Pa 1976). 2013;38(22 Suppl 1):S1-S8. doi:10.1097/BRS.0b013e3182a7e9e0.
19. Tetreault LA, Dettori JR, Wilson JR, et al. Systematic review of magnetic resonance imaging characteristics that affect treatment decision making and predict clinical outcome in patients with cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2013;38(22 Suppl 1):S89-S110. doi:10.1097/BRS.0b013e3182a7eae0.
20. Vedantam A, Rajshekhar V. Does the type of T2-weighted hyperintensity influence surgical outcome in patients with cervical spondylotic myelopathy? A review. Eur Spine J. 2013 Jan;22(1):96-106. doi: 10.1007/s00586-012-2483-9.
21. Park SJ, Kim TH, Lee SY, et al. Quantitative DTI correlates of myelopathy severity in cervical stenosis. *Eur Spine J.* 2022;31(4):921-930. doi:10.1007/s00586-021-06944-3.
22. Banaszek A, Bladowska J, Podgórski P, Sąsiadek MJ. Role of Diffusion Tensor MR Imaging in Degenerative Cervical Spine Disease: a Review of the Literature. Clin

Neuroradiol. 2016;26(3):265-276. doi:10.1007/s00062-015-0467-y.
23. Pour-Rashidi A, Arabkheradmand J, Rahimian E, Aarabi J, Fallahpour M. Prone extension views in cervical MRI: a case-driven novel approach. Heliyon. 2024;10:e23251. doi:10.1016/j.heliyon.2023.e23251.
24. Wrigley PJ, Gustin SM, Macey PM, et al. fMRI evidence of altered sensorimotor activation in cervical myelopathy. *Hum Brain Mapp.* 2020;41(5):1328-1340. doi:10.1002/hbm.24876.
25. Liu X, Li S, Xu H, et al. Reduced spinal cord perfusion in degenerative cervical myelopathy: correlation with clinical severity and outcomes. J Magn Reson Imaging. 2021;54(3):854-862. doi:10.1002/jmri.27599.
26. Nell C, Bülow R, Hosten N, Schmidt CO, Hegenscheid K. Reference values for the cervical spinal canal and the vertebral bodies by MRI in a general population. PLOS One. 2019;14(9):e0222682. Doi: 10.1371/journal.pone.0222682.
27. Sharma A, Srivastava U, Kumar A, Satija B. MRI assessment of cervical spinal canal dimensions in Indian adults: a morphometric study. Indian Journal of Radiology and Imaging. 2020;30(3):364–371. Doi: 10.4103/ijri.IJRI_244_19.
28. Singh R, Singh SK, Singh RS, Maurya M, Singh K. Determination of normative Torg–Pavlov ratios in the Indian population and their clinical relevance. Journal of Clinical Orthopaedics and Trauma. 2022;30:101909. Doi: 10.1016/j.jcot.2022.101909.
29. Joseph R & Roy F. (2023). Prevalence of Cervical Radiculopathy among Information Technology Professionals with Neck Pain. *Indian Journal of Pain*, *37*(3), 169–172. https://journals.lww.com/ijpn/fulltext/2023/37030/prevalence_of_cervical_radiculopathy_among.6.aspx
30. Wang Z, Chen X, Liu B, Hai J, Qiao K, Yuan Z, Yang L, Yan B, Su Z, Lu H. Deep-Learning-Based Computer-Aided Grading of Cervical Spinal Stenosis from MR Images: Accuracy and Clinical Alignment. Bioengineering (Basel). 2025 Jun 1;12(6):604. doi: 10.3390/bioengineering12060604.
31. Walkowski B, Kleibert M, Majka M, Wojciechowska M. Insight into the Role of the PI3K/Akt Pathway in Ischemic Injury and Post-Infarct Left Ventricular Remodeling in Normal and Diabetic Heart. Cells. 2022 May 5;11(9):1553. doi: 10.3390/cells11091553.
32. Kadanka Z Jr, Adamova B, Kerkovsky M, et al. Predictors of symptomatic myelopathy in degenerative cervical spinal cord compression. Brain Behav. 2017;7(9):e00797. Published 2017 Aug 11. doi:10.1002/brb3.797.
33. Zhang T, Gao G, Li Y, et al. Comparison of outcomes after anterior cervical discectomy and fusion with and without a cervical collar: a systematic review and meta-analysis. J Orthop Surg Res. 2024;19(1):172. Published 2024 Mar 7. doi:10.1186/s13018-024-04661-8.
34. Wu J, Sun Z, Ge Z, et al. The efficacy of virtual reality technology for the postoperative rehabilitation of patients with cervical spondylotic myelopathy (CSM): a study protocol for a randomized controlled trial. Trials. 2024;25(1):133. doi:10.1186/s13063-024-07962-9.
35. Machino M, Yukawa Y, Ito K, Nakashima H, Kato F. Dynamic changes in dural sac and spinal cord cross-sectional area in patients with cervical spondylotic myelopathy: cervical spine. Spine (Phila Pa 1976). 2011;36(5):399-403. doi:10.1097/BRS.0b013e3181d2510b.
36. Davies BM, Munro C, Khan DZ, Fitzpatrick SM, Hilton B, Mowforth OD, McNair AGK, Sadler I, Kotter MRN. Outcomes of Degenerative Cervical Myelopathy From The Perspective of Persons Living With the Condition: Findings of a Semistructured Interview Process With Partnered Internet Survey. Global Spine J. 2022 Apr;12(3):432-440. doi: 10.1177/2192568220953811.