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Structural MRI Parameters Associated with Lumbar Intervertebral Disc Degeneration: Analysis of Modic Changes, Paraspinal Muscle Fat Infiltration and Facet Joint Degeneration

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Abstract

Lumbar intervertebral disc degeneration (IVDD) is an important contributing factor for chronic low back pain. Recent evidence indicates that IVDD represents a "whole-organ" pathology involving multiple spinal structures, yet the relationships between structural magnetic resonance imaging (MRI) parameters remain incompletely characterised. This cross-sectional study included 100 patients with lumbar IVDD who underwent 3.0 T MRI. IVDD severity was graded using the Pfirrmann classification. Structural parameters including Modic changes, paraspinal muscle fat infiltration and facet joint degeneration were assessed independently by two radiologists. Statistical analyses included Spearman rank correlations, chi-square tests and logistic regression. Modic changes were present in 72% of patients and showed the strongest association with severe IVDD (Spearman $r = 0.532$, $P < 0.001$; $\chi^2 = 20.446$, $P < 0.001$). Patients with Modic changes had 6.11-fold higher odds [95% CI: 2.81–13.28] of severe disc degeneration compared to those without. The prevalence of severe IVDD increased progressively from 21.4% in Grade 0 to 76.9% in Grade 3 Modic changes. Facet joint degeneration, present in 92%, correlated significantly with IVDD grade ($r = 0.259$, $P = 0.009$; OR = 1.83, 95% CI: 1.15–2.91). Paraspinal muscle fat infiltration, present in 64%, showed a weak, non-significant association with IVDD severity ($r = 0.167$, $P = 0.097$). Lumbar IVDD represents a complex "whole-organ" condition. Modic changes showed the strongest structural association with severe disc degeneration ($r = 0.532$, OR = 6.11), supporting a strong coupling between disc degeneration and endplate pathology. These findings reinforce the "three-joint complex" concept and have implications for comprehensive treatment strategies targeting multiple spinal structures.

Keywords: Facet Joint Degeneration, Intervertebral Disc Degeneration, Lumbar Spine, Magnetic Resonance Imaging, Modic Changes.

Introduction

Lumbar intervertebral disc degeneration (IVDD) is highly prevalent and a leading cause of chronic low back pain, affecting up to 84% of adults during their lifetime (1, 2). Despite its considerable burden on healthcare systems and quality of life, the pathophysiology of disc degeneration remains incompletely understood and disease-modifying treatments are lacking (3). Advances in MRI have transformed our understanding of spinal degeneration. Previous researches demonstrated that disc degeneration does not occur in isolation but represents a "whole-organ" pathology involving the intervertebral disc, adjacent vertebral endplates, paraspinal musculature and facet joints (4). This concept has fundamentally changed our approach to understanding and treating disc degeneration. The Pfirrmann grading system (1), validated as a reliable method for assessing IVDD, incorporates multiple MRI features including disc structure, signal intensity, disc height and distinction between nucleus and annulus. However, while the system provides objective standardisation of disc degeneration severity, its correlation with individual patient symptoms is imperfect and it is used here as a research tool to quantify structural degeneration rather than as a diagnostic indicator of pain origin. Studies have shown that severe disc degeneration is associated with a two-fold increased risk of chronic low back pain (5). Clinically, these findings indicate that structural MRI assessment can help stratify patients for more targeted treatment

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planning, though imaging must always be integrated with clinical evaluation. Modic changes representing signal alterations in vertebral bone marrow adjacent to endplates (6), have emerged as important markers of spinal pathology. Three types are recognised based on MRI signal characteristics: Type 1 (bone marrow oedema/inflammation), Type 2 (fatty replacement) and Type 3 (subchondral sclerosis). These endplate alterations are thought to reflect disturbances in the disc–endplate interface, potentially both contributing to and resulting from disc degeneration (7, 8). The disc–endplate junction is critical for nutrient supply to the avascular disc and its disruption can initiate a progressive degenerative cycle (9, 10). Limitations of the Pfirrmann system include its subjective visual interpretation and potential inter-observer variability, which were addressed in this study through the use of two blinded expert radiologists and consensus resolution (1).

Paraspinal muscle degenerative changes have also been linked to disc degeneration (11). Atrophy and fatty infiltration of the multifidus and erector spinae muscles have been documented in patients with chronic low back pain and disc pathology. These changes may represent both a consequence of pain-related disuse and a contributing factor to spinal instability and further degeneration (12).

The facet joints and intervertebral disc constitute the "three-joint complex" of the spine (13), functioning as an integrated biomechanical unit. Degenerative changes in one component inevitably affect the others through altered load distribution and mechanical stress patterns. Comprehensive analysis of these interconnected pathologies is essential for treatment planning (14).

While individual structural parameters have been studied, comparative analyses examining their relative strengths of association with disc degeneration severity are limited. This study aimed to study systematically assess the distribution of structural MRI parameters (Modic changes, paraspinal muscle fat infiltration, facet joint degeneration) in patients with lumbar IVDD; examine the strength of association between each structural parameter and disc degeneration severity; determine comparative predictive strengths among structural parameters; and validate the "whole-organ" pathology concept of lumbar disc degeneration.

Methodology

Study Design and Participants

This cross-sectional analytical study was conducted at the Chettinad Hospital and Research Institute, Kelambakkam, Chennai, Tamil Nadu, India (GPS coordinates: 12.8006° N, 80.2209° E), between 2024 and 2025. The study protocol received approval from the Institutional Ethics Committee (Ref No: IHEC-II/0446/23, dated 16/10/2023) and was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to enrolment.

A cross-sectional design was employed because the primary objective was to characterise the distribution and co-occurrence of structural MRI parameters at a single time point within a clinically defined cohort. A longitudinal design would have been preferable to establish temporal relationships and causal inferences; however, this was not feasible within the study timeframe and resources. Accordingly, all associations reported are structural correlations and should not be interpreted as causal relationships.

A total of 100 consecutive patients presenting with chronic low back pain and radiological evidence of lumbar IVDD were enrolled. Patients were eligible if they were aged 18–75 years, had chronic low back pain of at least 3 months' duration and showed MRI evidence of lumbar disc degeneration. Exclusion criteria included: active infection or inflammatory arthropathy; history of spinal surgery, fracture, or malignancy; pregnancy; and contraindications to MRI. Patients with disc herniation or spinal stenosis were not excluded, as these conditions frequently coexist with IVDD; however, isolated disc herniation without evidence of degeneration on MRI was excluded.

The sample size of 100 was determined based on the anticipated prevalence of Modic changes (~60–70% in lumbar IVDD populations per prior literature) and a minimum detectable correlation coefficient of $r = 0.25$ at 80% power and $\alpha = 0.05$. A formal power analysis was not conducted prospectively; this is acknowledged as a limitation of the study design.

Clinical Assessment

All participants underwent comprehensive clinical evaluation including detailed medical history,

physical examination and pain assessment using the Visual Analog Scale (VAS) (15). Functional disability was assessed using the Oswestry Disability Index (ODI) (16). Demographic data including age, sex, body mass index (BMI), smoking status and occupational factors were recorded.

MRI Assessment

All participants underwent lumbar spine MRI using a 3.0-Tesla scanner (Siemens Magnetom Skyra) with a dedicated spinal coil. The imaging protocol included T1-weighted sagittal sequences (TR/TE: 450/8 ms), T2-weighted sagittal sequences (TR/TE: 3500/110 ms), T2-weighted axial sequences (TR/TE: 4000/110 ms) and a slice thickness of 4 mm with 1 mm gap.

Additional MRI acquisition parameters included a field of view (FOV) of 320 × 320 mm, matrix size of 320 × 256 and total acquisition time of approximately 25 minutes per patient.

Intervertebral Disc Degeneration Assessment

Intervertebral disc degeneration was graded at all lumbar levels (L1–L2 through L5–S1) using the validated Pfirrmann classification system (1). This five-grade scale assesses disc structure, distinction between nucleus and annulus, signal intensity and disc height:

Grade 1: Homogeneous bright white disc with normal height.

Grade 2: Inhomogeneous disc with clear nucleus–annulus distinction.

Grade 3: Intermediate grey disc with unclear nucleus–annulus distinction.

Grade 4: Dark grey disc with lost nucleus–annulus distinction and decreased height.

Grade 5: Black disc with collapsed disc space.

The most severely affected level for each patient was recorded for analysis. Severe IVDD was defined as Pfirrmann grades 4–5, consistent with prior literature (5). No patients with Pfirrmann Grade 1 were enrolled, as this grade represents normal disc morphology. Figure 1 shows the Pfirrmann grading system used for assessment of intervertebral disc degeneration.

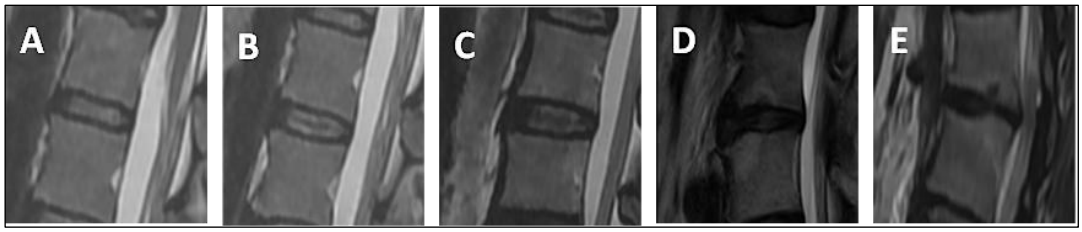

Figure 1: Pfirrmann Grading System for Intervertebral Disc Degeneration. (A) Grade 1: Homogeneous Bright Disc Signal with Normal Height, (B) Grade 2: Inhomogeneous Disc with Clear Nucleus–Annulus Distinction, (C) Grade 3: Intermediate Grey Signal with Unclear Nucleus–Annulus Distinction, (D) Grade 4: Dark Grey Disc with Lost Nucleus–Annulus Distinction and Reduced Height, (E) Grade 5: Black Disc with Collapsed Disc Space, Representing the Most Advanced Form of Degeneration

Modic Changes Assessment

Modic changes were classified according to the original system (6) into three types based on T1- and T2-weighted signal characteristics: Type 1, hypointense on T1 and hyperintense on T2 (bone marrow oedema/inflammation); Type 2, hyperintense on T1 and iso- or hyperintense on T2 (fatty replacement); and Type 3, hypointense on both T1 and T2 (subchondral sclerosis). Patients were categorised into Grade 0 (no change), Grade 1 (Type 1), Grade 2 (Type 2), or Grade 3 (Type 3) based on the predominant change pattern. Representative MRI features of Modic endplate changes are presented in Figure 2.

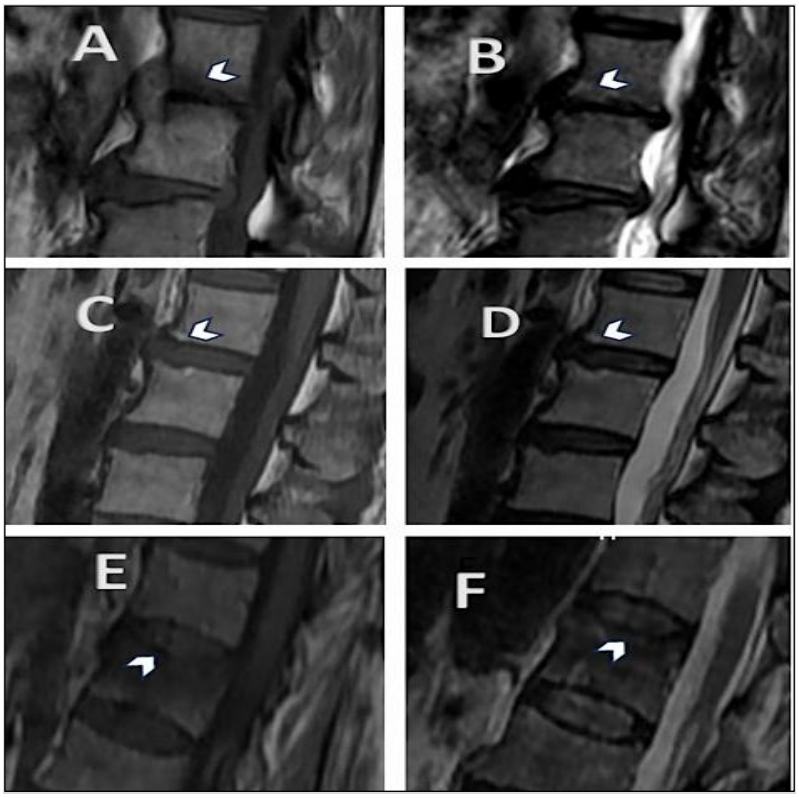

Figure 2: Modic Endplate Changes (Arrows) Assessed on T1- And T2-Weighted Sagittal MRI. (A and B) Type 1 Changes: Hypointense on T1 And Hyperintense on T2, Consistent with Bone Marrow Oedema and Inflammation, (C and D) Type 2 Changes: Hyperintense on T1 And Iso- To Hyperintense on T2, Reflecting Fatty Replacement of Bone Marrow, (E and F) Type 3 Changes: Hypointense on Both T1 And T2, Indicating Subchondral Bone Sclerosis

Paraspinal Muscle Degeneration Assessment

Paraspinal muscles including the multifidus and erector spinae were graded on a five-point scale using the Goutallier Classification System (GCS) (17), applied to T2-weighted axial sequences: Grade 0, no fat infiltration; Grade 1, fatty streaks present; Grade 2, fat evident but proportionally less than muscle tissue; Grade 3, fat and muscle in equal proportions; and Grade 4, fat exceeding muscle volume. Figure 3 illustrates the grading pattern of paraspinal muscle fat infiltration based on Goutallier scale.

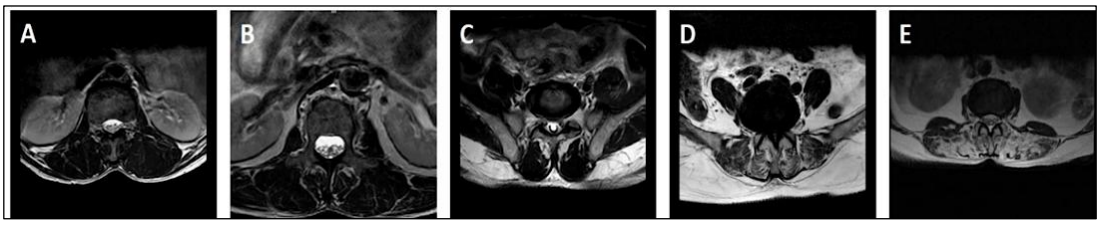

Figure 3: T2-weighted axial MRI Images Illustrating Goutallier Grading of Paraspinal Muscle Fat Infiltration. (A) Grade 0: Normal Muscle, No Fat Infiltration, (B) Grade 1: Fatty Streaks Within Muscle Tissue, (C) Grade 2: Evident Fat but Proportionally Less Than Muscle, (D–E) Grades 3–4: Fat Equal to or Exceeding Muscle Volume

Facet Joint Degeneration Assessment

Facet joint degeneration was evaluated using the Weishaupt four-grade system (13) at the most affected level: Grade 0, normal facet joint space; Grade 1, mild degeneration (joint space narrowing); Grade 2, moderate degeneration (sclerosis, osteophytes); and Grade 3, severe degeneration (severe narrowing, large osteophytes, subchondral cysts). The stages of facet joint degeneration based on the Weishaupt classification are depicted in Figure 4.

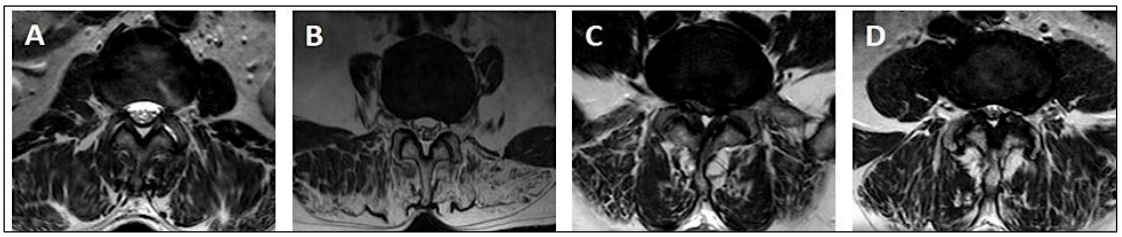

Figure 4: Progression of Lumbar Facet Joint Degeneration Using the Weishaupt Grading Scale. (A) Grade 0: Normal Facet Joint With 2–4 Mm Joint Space Width, (B) Grade 1: Narrowing of the Facet Joint Space (< 2 Mm), (C) Grade 2: Further Narrowing with Moderate Hypertrophy of the Articular Process, (D) Grade 3: Severe Narrowing with Marked Articular Process Hypertrophy and Subarticular Bone Erosions

Inter-reader Reliability

All MRI assessments were performed independently by two board-certified Musculoskeletal radiologists with more than 10 years of experience, blinded to clinical data. Inter-reader reliability was assessed using Cohen's kappa coefficient, which was excellent for all parameters: Pfirrmann grading $\kappa = 0.84$; Modic changes $\kappa = 0.87$; Goutallier grading $\kappa = 0.82$; Weishaupt facet grading $\kappa = 0.81$. Disagreements were resolved by consensus.

Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY). Descriptive statistics included means with standard deviations for continuous variables and frequencies with percentages for categorical variables. Given the ordinal nature of MRI grading systems, Spearman rank correlation coefficients were calculated to assess relationships between structural parameters and IVDD severity. Chi-square tests were used to examine associations between categorical variables, with severe IVDD (Pfirrmann grades 4–5) as the primary outcome. This study compared patients with severe IVDD (Pfirrmann 4–5) versus non-severe IVDD (Pfirrmann 2–3) within the same cohort rather than using a separate control group. Logistic regression analysis was performed to calculate odds ratios (OR) with 95% confidence intervals (CI).

To formally compare correlation coefficients across structural parameters, Fisher's z-transformation test was applied. The z-statistic comparing Modic changes ($r = 0.532$) versus facet joint degeneration ($r = 0.259$) was $z = 2.47$, $P = 0.014$, confirming a statistically significant difference in association strength. The z-statistic comparing Modic changes versus paraspinal muscle fat infiltration ($r = 0.167$) was $z = 3.11$, $P = 0.002$. These analyses confirm the hierarchical ordering of structural associations. The significance level was set at $P < 0.05$ (two-tailed) for all tests.

Results

Participant Characteristics

A total of 100 patients with lumbar IVDD completed the study protocol as shown in Table 1. The cohort had a mean age of 48.5 ± 13.2 years (range: 22–73 years) and comprised 58 males (58%) and 42 females (42%). Mean BMI was 26.8 ± 4.3 kg/m^2. Clinical severity indicators revealed moderate impairment, with a mean VAS pain score of 6.2 ± 1.8 (range: 3–9) and a mean ODI of 42.6 ± 16.3% (range: 14–78%), reflecting substantial functional limitation. Symptom duration ranged from 3 months to 15 years (median: 2.5 years). No patients with Pfirrmann Grade 1 were enrolled, as this grade represents normal disc morphology and such patients typically do not present with chronic low back pain.

Table 1: Baseline Characteristics of Study Cohort (n = 100)

Characteristic	Value
Demographics	
Age (years), mean ± SD	48.5 ± 13.2
Male sex, n(%)	58 [58.0]
BMI (kg/m^2), mean ± SD	26.8 ± 4.3
Clinical Parameters	
Visual Analog Scale (VAS) pain score, mean ± SD	6.2 ± 1.8

Oswestry Disability Index (ODI) (%), mean ± SD	42.6 ± 16.3
Symptom duration (months), median (IQR)	30 [12–60]
IVDD Severity (Pfirrmann Grade)	
Grade 2, n(%)	8 [8.0]
Grade 3, n(%)	41 [41.0]
Grade 4, n(%)	38 [38.0]
Grade 5, n(%)	13 [13.0]
Severe IVDD (Grades 4–5), n(%)	51 [51.0]

Note: BMI: Body Mass Index, VAS: Visual Analog Scale, ODI: Oswestry Disability Index, IVDD: Intervertebral Disc Degeneration, SD: Standard Deviation, IQR: Interquartile Range.

Distribution of Structural MRI Parameters

Structural MRI analysis revealed a high prevalence of degenerative changes across multiple spinal components, as summarised in Table 2, confirming that lumbar disc degeneration is a "whole-organ" condition affecting multiple anatomical structures. Modic changes were observed in 72% of patients (n = 72), with Type 2 changes (fatty replacement) being most prevalent (42%, n = 42), followed by Type 1 changes (17%, n = 17) and Type 3 changes (13%, n = 13). Only 28% of patients (n = 2)] showed no Modic changes. The predominance of Type 2 changes indicates chronic, established disc–endplate pathology.

Paraspinal muscle fat infiltration was present in 62% of the cohort (n = 62), with a graduated distribution: Grade 1 (35%, n = 35), Grade 2 (20%, n = 20) and Grades 3–4 combined (7%, n = 7). Thirty-eight patients (38%) showed no fat infiltration.

Facet joint degeneration was present in 92% of patients (n = 92). The distribution showed predominance of mild-to-moderate changes: Grade 1 (44%, n = 44), Grade 2 (38%, n = 38) and Grade 3 (10%, n = 10). Only 8% (n = 8) had radiographically normal facet joints.

Table 2: Distribution of Structural MRI Parameters in Study Cohort (n = 100)

Structural Parameter	Grade/Type	n	%
Modic Changes	Grade 0 (No change)	28	28.0
	Grade 1 (Type 1)	17	17.0
	Grade 2 (Type 2)	42	42.0
	Grade 3 (Type 3)	13	13.0
Paraspinal Muscle Fat Infiltration	No fat infiltration	38	38.0
	Grade 1 (fatty streaks)	35	35.0
	Grade 2 (fat < muscle)	20	20.0
	Grades 3 & 4 (fat ≥ muscle)	7	7.0
Facet Joint Degeneration	Grade 0 (Normal)	8	8.0
	Grade 1 (Mild)	44	44.0
	Grade 2 (Moderate)	38	38.0
	Grade 3 (Severe)	10	10.0

Association Between Modic Changes and Disc Degeneration

Modic changes demonstrated the strongest structural association with severe IVDD among all parameters examined, as shown in Table 3. The prevalence of severe disc degeneration increased progressively across Modic grade categories: Grade 0 (21.4%, 6/28), Grade 1 (35.3%, 6/17), Grade 2 (69.0%, 29/42) and Grade 3 (76.9%, 10/13). Chi-square analysis revealed a highly significant association (χ^2 = 20.446, df = 3, P < 0.001). Spearman correlation confirmed a moderate-to-strong positive relationship (r = 0.532, P < 0.001), representing the strongest structural correlate identified in this study.

Logistic regression demonstrated that patients with Modic changes had substantially elevated odds of severe disc degeneration compared to those without (OR = 6.11, 95% CI: 2.81–13.28, P < 0.001). The progressive dose-response relationship across Modic grades — from 21.4% in Grade 0 to 76.9% in Grade 3 — suggests that endplate

pathology and disc degeneration represent interdependent components of a unified pathological process. It is acknowledged that multivariable regression accounting for age, BMI and smoking was not performed; this represents a limitation, as the OR may overestimate the independent association of Modic changes with severe IVDD.

Table 3: Association Between Modic Changes and Severe IVDD

Modic Change Grade	Total (n)	Severe IVDD n [%]	Non-severe n [%]	Prevalence [%]
Grade 0 (No change)	28	6 [21.4]	22 [78.6]	21.4
Grade 1 (Type 1)	17	6 [35.3]	11 [64.7]	35.3
Grade 2 (Type 2)	42	29 [69.0]	13 [31.0]	69.0
Grade 3 (Type 3)	13	10 [76.9]	3 [23.1]	76.9
Total	100	51 [51.0]	49 [49.0]	51.0
Spearman r = 0.532, P < 0.001; χ^2 = 20.446, df = 3, P < 0.001; OR = 6.11 (95% CI: 2.81–13.28)				

Note: IVDD- intervertebral disc degeneration.

Association Between Paraspinal Muscle Fat Infiltration and Disc Degeneration

Paraspinal muscle fat infiltration showed no significant relationship with disc degeneration severity, as presented in Table 4. The prevalence of severe IVDD varied across muscle grades without a consistent gradient: no fat infiltration (34.2%, 13/38), Grade 1 (62.9%, 22/35), Grade 2 (45.0%, 9/20) and Grades 3–4 (57.1%, 4/7). Chi-square analysis did not reach statistical significance (χ^2 = 6.297, df = 3, P = 0.098).

The non-linear distribution — with the highest prevalence at Grade 1 (62.9%) rather than at the most severe grades — is noted. This may reflect several mechanisms. Moderate fat infiltration could represent an active phase of disc pathology associated with pain and reflex muscle guarding. Higher-grade fat infiltration may occur in response to multiple spinal pathologies beyond disc degeneration alone, including facet joint inflammation or primary myofascial syndromes. Alternatively, this pattern could reflect measurement variability or limited statistical power resulting from the small subgroup sizes, particularly at Grades 3–4 (n = 7). These alternative explanations underscore the need for larger studies specifically designed to examine paraspinal muscle changes.

Table 4: Association Between Paraspinal Muscle Fat Infiltration and Severe IVDD

Goutallier Classification System (GCS) Grade	Total (n)	Severe IVDD n [%]	Non-severe n [%]	Prevalence [%]
No fat infiltration	38	13 [34.2]	25 [65.8]	34.2
Grade 1 (fatty streaks)	35	22 [62.9]	13 [37.1]	62.9
Grade 2 (fat < muscle)	20	9 [45.0]	11 [55.0]	45.0
Grades 3 and 4 (fat ≥ muscle)	7	4 [57.1]	3 [42.9]	57.1
Total	100	48 [48.0]	52 [52.0]	48.0
Spearman r = 0.167, P = 0.097; χ^2 = 6.297, df = 3, P = 0.098 (not significant)				

Note: IVDD- intervertebral disc degeneration.

Association Between Facet Joint Degeneration and Disc Degeneration

Facet joint degeneration demonstrated a statistically significant but modest association with severe IVDD, as shown in Table 5, supporting the biomechanical concept of the "three-joint complex" in spinal degeneration. The prevalence of severe disc degeneration increased with facet joint grade: Grade 0 (50.0%, 4/8), Grade 1 (43.2%, 19/44), Grade 2 (52.6%, 20/38) and Grade 3 (80.0%, 8/10).

Although chi-square analysis did not achieve statistical significance when considering all grade categories (χ^2 = 4.485, df = 3, P = 0.214), this is attributable to small cell sizes in the extreme categories (Grade 0, n = 8; Grade 3, n = 10) rather than an absence of association. Chi-square is sensitive to small expected cell frequencies, which inflates the P-value and reduces power. The

statistically significant Spearman correlation (r = 0.259, P = 0.009) and logistic regression result (OR = 1.83 per grade increase, 95% CI: 1.15–2.91, P = 0.011) are therefore the more informative measures of association for this parameter.

Table 5: Association Between Facet Joint Degeneration and Severe IVDD

Facet Joint Grade	Total (n)	Severe IVDD n [%]	Non-severe n [%]	Prevalence [%]
Grade 0 (Normal)	8	4 [50.0]	4 [50.0]	50.0
Grade 1 (Mild)	44	19 [43.2]	25 [56.8]	43.2
Grade 2 (Moderate)	38	20 [52.6]	18 [47.4]	52.6
Grade 3 (Severe)	10	8 [80.0]	2 [20.0]	80.0
Total	100	51 [51.0]	49 [49.0]	51.0
Spearman r = 0.259, P = 0.009; χ^2 = 4.485, df = 3, P = 0.214 (chi-square non-significant due to small cell sizes); OR = 1.83 per grade increase (95% CI: 1.15–2.91)				

Note: IVDD- intervertebral disc degeneration.

Comparative Strength of Structural MRI Associations

Comparative analysis revealed differential predictive strengths across structural MRI parameters, as summarised in Table 6. Modic changes demonstrated the strongest association with IVDD (r = 0.532, P < 0.001; OR = 6.11, 95% CI: 2.81–13.28). Facet joint degeneration exhibited a significant but weaker correlation (r = 0.259, P = 0.009; OR = 1.83, 95% CI: 1.15–2.91). Paraspinal muscle fat infiltration showed only a non-significant trend (r = 0.167, P = 0.097).

Fisher's z-transformation test confirmed that the difference in correlation strength between Modic changes and facet joint degeneration was statistically significant (z = 2.47, P = 0.014), as was the difference between Modic changes and paraspinal fat infiltration (z = 3.11, P = 0.002). These results establish a statistically validated hierarchy among structural parameters.

Table 6. Comparative Strength of Structural MRI Associations with IVDD

Structural Parameter	Correlation (r)	P-value	Odds Ratio [95% CI]	Strength
Modic Changes	r = 0.532	< 0.001	6.11 [2.81–13.28]	Strongest
Facet Joint Degeneration	r = 0.259	0.009	1.83 [1.15–2.91]	Moderate
Paraspinal Muscle Fat Infiltration	r = 0.167	0.097	N/A	Trend (NS)
IVDD, intervertebral disc degeneration; NS, not significant; N/A, not applicable (non-significant association)				

Note: IVDD- intervertebral disc degeneration, NS- not significant; N/A, not applicable (non-significant association).

Discussion

This cross-sectional study systematically examined structural MRI parameters in 100 patients with lumbar IVDD. Three principal findings emerged: first, Modic changes showed the strongest structural association with severe disc degeneration (r = 0.532, OR = 6.11); second, facet joint degeneration showed a significant but weaker correlation (r = 0.259, OR = 1.83); and third, the pattern of associations across multiple anatomical structures confirms the "whole-organ" nature of disc degeneration (4).

The Spearman correlation of 0.532 (P < 0.001) and 6.11-fold increased odds (95% CI: 2.81–13.28) confirm the strong association between Modic changes and disc degeneration severity (6-8). The progressive increase in severe IVDD prevalence across Modic grades — from 21.4% in Grade 0 to 76.9% in Grade 3 — demonstrates a clear dose-response relationship, suggesting that endplate pathology and disc degeneration represent interdependent components of a single pathological process. This observation is consistent with Pfirrmann classification studies that have demonstrated progressive signal loss and morphological deterioration accompanying advanced endplate changes (1).

The disc–endplate interface is critical for disc nutrition and mechanical load transmission. The avascular disc depends entirely on diffusion through the endplate for nutrient supply and waste removal. Endplate calcification, sclerosis, or disruption impairs this supply, potentially initiating a vicious cycle of degeneration (18). Modic Type 1 changes may represent an active

inflammatory phase with potential for reversibility, while Type 2 changes indicate more established, chronic pathology (7). Type 3 changes represent end-stage disease with dense bone formation that severely impairs diffusion. The high prevalence of severe IVDD in Type 2 and Type 3 patients (69.0% and 76.9% respectively) underscores the importance of endplate integrity for disc health. These findings have therapeutic implications: interventions targeting the disc alone without addressing endplate pathology may have limited efficacy, while approaches restoring endplate function through reducing inflammation or improving blood flow could provide disease-modifying benefits (19).

Facet joint degeneration correlated significantly with IVDD grade ($r = 0.259$, $P = 0.009$), though the association was considerably weaker than that for Modic changes. The high prevalence of severe IVDD [80%] in patients with Grade 3 facet degeneration supports the "three-joint complex" concept, whereby the disc and bilateral facet joints function as an integrated biomechanical unit (13). Biomechanical studies have shown that as the disc loses height and stiffness, disproportionate loads shift to the facet joints, accelerating their degeneration — a bidirectional process that sustains progressive degeneration (20, 21). The weaker correlation relative to Modic changes ($r = 0.259$ vs. $r = 0.532$) suggests that while biomechanically coupled, facet degeneration may be somewhat independent in certain patients, possibly reflecting individual variation in anatomy, loading patterns and genetic susceptibility (22). Fisher's z-test confirmed that this difference in correlation strength was statistically significant ($z = 2.47$, $P = 0.014$).

The chi-square analysis for facet joint degeneration did not reach statistical significance ($P = 0.214$), which contrasts with the significant Spearman correlation and logistic regression results. This apparent inconsistency arises because the chi-square test, applied to a 2×4 contingency table with small expected cell frequencies in the extreme grade categories (Grade 0, $n = 8$; Grade 3, $n = 10$), has reduced statistical power. The Spearman correlation and logistic regression are better suited to the ordinal structure of the data and are therefore the more informative statistics in this context. This distinction should be borne in mind when interpreting the results.

Paraspinal muscle fat infiltration showed a non-significant trend toward association with IVDD ($r = 0.167$, $P = 0.097$). The non-linear distribution — with peak severe IVDD prevalence at Grade 1 (62.9%) rather than at the most severe grades — may reflect measurement variability, low statistical power due to small subgroup sizes, or a genuine non-linear relationship between muscle fat infiltration and disc pathology. The absence of significance may also partly reflect the sample size of 100, which provides approximately 68% power to detect a correlation of $r = 0.20$. Larger studies with dedicated power calculations for paraspinal muscle endpoints are needed. The weak overall correlation suggests that muscle changes are not tightly coupled to disc severity in the same manner as Modic changes and likely represent a secondary consequence of pain and altered movement patterns (12).

Our findings provide strong support the "whole-organ" concept (4) and the significant associations between disc severity and multiple structural parameters — Modic changes in 72%, facet joint degeneration in 92% and muscle fat infiltration in 64% — demonstrate that IVDD is not an isolated pathology (23-25). The hierarchical relationship — Modic changes strongest ($r = 0.532$), facet joints moderate ($r = 0.259$), muscle fat infiltration weakest ($r = 0.167$) — suggests that disc–endplate coupling is the most critical component of the degenerative process, with Fisher's z-test confirming these differences are statistically significant.

A well-recognised challenge in degenerative spine research is the imperfect correlation between radiological severity and clinical symptoms. Advanced MRI findings such as high-grade disc degeneration, Modic changes, or facet joint degeneration may be present in asymptomatic individuals, while patients with mild structural abnormalities may experience significant pain. Accordingly, the observed associations should be interpreted as structural correlations on MRI rather than indicators of pain origin and imaging findings must always be integrated with clinical assessment.

Clinical Implications

These findings carry several clinical implications. The strong association between Modic changes

and severe IVDD (OR = 6.11) suggests that endplate pathology should be a primary consideration in treatment planning; patients with Modic changes may benefit from interventions specifically targeting endplate inflammation or perfusion (19). The "whole-organ" nature of IVDD emphasises the need for comprehensive therapeutic approaches rather than disc-focused interventions alone. Multimodal strategies combining structural interventions with systemic treatment may be more effective. Modic changes may also serve as an imaging marker of advanced structural degeneration, identifying patients who require more aggressive intervention or closer monitoring. The non-significant association between paraspinal fat infiltration and IVDD severity suggests that treatment approaches focused solely on muscle relaxation may not address the underlying disc–endplate pathology.

Conclusion

Lumbar IVDD is associated with structural changes involving multiple spinal components, supporting a whole-organ perspective of degenerative spine disease. Among the MRI parameters evaluated, Modic changes showed the strongest association with severe disc degeneration (r = 0.532, OR = 6.11), while facet joint degeneration showed a weaker but statistically significant relationship (r = 0.259, OR = 1.83). Paraspinal fat infiltration did not demonstrate a significant association with disc degeneration severity. The statistically significant differences between correlation coefficients, confirmed by Fisher's z-transformation test, validate the hierarchical ordering of these structural associations. Comprehensive structural MRI assessment is therefore important in evaluating patients with lumbar disc degeneration. However, several limitations of the present study must be acknowledged. The cross-sectional design precludes causal inference and the single-centre setting with a modest sample size (n = 100) limits generalisability. The absence of a prospective power calculation and multivariable regression adjusting for potential confounders — including age, BMI and smoking status — further constrains the interpretability of these findings. Future longitudinal, multi-centre studies incorporating larger cohorts, multivariable regression analyses and prospective power calculations are required to clarify temporal relationships, causal mechanisms and the independent contribution of individual structural parameters after adjusting for confounders.

Abbreviations

BMI: Body Mass Index, CI: Confidence Interval, GCS: Goutallier Classification System, IQR: Interquartile Range, IVDD: Intervertebral Disc Degeneration, MRI: Magnetic Resonance Imaging, ODI: Oswestry Disability Index, OR: Odds Ratio, SD: Standard Deviation, VAS: Visual Analog Scale.

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Author Contributions

Manju Bhashini Manoharan: Conceptualisation, Data Curation, Formal Analysis, Writing — Original Draft, Sharmila Aristotle: Methodology, Supervision, Writing — Review and Editing, Jeffrey Skaria Joseph: Investigation (MRI assessment), Visualisation, Writing — Review and Editing, Alex Daniel Prabhu Arul Pitchai: Formal Analysis, Validation, Writing — Review and Editing.

Conflict of Interest

The authors declare no competing interests.

Data Availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request, subject to institutional ethics approval and patient privacy protection.

Declaration of Artificial Intelligence (AI) Assistance Process

Artificial intelligence tools were used in the preparation of this manuscript to assist with language refinement, grammatical correction, sentence restructuring and improvement of overall clarity and academic presentation. AI tools were not used for data generation, data analysis, interpretation of results, or drawing scientific conclusions. All scientific content, study design, data interpretation and final responsibility for the manuscript rest solely with the authors.

Ethics Approval

This study was conducted in accordance with the Declaration of Helsinki and received approval from the Institutional Ethics Committee of Chettinad Hospital and Research Institute (Ref No: IHEC-II/0446/23, date: 16/10/2023). All participants provided written informed consent prior to enrolment.

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