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RESEARCH

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Correlation between lumbar spinal canal magnetic resonance imaging grading systems and parameters in lumbar spinal canal compromise

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Abstract

Background: There is a need to assess how commonly used classification systems of intervertebral disc degeneration reflect the compromise of neural elements. This study aims to explore the relationship between lumbar discs degenerative diseases using the Pfirrmann and the Combined Task Forces (CTF) of the North American Spine Society (NASS) grading systems as well as qualitative and quantitative grades of lumbar spinal stenosis. This retrospective cohort study included adult patients undergoing non-contrast MR imaging of lumbosacral spine. The radiological assessment included the Pfirrmann grading system, Van Rijn classification, Combined Task Force (CTF) classification, measurement of the cross-sectional area of the dural sac, mid-sagittal antero-posterior diameter of the thecal sac, the degree of dural sac compression at disc level, lateral recesses heights, and intervertebral foramina diameters. The degree of stenosis of the spinal canal and intervertebral foramina was assessed.

Results: One hundred patients were included in the study. At all levels, Pfirrmann grades had a moderate, significant, positive correlation with the severity of stenosis of the central and lateral spinal canals as well as foraminal stenosis. The grades of lumbar spinal canal and foraminal stenosis had a significant positive correlation with degree of disc displacement as assessed by CTF classification and had a significant negative correlation with the quantitative lumbar spinal canal and foraminal measures.

Conclusions: There is a good correlation between Pfirrmann classification, CTF classification of NASS, qualitative grading and quantitative measures of lumbar spinal canal that reflects the severity of lumbar spinal canal stenosis and nerve root compression.

Keywords: Disc degeneration, Lumbar spine, Magnetic resonance imaging, Pfirrmann grade, Spinal stenosis

Introduction

Degeneration of the intervertebral discs represents the most frequent cause of lower back pain among the elderly [1]. Degenerated discs become gradually reduced in height, resulting in various effects on the nearby anatomical structures. With the advance of the degenerative changes, the spinal canal becomes narrower and stenotic with compression of neural tissues that gives rise to pain and disability [2].

Magnetic resonance imaging is considered the gold standard imaging modality for assessment of the intervertebral disc herniation and subsequent neural elements compression. Lumbar disc herniation descriptive terminologies have always been a source of confusion

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between radiologist and clinicians. Poor patient care may results from ineffective communication between radiologist and clinicians. Clinicians need accurate, precise and reliable terminologies to describe lumbar discs pathologies in order to make precise and accurate therapeutic decisions for lumbar disc herniation and neural elements compromise [3].

Evaluation of the spine using traditional MRI has depended largely on the use of classification systems, including the Van Rijn classification, the Pfirrmann grading system, the Combined Task Forces of the North American Spine Society, American Society of Spine Radiology, and American Neuroradiology (NASS) system, and several other systems. However, these systems are subjective and lack quantitative parameters that can be objectively measured [4].

As the intervertebral discs vary across the lumbar spines in terms of their composition as well as their resistance and response to loads [5, 6], evaluation of the disc degeneration and its impact on neural elements should be stratified according to the level of the disc.

This study aimed to explore the relationship between MR grading system of lumbar disc degeneration (Pfirrmann grading system), grading systems of lumbar disc displacement (NASS or combined task force grading systems), qualitative grading systems of lumbar spinal canal and neural foraminal compromise and the lumbar spinal canal and neural foraminal quantitative measures.

Methods

This retrospective cohort study was carried out at the Neurosurgery, Neurology and Radiology Departments, from January 2021 to October 2021. Confidentiality of patients' information was maintained by keeping anonymous records after assigning code numbers to patients. The study included 100 patients who had a history of low back pain and clinically suspected to have lumbar disc displacement.

Adult patients presenting to the outpatient clinic and who had MRI of the lumbosacral spine without contrast were included. Patients were excluded if they had fracture spine, infection, or malignancy.

MR imaging of lumbosacral spine was done for all attendance using 1.5 T MR machine (Magnetom Aera, Siemens Health Care, Germany) with spine array coil. Sagittal T1 fast spin-echo images were done using an echo time (TE) of 7–15 ms, a repetition time (TR) of 400–500 ms, 30 cm field of view (FOV) and 4 mm slice thickness. Axial and sagittal T2-weighted spin-echo images were done using an echo time (TE) of 100 ms, a repetition time (TR) of 2875 ms, 30 cm field of view (FOV) and 4 mm slice thickness.

The data were collected from a prospectively kept patients' recording system. Collected data included the age and sex of the patient as well as radiological assessment. All MR images were assessed by a single radiologist with more than 15 years experience in spine imaging. The radiological assessment included the Pfirrmann grading system, nerve root compression according to Van Rijn classification system, lumbar disc prolapse, and herniation according to the Combined Task Forces of the North American Spine Society, American Society of Spine Radiology, and American Neuroradiology (NASS). The cross-sectional area of the dural sac, mid-sagittal antero-posterior diameter of the thecal sac, and the degree of dural sac compression at the disc level were also measured. The central and lateral spinal canals, the lateral recesses, and the diameter of intervertebral foramina were also measured and graded.

Pfirrmann grading system (Fig. 1) is a reliable classification system used for grading degeneration of lumbar disc utilizing MRI. Degeneration is classified into five grades depending on the disc signal intensity, disc structure, distinction between nucleus and annulus, and disc height [7].

In Pfirrmann grading system lumbar discs graded into grade II in which there is normal disc height with homogeneous high signal intensity in sagittal T2-weighted images, grade II in which there is normal disc height with inhomogeneous high signal intensity in sagittal T2-weighted images also there is clear differentiation between nucleus and annulus in axial T2-weighted

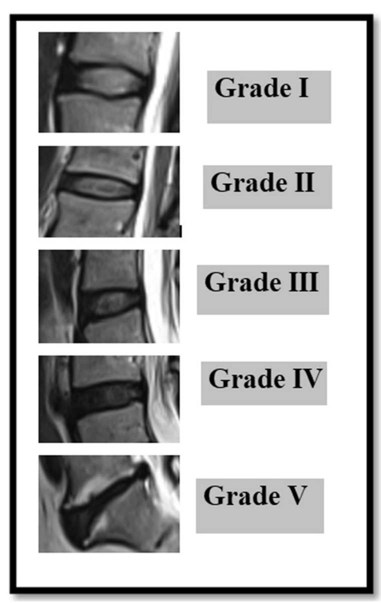

Fig. 1 MR grades of Pfirrmann grading system

images, grade III in which there is normal or mild decrease of disc height with inhomogeneous intermittent grey signal intensity in sagittal T2-weighted images and there is unclear differentiation between nucleus and annulus in axial T2-weighted images, grade IV in which there is mild or moderate decrease of disc height with inhomogeneous low and dark grey signal intensities in sagittal T2-weighted images there is also no differentiation between nucleus and annulus in axial T2-weighted images and grade V in which there is collapsed disc space with inhomogeneous low signal intensity in sagittal T2-weighted images there is also no differentiation between nucleus and annulus in axial T2-weighted images [8].

Van Rijn classification system classifies lumbar discs according to the presence or absence of root compression into 2 grades. These two grades include grade A with no root compression, which further includes 3 grades which are grade 1 with no definite root compression, grade 2 no possible root compression, and grade 3 indeterminate root compression and grade B include presence of root compression, which further includes 2 grades which are grade 1 with possible root compression and grade 2 with definite root compression [3].

Combined Task Forces (CTF) of the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neuroradiology (NASS) (Fig. 2): in this system, the disc circumference is subdivided into four parts. Each part has a circumference equal to 90° or 25% of the whole disk circumference.

This system classifies lumbar discs displacements into normal disc in which the disc is located within the disc space boundaries with no displacement, bulging disc in which there is a diffuse displacement of the disc material more than 180° or more than 50% beyond the disc space boundaries (it is further classified into either symmetric or asymmetric) and herniated disc in which there is a localized displacement of the disc material less than 180° or less than 50% of the disc space boundaries.

Herniation is further classified according to the extent of disc displacement into either broad-based herniation (the herniation is less than 180° or less than 50% of the disc boundaries) or focal herniation (the herniation is less than 90° or less than 25% of the disc boundaries).

The focal herniation is classified into either protrusion in which the diameter of the base of the displaced fragment is broader than its diameter toward the spinal canal or extrusion in which the diameter of the displaced

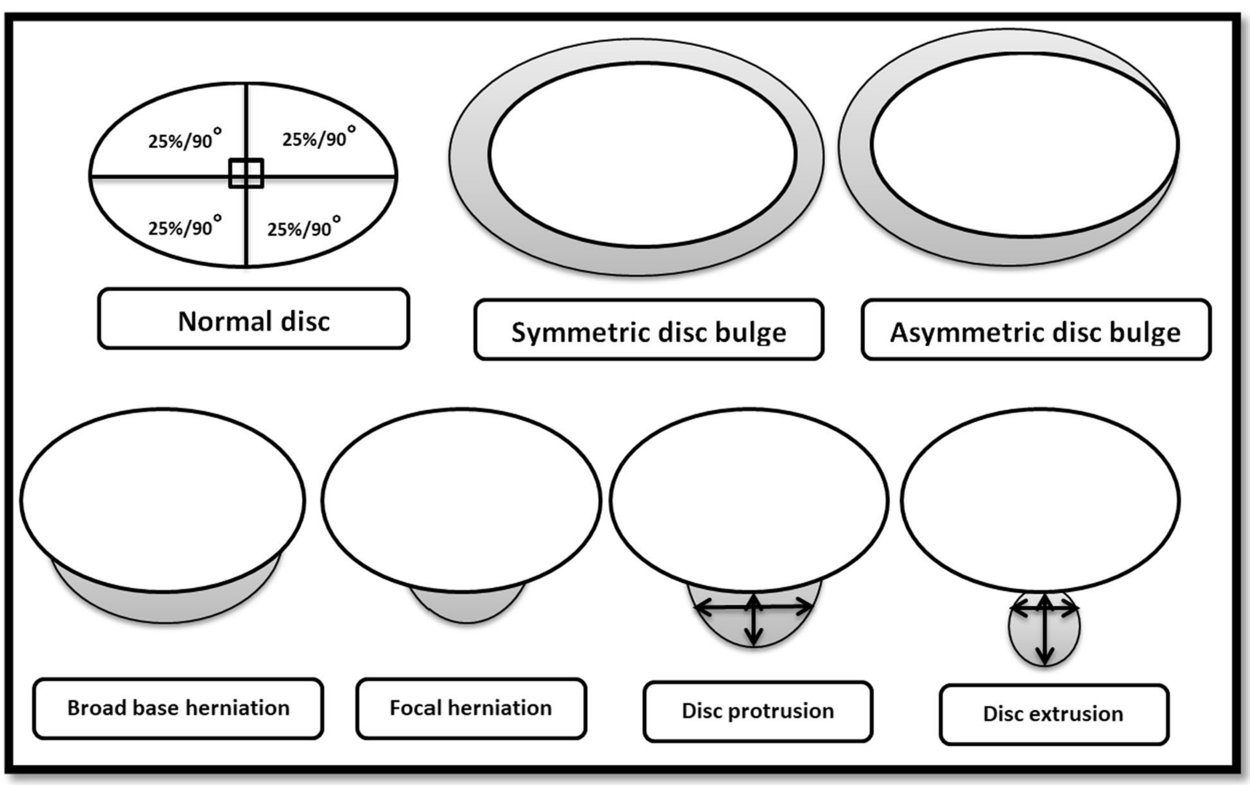

Fig. 2 Combined Task Forces (CTF) of the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neuroradiology (NASS)

fragment toward the spinal canal is broader than the diameter of its base. In a sagittal image, an extrusion is diagnosed if a displaced disc fragment overlaps the intervertebral disc level. A sequester is formed when a part of the displaced disc is separated.

Also, herniation is classified into either focal herniation in which the disc displacement is less than 90° or less than 25% of disc space boundaries or broad base herniation in which the disc displacement is less than 180° and more than 90° or less than 50% and more than 25% of disc space boundaries [9].

Central spinal canal grading (Fig. 3) depends on the aggregation of the cauda equina nerve root in the spinal canal. It is assessed in axial T2-weighted images.

In central spinal canal grading, the spinal canal is divided into the following grades grade 0 in which there is a normal spinal canal, grade 1 (mild stenosis) in which there is mild obliteration of anterior cerebrospinal fluid (CSF) space with clear separation of the cauda equina nerve roots from each other, grade 2 (moderate stenosis) in which there is moderate spinal canal stenosis with aggregation of cauda equina nerve roots and grade 3 (severe stenosis) in which there is severe spinal canal stenosis with the whole cauda equina nerve roots become a bundle.

Right and left lumbar lateral spinal canal (LSC) grading system (Fig. 3) assessed in axial T2-weighted image. In this system the LSC divided into the following grades grade 0 (normal) in which there is no LSC stenosis, grade 1 (mild stenosis) in which there is mild LSC stenosis with lateral recess narrowing without flattening or compression on nerve roots, grade 2 (moderate stenosis) in which there is moderate LSC stenosis with lateral recess narrowing and nerve root flattening (preservation of the space lateral to the root in the lateral recess) and grade 3 (severe stenosis) in which there is severe root

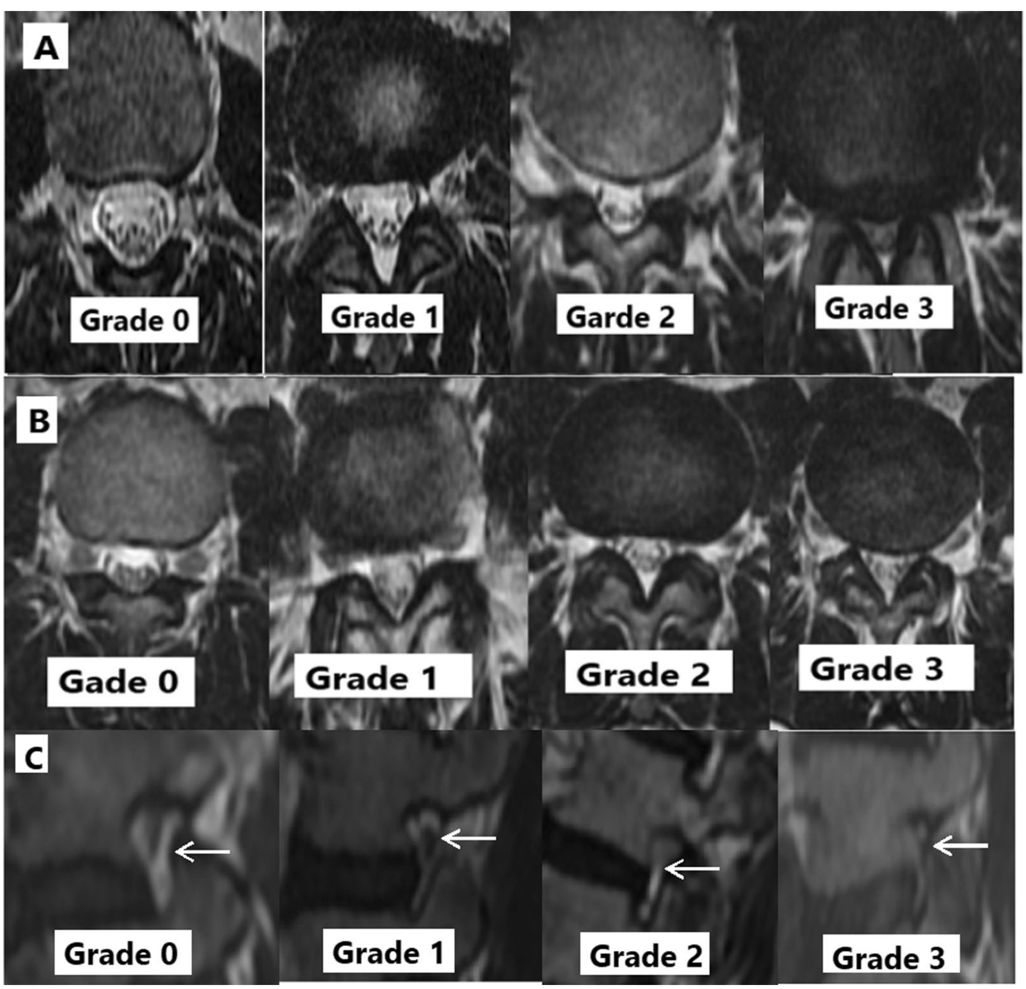

Fig. 3 MR grading of lumbar spinal canal and foraminal stenosis. **A** Central spinal canal grades, **B** lateral spinal canal grades and **C** grades of lumbar foraminal stenosis (white arrows point to the foramen)

compression with severe narrowing and complete obliteration of the CSF space surrounding or lateral to the nerve root.

Grade of lumbar foraminal stenosis (Fig. 3) assessed at foraminal zones of sagittal T1- or T2-weighted MRI images. In this system the Lumbar foramina divided into the following grades grade 0 in which there is no foraminal stenosis, grade 1 (mild stenosis) in which there is deformity of the foraminal epidural fat while the remaining fat still completely surrounds the existing nerve root, grade 2 (moderate stenosis) in which there is marked foraminal stenosis where epidural fat only partially surrounding the nerve root and grade 3 (advanced stenosis) in which there is complete obliteration of the foraminal epidural fat [10].

The following measurements were measured at L3–4, L4–5 and L5–S1 intervertebral discs which are mid-sagittal antero-posterior (AP) diameter of dural sac (Fig. 4) was measured in the mid-sagittal T2 image at the mid-vertebral level.

The cross-sectional area of the dural sac (Fig. 4) was measured in axial T2 image at the disc level.

Degree of the dural sac compression at disc level which is defined as a percentage value expressing the degree of stenosis at the disc level. It is calculated by dividing the AP diameter of the dural sac at the disc level with the normal AP diameter of the dural sac of the neighboring vertebral body at the mid-vertebral level in a mid-sagittal T2 image.

Right and left lateral recesses heights (Fig. 4) that represent the distances between the most anterior part of the superior articular facet and the posterior border of the vertebral body. It was measured bilaterally in axial T2 images.

Diameter of intervertebral foramen (right and left) (Fig. 4) represents the largest AP diameters of the intervertebral foramen. It was measured bilaterally at the foraminal zones of sagittal MRI images [9].

Statistical analysis

The data were entered into an Excel spreadsheet and then transferred to the Statistical Package for Social Sciences (IBM SPSS Statistics) for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). The distribution of

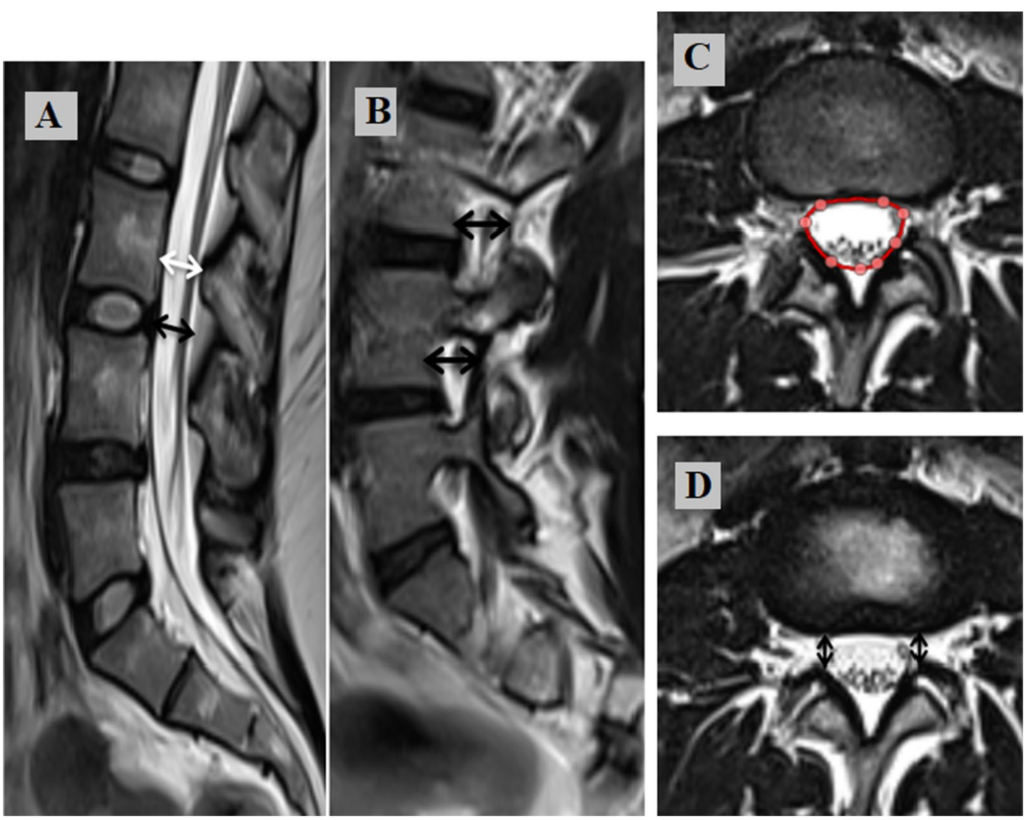

Fig. 4 MR lumbar spinal canal and foraminal measures. **A** Mid-sagittal antero-posterior (AP) diameter of dural sac (white arrow) and degree of stenosis at the disc level (black arrows); **B** diameter of intervertebral foramen (black arrows); **C** the cross-sectional area of the dural sac and **D** right and left lateral recesses heights (black arrows)

continuous numerical variables was assessed using the Shapiro–Wilk test. Variables that followed the normal distribution were summarized using the mean ± standard deviation (SD). Variables not following the normal distribution and grades were summarized using the median and interquartile range (IQR, expressed as the 25th–75th percentiles). Comparisons between the grades were conducted using the Kruskal–Wallis test, followed by the post hoc Dunn–Bonferroni test if significant. Correlations between the Pfirrmann grading system and measurements/grades of neural elements were performed using Spearman's rank-order correlation. Categorical variables were summarized as frequencies (count and percentage). A p-value < 0.05 was chosen to interpret the results of statistical tests. The statistical Package for Social Sciences (SPSS) was used for conducting the analysis (IBM corp. Releases 2013. IBM SPSS Statistics for windows, version 22.0. Armonk, NY: IBM Corp.)

Results

The present study included 100 patients with degenerative changes of the lumbar disc. The patients' age ranged from 18 to 76 years, with an average (SD) of 48.2 (14.1) years. Female patients accounted for 52% of the studied sample. The lumbar disc degenerative disease was assessed at the levels of L3–4, L4–5, and L5–S1, showing varying grades at each level. Discs at the level of L4–5 and L5–S1 tended to have a severer grade of degenerative changes relative to the discs at L3–4.

Table 1 shows relationship between grades of central spinal canal, lateral spinal canal (right and left lateral recesses), and intervertebral foramen (right and left) compression and degree of the dural sac compression at disc level (%), mid-sagittal AP diameter of dural sac at disc level (mm), cross-sectional area of dural sac (mm^2), lateral spinal canal height (right and left lateral recesses) and intervertebral foramen diameter (right, left) at levels of L3–4, L4–5, and L5–S1 disc levels.

For assessing the relationship of Pfirrmann grading and nerve root compression at each level, the patients were categorized based on Pfirrmann classification into two groups: Grades 1–2 and Grades 3–5.

At the level of L3–4 disc, Pfirrmann grades 3–5 were significantly associated with root compression (RC) as identified by Van Rijn classification (86.4 versus 17.9%, $p < 0.001$) and a lower percentage of normal disc displacement according to NASS classification (9.1 versus. 67.9%, $p < 0.001$). In addition, grades 3–5 had a significantly lower mean cross-sectional area of dural sac (150.6 ± 46.3 versus 200.6 ± 47.8, $p = 0.001$) and degree of the dural sac compression at disc level (64.9 ± 20.7 versus 85.1 ± 7.1, $p < 0.001$). Severe stenosis of the central spinal canal and lateral spinal canals was observed in a significantly higher percentage of patients with Pfirrmann grades 3–5 ($p < 0.001$). The diameter of the right intervertebral foramen was significantly reduced in grades 3–5 (9.8 ± 2.1 versus 11.2 ± 1.7, $p = 0.011$), however this significant difference did not show when assessing the grade of foramen stenosis ($p = 0.195$). The diameter and grade of stenosis of left intervertebral foramen did not differ significantly between the two groups ($p > 0.05$, Table 2).

As for the level of L4–5, all Pfirrmann grades 3–5 had root compression compared to 52.6% in the group with grades 1–2 ($p < 0.001$). The disc appearance by NASS classification was abnormal in all patients with grades 3–5, with focal protrusion and extrusion observed in 6.5% each ($p = 0.005$). The 3–5 grades showed a significantly lower mean cross-sectional area of dural sac (129.8 ± 50.7 versus 202.6 ± 52.1, $p < 0.001$) and degree of the dural sac compression at disc level (60.8 ± 20.0 versus 82.0 ± 11.1, $p < 0.001$). Pfirrmann grades 3–5 were significantly associated with lower median right and left lateral spinal canal heights and severer stenosis of both the central and lateral spinal canal ($p < 0.05$). The diameter of right and left intervertebral foramina was significantly reduced in the grades 3–5 ($p < 0.001$), with severe grades of foraminal stenosis in the Pfirrmann grades 3–5 ($p < 0.05$, Table 3).

At the level of L5–S1, Pfirrmann grades 3–5 were significantly associated with root compression (77.4 versus 36.8%, $p < 0.001$), but not with disc appearance ($p = 0.079$). The mean cross-sectional area of the dural sac, as well as the degree of the dural sac compression at disc level, was significantly reduced in grades 3–5 ($p < 0.05$). The central and left lateral spinal canals were severely stenosed in 29% of Pfirrmann grades 3–5, while 35.5% had severe stenosis of the right lateral spinal canal ($p < 0.05$).

The diameter of right and left intervertebral foramina was significantly reduced in Pfirrmann grades 3–5 ($p < 0.05$), with a significantly higher percentage of patients with severe stenosis of the left foramen in the Pfirrmann grades 3–5 (22.6 versus 0%, $p = 0.024$). However, the severity of right foramen stenosis was not significantly associated with Pfirrmann grades ($p = 0.054$, Table 4).

The correlation between Pfirrmann grades and nerve root assessments was analyzed at each level. Pfirrmann grades correlated moderately and negatively with the cross-sectional area of the dural sac, degree of the dural sac compression at disc level, the height of lateral spinal canals, and the diameter of intervertebral foramina at all levels (rs = − 0.3 to − 0.7, $p < 0.05$). A moderate, significant, positive correlation (rs: 0.3 to 0.7, $p < 0.05$) was detected between Pfirrmann grades and the severity of

Table 1 Relationship between quantitative measures of lower lumbar spinal canal

Variables		L3–4	L4–5	L5–S1
Degree of the dural sac compression at disc level (%)				
Min–Max		86.0–96.0	86.0–95.0	85.0–95.0
		78.0–84.0	77.0–84.0	76.0–84.0
		69.0–74.0	67.0–75.0	65.0–74.0
		17.0–64.0	24.0–64.0	42.0–64.0
Mid-sagittal AP diameter of dural sac at disc level (mm)				
0	Min–Max	16.0–19.0	16.8- 20.3	17.3–22.1
1		15.5–16.3	14.8–16.3	15.0–17.0
2		13.5–15.0	13.8–15.3	14.0–15.5
3		11.5–13.0	10.8–12.5	11.0–12.6
The cross-sectional area of the dural sac (mm^2)				
0	Min–Max	180–31	190–302	190–374
1		158–188	160–198	164–193
2		115–160	118–158	119–155
3		60–106	31–105	90–107
Rt. LSC height for grades of right LSC (mm)				
0	Min–Max	5.2–8.3	5.0–7.0	5.2–9.0
1		3.1–4.8	3.5–4.5	4.0–4.8
2		1.7–3.0	1.5–3.4	1.7–3.4
3		0.0–1.3	0.0–1.5	0.0–1.4
Lt. LSC height for grades of left LSC (mm)				
0	Min–Max	5.2–7.5	5.5–7.4	5.0–8.8
1		3.2–4.8	3.5–4.9	4.0–4.8
2		2.0–4.8	1.7–3.4	1.6–3.4
3		0.0–1.5	0.0–1.5	0.0–1.5
Diameter of right intervertebral foramen for grades of Rt. lumbar foraminal stenosis (mm)				
0	Min–Max	9.5–14.0	9.2–13.0	8.5–14.0
1		8.3–9.0	7.1–8.9	7.0–8.3
2		4.4–7.0	4.2–7.0	4.2–6.5
3		3.5–3.9	2.7–3.3	2.7–3.2
Diameter of left intervertebral foramen for grades of Lt. lumbar foraminal stenosis (mm)				
0	Min–Max	9.5–13.6	9.0–13.6	8.5–13.0
1		8.2–9.3	7.5–8.5	6.6–8.2
2		4.6–7.4	4.3–7.0	4.5–6.5
3		3.3–3.7	2.6–3.2	2.6–3.3

Min minimum; *Max* maximum; *LSC* lateral spinal canal

stenosis of the central and lateral spinal canals and the intervertebral foramina (Table 5).

Comparison of the grade of stenosis of the central and lateral spinal canals as well as lumbar foraminal stenosis across the different categories of the disc (NASS classification) showed significant differences (all $p < 0.05$). The severity of stenosis tended to increase with the increase in bulging and protrusion. However, the low number of cases in some categories of NASS classification rendered the comparisons unfeasible for all categories (Table 6).

Discussion

Traditional MRI plays an important role in guiding the management of intervertebral disc degeneration. We investigated the relation between MR lumbar degenerative changes grading systems and lumbar neural elements compromise. Up to the best of the authors' knowledge, this research question has never been addressed by previous studies.

The mean age of the included patients was 48.2 ± 14.1 years, with nearly half the patients below the age of 45 years and 26% above 60 years. Disc degeneration

Table 2 Relationship between Pfirrmann grading and nerve root compression at L3–4 level

	Total (*n* = 50)		Grades 1–2 (*n* = 56)		Grades 3–5 (n = 44)		*p*-value
Van Rijn							
No RC	52	52.0%	46	82.1%	6	13.6%	< 0.001*
RC	48	48.0%	10	17.9%	38	86.4%	
NASS L3 4							
Normal	42	42.0%	38	67.9%	4	9.1%	< 0.001*
Asymmetric bulge	10	10.0%	2	3.6%	8	18.2%	
Diffuse bulge	46	46.0%	16	28.6%	30	68.2%	
Focal protrusions	2	2.0%	0	0.0%	2	4.5%	
Mid-sagittal AP diameter of dural sac							
Mean ± SD	15.0 ± 1.5		15.1 ± 1.7		14.9 ± 1.4		0.678
Min–Max	11.5–19.0		12.0–18.0		11.5–17.0		
Cross-sectional area of dural sac							
Mean ± SD	178.6 ± 53.0		200.6 ± 47.8		150.6 ± 46.3		0.001*
Min–Max	60.0–311.0		115.0–311.0		60.0–220.0		
Degree of the dural sac compression at disc level (%)							
Mean ± SD	76.2 ± 17.7		85.1 ± 7.1		64.9 ± 20.7		< 0.001*
Min–Max	17.0–96.0		69.0–96.0		17.0–95.0		
Central spinal canal grading							
0	42	42.0%	34	60.7%	8	18.2%	< 0.001*
1	16	16.0%	14	25.0%	2	4.5%	
2	24	24.0%	8	14.3%	16	36.4%	
3	18	18.0%	0	0.0%	18	40.9%	
Rt. LSC							
Median [IQR]	4.5 [2.3–6.5]		6.0 [4.0–7.0)		2.8 [1.3–4.5]		0.001*
Min–Max	0.0–8.3		1.0–8.3		0.0–8.0		
Grade of Rt. LSC							
0	44	44.0%	38	67.9%	6	13.6%	< 0.001*
1	26	26.0%	12	21.4%	14	31.8%	
2	16	16.0%	4	7.1%	12	27.3%	
3	14	14.0%	2	3.6%	12	27.3%	
Lt. LSC							
Median [IQR]	4.8 [2.6–6.5]		5.9 [4.5–6.5]		3.1 [2.0–4.8]		0.001*
Min–Max	0.0–7.5		1.5–7.5		0.0–7.0		
Grade of Lt. LSC							
0	48	48.0%	40	71.4%	8	18.2%	0.001*
1	22	22.0%	10	17.9%	12	27.3%	
2	18	18.0%	4	7.1%	14	31.8%	
3	12	12.0%	2	3.6%	10	22.7%	
Diameter of Rt. intervertebral foramen							
Mean ± SD	10.6 ± 2.0		11.2 ± 1.7		9.8 ± 2.1		0.011*
Min–Max	3.5–14.0		7.0–14.0		3.5–13.0		
Grade of Rt. lumbar foraminal stenosis							
0	78	78.0%	48	85.7%	30	68.2%	0.195
1	10	10.0%	6	10.7%	4	9.1%	
2	8	8.0%	2	3.6%	6	13.6%	
3	4	4.0%	0	0.0%	4	9.1%	
Diameter of Lt. intervertebral foramen							

Table 2 (continued)

	Total ($n = 50$)		Grades 1–2 ($n = 56$)		Grades 3–5 (n = 44)		*p*-value
Median [IQR]	11.0 [10.0–12.0]		11.0 [10.0–11.7]		10.5 [9.3–12.0]		0.160
Min–Max	3.3–13.6		7.7–13.6		3.3–12.8		
Grade of Lt. lumbar foraminal stenosis							
0	84	84.0%	52	92.9%	32	72.7%	0.089
1	8	8.0%	4	7.1%	4	9.1%	
2	4	4.0%	0	0.0%	4	9.1%	
3	4	4.0%	0	0.0%	4	9.1%	

IQR interquartile range; *LSC* lateral spinal canal; *Lt.* left; *Max* maximum; *Min* minimum; *n* number; *Rt.* right; *SD* standard deviation

*Significant at $p < 0.05$

is well known to correlate with the advancement of age [11].

The study of Brinjikji and his colleagues reported that lumbar degenerative changes imaging findings like disc bulge, disc height or signal loss are caused by normal aging not due to pathological processes. They also reported that about a half of 30 to 39 years aged asymptomatic individuals and even young adults exhibited disc bulge, disc signal or height loss. These degenerative disc changes may be seen as incidental imaging findings and not necessary to be the cause of the presenting symptoms [12].

The lumbar disc degenerative disease was assessed at the levels of L3–4, L4–5, and L5–S1 discs with a severer grade of degenerative changes at the level of L4–5 and L5–S1 compared to the L3–4 level. This finding is in line with previous research as the level of L4–5 was reported as the most frequent site of abnormalities, followed by L5–S1, and then L3–4 [13, 14].

The prevalence rate of the stenosis of the lumbar central spinal canal in the present study was 58%, which is higher than that reported by a recent meta-analysis (38%) in the general population-based on imaging studies [15]. This may be due to using different criteria for defining stenosis of the spinal canal across the studies.

We found that, at all levels, Pfirrmann grades 3–5 were significantly associated with root compression as identified by Van Rijn classification ($p < 0.001$) and severe stenosis of the central spinal canal and lateral spinal canals ($p < 0.001$). These findings were supported by the moderate, significant, positive correlation observed between Pfirrmann grades and the severity of stenosis of the central and lateral spinal canals.

In the present study, the association of Pfirrmann grades 3–5 with severe grades of foraminal stenosis was significant at the levels of L4–5 and L5–S1, but not at the level of L3–4. Correlation analysis revealed a moderate, significant, positive correlation between Pfirrmann grades and the severity of foraminal stenosis. However, the strength of correlation was lower at the L3–4 level, accounting for the non-significant difference found between Pfirrmann categories 1–2 and 3–5.

The results of the current study showed that the severity of the spinal canal and foraminal stenosis tended to increase with increased bulging and protrusion as assessed by the CTF classification of NASS. However, some categories included low numbers of patients, thus we were not able to compare the severity of stenosis across all NASS categories.

The study of Li and his colleagues reported that the commonest system used for assessment of lumbar disc herniation is the CTF of NASS while other classification systems like van Rijn and Pfirrmann classification systems are used for classifying the lumbar neural element compression [3].

Many studies concluded that the CTF and van Rijn classifications systems had significant interobserver agreement and they considered as the most reliable systems for assessment of lumbar intervertebral disc herniation and lumbar neural element compression [16–20].

The studies of Zileli and his colleagues, Park and his colleagues, Kushchayev and his colleagues and Andreisek and his colleagues reported lumbar spinal canal stenosis qualitative imaging parameters. These parameters aimed to identify qualitative imaging criteria that should be used as a standard in writing radiologic reports for suspected lumbar spinal canal stenosis. These imaging parameters did not depend on any lumbar spinal canal quantitative measures as they reported that measurement of lumbar spinal canal parameters is time consuming, has moderate reliability and lacked evidence correlation between lumbar spinal canal parameters and patients symptoms [21–24].

They also reported five qualitative imaging criteria that should be radiologically reported for patient with suspected lumbar spinal canal stenosis. These criteria

Table 3 Relationship between Pfirrmann grading and nerve root compression at L4–5 level

	Total (*n* = 100)		Grades 1–2 (*n* = 38)		Grades 3–5 (*n* = 62)		*p*-value
Van Rijn							
No RC	18	18.0%	18	47.4%	0	0.0%	< 0.001*
RC	82	82.0%	20	52.6%	62	100.0%	
NASS							
Normal	12	12.0%	12	31.6%	0	0.0%	0.005*
Asymmetric bulge	24	24.0%	10	26.3%	14	22.6%	
Diffuse bulge	56	56.0%	16	42.1%	40	64.5%	
Focal protrusion	4	4.0%	0	0.0%	4	6.5%	
Extrusion	4	4.0%	0	0.0%	4	6.5%	
Mid-sagittal AP diameter of dural sac							
Mean ± SD	15.8 ± 1.5		16.2 ± 1.7		15.5 ± 1.4		0.117
Min–Max	10.8–20.0		13.5–19.0		10.8–17.8		
Cross-sectional area of dural sac							
Mean ± SD	157.5 ± 62.0		202.6 ± 52.1		129.8 ± 50.7		< 0.001*
Min–Max	31.0–302.0		120.0–302.0		31.0–225.0		
Degree of the dural sac compression at disc level (%)							
Mean ± SD	68.9 ± 20.0		82.0 ± 11.1		60.8 ± 20.0		< 0.001*
Min–Max	24.0–95.0		57.0–94.0		24.0–95.0		
Central spinal canal grading							
0	28	28.0%	20	52.6%	8	12.9%	0.002*
1	18	18.0%	10	26.3%	8	12.9%	
2	10	10.0%	2	5.3%	8	12.9%	
3	44	44.0%	6	15.8%	38	61.3%	
Rt. LSC							
Median [IQR]	2.5 [1.2–4.0]		4.2 [2.7–6.0]		1.5 [0.0–2.8]		< 0.001*
Min–Max	0.0–7.0		0.0–7.0		0.0–4.5		
Grade of Rt. LSC							
0	18	18.0%	18	47.4%	0	0.0%	< 0.001*
1	16	16.0%	6	15.8%	10	16.1%	
2	30	30.0%	10	26.3%	20	32.3%	
3	36	36.0%	4	10.5%	32	51.6%	
Lt. LSC							
Median [IQR]	2.5 [0.0–3.5]		4.5 [2.4–6.5]		1.2 [0.0–2.8]		< 0.001*
Min–Max	0.0–7.4		0.0–7.4		0.0–4.5		
Grade of Lt. LSC							
0	16	16.0%	16	42.1%	0	0.0%	< 0.001*
1	10	10.0%	6	15.8%	4	6.5%	
2	32	32.0%	12	31.6%	20	32.3%	
3	42	42.0%	4	10.5%	38	61.3%	
Diameter of Rt. intervertebral foramen							
Mean ± SD	9.3 ± 2.2		10.6 ± 1.1		8.5 ± 2.3		< 0.001*
Min–Max	2.7–13.0		8.3–13.0		2.7–13.0		
Grade of Rt. lumbar foraminal stenosis							
0	60	60.0%	34	89.5%	26	41.9%	0.002*
1	22	22.0%	4	10.5%	18	29.0%	
2	16	16.0%	0	0.0%	16	25.8%	
3	2	2.0%	0	0.0%	2	3.2%	
Diameter of Lt. intervertebral foramen							

Table 3 (continued)

	Total (*n* = 100)		**Grades 1–2 (*n* = 38)**		**Grades 3–5 (*n* = 62)**		***p*-value**
Mean ± SD	9.3 ± 2.3		10.5 ± 1.5		8.6 ± 2.4		0.001*
Min–Max	2.6–13.6		8.0–13.6		2.6–13.0		
Grade of Lt. lumbar foraminal stenosis							
0	60	60.0%	32	84.2%	28	45.2%	0.004*
1	14	14.0%	6	15.8%	8	12.9%	
2	22	22.0%	0	0.0%	22	35.5%	
3	4	4.0%	0	0.0%	4	6.5%	

IQR interquartile range; *LSC* lateral spinal canal; *Lt.* left; *Max* maximum; *Min* minimum; *n* number; *Rt.* right; *SD* standard deviation

*Significant at $p < 0.05$

Table 4 Relationship between Pfirrmann grading and nerve root compression at L5–S1 level

	Total (*n* = 100)		**Grades 1–2 (*n* = 38)**		**Grades 3–5 (*n* = 62)**		***p*-value**
Van Rijn							
No RC	38	38.0%	24	63.2%	14	22.6%	0.004*
RC	62	62.0%	14	36.8%	48	77.4%	
NASS							
Normal	20	20.0%	14	36.8%	6	9.7%	0.079
Asymmetric bulge	22	22.0%	8	21.1%	14	22.6%	
Diffuse bulge	32	32.0%	6	15.8%	26	41.9%	
Focal protrusion	26	26.0%	10	26.3%	16	25.8%	
Mid-sagittal AP diameter of dural sac							
Mean ± SD	16.8 ± 2.0		17.2 ± 2.2		16.6 ± 1.9		0.384
Min–Max	11.0–22.0		14.2–22.0		11.0- 16		
Cross-sectional area of dural sac							
Mean ± SD	199.0 ± 69.6		229.9 ± 69.4		180.1 ± 63.6		0.013*
Min–Max	90.0–374.0		136.0–374.0		90.0–350.0		
Degree of the dural sac compression at disc level (%)							
Mean ± SD	76.4 ± 13.4		83.2 ± 9.4		72.2 ± 13.9		0.002*
Min–Max	42.0–95.0		66.0–95.0		42.0–90.0		
Central spinal canal grading							
0	34	34.0%	20	52.6%	14	22.6%	0.023*
1	28	28.0%	10	26.3%	18	29.0%	
2	20	20.0%	8	21.1%	12	19.4%	
3	18	18.0%	0	0.0%	18	29.0%	
Rt. LSC							
Median [IQR]	4.2 [2.0–6.0]		6.0 [4.8–6.5]		2.6 [0.8–4.8]		< 0.001*
Min–Max	0.0–9.0		1.7–9.0		0.0–7.1		
Grade of Rt. LSC							
0	42	42.0%	28	73.7%	14	22.6%	0.001*
1	10	10.0%	4	10.5%	6	9.7%	
2	26	26.0%	6	15.8%	20	32.3%	
3	22	22.0%	0	0.0%	22	35.5%	
Lt. LSC							
Median [IQR]	3.7 [1.7–6.0]		5.5 [4.0–6.9]		2.5 [1.3–4.8]		0.006*
Min–Max	0.0–8.8		1.6–8.8		0.0–7.0		

Table 4 (continued)

	Total (*n* = 100)		**Grades 1–2 (*n* = 38)**		**Grades 3–5 (*n* = 62)**		***p*-value**
Grade of Lt. LSC							
0	38	38.0%	24	63.2%	14	22.6%	0.013*
1	12	12.0%	6	15.8%	6	9.7%	
2	28	28.0%	4	10.5%	24	38.7%	
3	22	22.0%	4	10.5%	18	29.0%	
Diameter of Rt. intervertebral foramen							
Mean ± SD	8.7 ± 2.5		10.2 ± 1.8		7.8 ± 2.4		< 0.001*
Min–Max	2.7–14.0		6.5 – 14.0		2.7–12.0		
Grade of Rt. lumbar foraminal stenosis							
0	64	64.0%	32	84.2%	32	51.6%	0.054
1	10	10.0%	4	10.5%	6	9.7%	
2	20	20.0%	2	5.3%	18	29.0%	
3	6	6.0%	0	0.0%	6	9.7%	
Diameter of Lt. intervertebral foramen							
Mean ± SD	8.6 ± 2.7		10.1 ± 2.1		7.8 ± 2.6		0.002*
Min–Max	2.6–13.0		6.6 – 13.0		2.6–12.0		
Grade of Lt. lumbar foraminal stenosis							
0	58	58.0%	30	78.9%	28	45.2%	0.024*
1	20	20.0%	8	21.1%	12	19.4%	
2	8	8.0%	0	0.0%	8	12.9%	
3	14	14.0%	0	0.0%	14	22.6%	

IQR interquartile range; *LSC* lateral spinal canal; *Lt.* left; *Max* maximum; *Min* minimum; *n* number; *Rt.* right; *SD* standard deviation

*Significant at $p < 0.05$

included central canal compromise and the relation between cauda equina and lumbar cerebrospinal fluid (CSF), compression of nerve root in both lumbar lateral recesses and both foraminal zones compromise and impingement of nerve root. According to these imaging parameters central, both lateral and both foraminal lumbar spinal canal stenosis classified into 4 grades from grade 0 (no stenosis) to grade 3 (severe stenosis) [21–24].

Many studies determined multiple quantitative parameters for assessment of lumbar spinal canal stenosis. These parameters included lumbar spinal canal antero-posterior (AP) diameter; lumbar dural sac cross-sectional area, percentage of lumbar dural sac compression, height of both lateral recess and diameter of lumbar intervertebral foramina [21].

In this study, we correlated the qualitative parameters of central, both lateral and both foraminal lumbar spinal canal stenosis grades with the quantitative measures of central lumbar spinal canal measures, both lumbar lateral recesses heights and both lumbar foraminal diameters at L3–4, L4–5 and L5–S1 lumbar vertebral disc levels.

The study of Zileli and his colleagues reported that the most reliable measures used for diagnosis of central lumbar spinal canal stenosis were the AP diameter and cross-sectional area of the lumbar spinal canal. They also reported that height of lateral recess is the most reliable measure used for diagnosis of lateral lumbar spinal canal stenosis and foraminal diameter is the most reliable measures used for diagnosis of foraminal stenosis [21].

Many studies concluded that the diagnosis of central spinal canal stenosis was established if the AP diameter of lumbar spinal canal is less than 12 mm. These results were matched with the results of this study as this study concluded that the diagnosis of grade 3 severe central spinal canal stenosis established if the measurement of AP diameter of lumbar spinal canal at L3–4, L4–5 and L5–S1 were equal or less than 13 mm, 12.5 mm and 12.6 mm, respectively [21, 25–27].

Many studies concluded that the diagnosis of central spinal canal stenosis was established if the lumbar dural sac cross-sectional area is less than 100 mm^2. These results were matched with the results of this study as this study concluded that the diagnosis of grade 3 severe central spinal canal stenosis established if lumbar dural sac cross-sectional area measurement at L3–4, L4–5 and L5–S1 were less than or equal 106 mm^2, 105 mm^2 and 107 mm^2, respectively [21, 25–28].

Table 5 Correlation between Pfirrmann classification and the degree of nerve root compression

	Pfirrmann L3–4	Pfirrmann L4–5	Pfirrmann L5–S1
Mid-sagittal AP diameter of dural sac			
r_s	0.020	−0.193	0.000
p	0.888	0.180	1.000
Cross-sectional area of dural sac			
r_s	−0.527	−0.670	−0.333
p	<0.001*	<0.001*	0.018*
Degree of the dural sac compression at disc level (%)			
r_s	−0.668	−0.620	−0.486
p	<0.001*	<0.001*	<0.001*
Central spinal canal grading			
r_s	0.684	0.612	0.473
p	<0.001*	<0.001*	0.001*
Rt. LSC			
r_s	−0.576	−0.605	−0.619
p	<0.001*	<0.001*	<0.001*
Grade of Rt. LSC			
r_s	0.643	0.602	0.675
p	<0.001*	<0.001*	<0.001*
Lt. LSC			
r_s	−0.564	−0.554	−0.539
p	<0.001*	<0.001*	<0.001*
Grade of Lt. LSC			
r_s	0.651	0.642	0.557
p	<0.001*	<0.001*	<0.001*
Diameter of Rt. intervertebral foramen			
r_s	−0.457	−0.610	−0.576
p	0.001*	<0.001*	<0.001*
Grade of Rt. lumbar foraminal stenosis			
r_s	0.392	0.652	0.475
p	0.005*	<0.001*	<0.001*
Diameter of Lt. intervertebral foramen			
r_s	−0.327	−0.529	−0.560
p	0.020*	<0.001*	<0.001*
Grade of Lt. lumbar foraminal stenosis			
r_s	0.382	0.550	0.536
p	0.006*	<0.001*	<0.001*

r_s coefficient of Spearman's rank-order correlation

*Significant at $p < 0.05$

With regard to the degree of the dural sac compression at disc level (%), this study concluded that a dural sac compression ratio of 64% or less is significant for diagnosis of grade 3 central lumbar spinal canal stenosis. These results were in agreement with the results of Laurencin and his colleagues. They concluded that stenotic ratio used for diagnosis of L3–4, L4–5 and L5–S1 central spinal canal stenosis were 66%, 62% and 73%, respectively [29].

In this study, severe lateral spinal canal stenosis was diagnosed if the average diameter of both lateral recesses at L3–4, L4–5 and L5–S1 disc levels was equal or less than 1.4 mm, 1.5 mm, 1.45 mm, respectively. These results were in agreement with the study of Steurer and his colleagues. They reported that lateral lumbar recess height of 2 mm or less is diagnostic of lateral lumbar spinal canal stenosis [26]. The study of Strojnik and his colleagues concluded that lateral recess height of 3.6 mm or less is considered the cut-off value used for diagnosis of lateral lumbar spinal canal stenosis [30].

In this study, severe lumbar foraminal stenosis was diagnosed if the average diameter of both intervertebral foramen at L3–4, L4–5 and L5–S1 disc levels was equal or less than 3.8 mm, 3.25 mm, 3.25 mm, respectively. These results were in agreement with many studies who reported that an intervertebral foramen measurement below the cut-off value of 3 mm is diagnostic of a foraminal stenosis [9, 26].

The present study attempted to fill a gap of knowledge considering the correlation between the commonly used classifications of intervertebral disc degeneration and the degree of the spinal canal and foraminal stenosis. However, the relatively small number of included patients resulted in some categories of classifications, particularly the NASS classification, lacking adequate numbers for carrying out comparisons. This limits the generalization of the current findings to other populations. In addition, due to the retrospective nature of the study, the radiological findings were not correlated with the clinical presentation of the patients and the severity of pain or disability. However, previous studies showed a poor association between the degree of spinal stenosis and clinical findings [31, 32].

In conclusion, Pfirrmann classification showed a good correlation with neural element compromise, reflecting the severity of spinal canal stenosis, foraminal stenosis, and nerve root compression at different levels of the lumbar spine.

There is significant correlation between the degrees of disc displacement in CTF classification of NASS, the qualitative grading and the quantitative measures of central lumbar spinal canal, lateral lumbar spinal canal and lumbar foraminal stenosis for assessment of severity of lumbar spinal canal stenosis.

Further studies with a larger sample size are required to reproduce these findings and assess the association of NASS classification with spinal canal and foraminal stenosis,

Table 6 Comparison of NASS classification and the degree of nerve root compression

		Normal	Asymmetric bulge	Diffuse bulge	Focal protrusion	Extrusion	*p*-value
L3–4							
Number		42	10	46	2	0	
Central spinal canal grading	Median [IQR]	0 [0–0][b,c]	2 [2][a]	2 [1–3][a]	0 [0–0]	–	< 0.001*
	Min–Max	(0–1)	(1–3)	(0–3)	(0–0)	–	
Grade of Rt. LSC	Median [IQR]	0 [0–0][b,c]	2 [1, 2][a]	2 [1–3][a]	1 [1]	–	< 0.001*
	Min–Max	(0–1)	(0–3)	(0–3)	(1–1)	–	
Grade of Lt. LSC	Median [IQR]	0 [0–0][b,c]	1 [1, 2][a]	2 [1, 2][a]	0 [0–0]	–	< 0.001*
	Min–Max	(0–1)	(0–3)	(0–3)	(0–0)	–	
Grade of Rt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][b]	1 [0–2][a]	0 [0–1]	0 [0–0]	–	0.013*
	Min–Max	(0–1)	(0–2)	(0–3)	(0–0)	–	
Grade of Lt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][b]	1 [0–1][a]	0 [0–0]	0 [0–0]	–	0.005*
	Min–Max	(0–0)	(0–2)	(0–3)	(0–0)	–	
L4–5							
Number		12	24	56	4	4	
Central spinal canal grading	Median [IQR]	0 [0–0][c]	2 [0–3]	3 [1–3][a]	1 [0–2]	2 [1–3]	0.003*
	Min–Max	(0–1)	(0–3)	(0–3)	(0–2)	(1–3)	
Grade of Rt. LSC	Median [IQR]	0 [0–0][b,c]	2 [1–3][a]	3 [2, 3][a]	1 [1]	2 [1, 2]	< 0.001*
	Min–Max	(0–0)	(0–3)	(1–3)	(1–1)	(1–2)	
Grade of Lt. LSC	Median [IQR]	0 [0–0][b,c]	2 [2, 3][a]	3 [2, 3][a]	3 [2, 3]	2 [1, 2]	< 0.001*
	Min–Max	(0–0)	(0–3)	(0–3)	(2–3)	(1–2)	
Grade of Rt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][c]	0 [0–1]	1 [0–2][a]	0 [0–0]	0 [0–0]	0.027*
	Min–Max	(0–0)	(0–2)	(0–3)	(0–0)	(0–0)	
Grade of Lt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][c]	0 [0–1]	1 [0–2] [a]	1 [0–2]	1 [0–1]	0.046*
	Min–Max	(0–0)	(0–2)	(0–3)	(0–2)	(0–1)	
L5–S1							
Number		20	22	32	26	0	
Central spinal canal grading	Median [IQR]	0 [0–1][c]	1 [1, 2]	1 [1, 2][a]	2 [0–3]	–	0.028*
	Min–Max	(0–1)	(0–3)	(0–3)	(0–3)	–	
Grade of Rt. LSC	Median [IQR]	0 [0–0][c]	1 [0–3]	2 [2, 3][a]	0 [0–2]	–	0.001*
	Min–Max	(0–1)	(0–3)	(0–3)	(0–3)	–	
Grade of Lt. LSC	Median [IQR]	0 [0–0][b,c]	2 [1–3][a]	2 [2, 3][a,d]	0 [0–2] [c]	–	< 0.001*
	Min–Max	(0–1)	(0–3)	(1–3)	(0–3)	–	
Grade of Rt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][c]	1 [0–2]	1 [0–2] [a]	0 [0–1]	–	0.029*
	Min–Max	(0–0)	(0–2)	(0–3)	(0–2)	–	
Grade of Lt. lumbar foraminal stenosis	Median [IQR]	0 [0–0][b,c]	1 [0–2] [a]	1 [0–2][a]	0 [0–1]	–	0.025*
	Min–Max	(0–0)	(0–3)	(0–3)	(0–3)	–	

IQR interquartile range; *Max* maximum; *Min* minimum

*Significant at $p < 0.05$

[a] Significant difference from the normal disc

[b] Significant difference from asymmetric bulge

[c] Significant difference from diffuse bulge

[d] Significant difference from focal protrusion; categories with less than 5 patients were not included in the statistical test

Conclusions

There is a good correlation between Pfirrmann classification, CTF classification of NASS, qualitative grading and quantitative measures of lumbar spinal canal that reflects the severity of lumbar spinal canal stenosis and nerve root compression.

Abbreviations

CTF: Combined Task Forces; NASS: North American Spine Society, American Society of Spine Radiology, and American Neuroradiology system; TE: Echo time; TR: Repetition time; FOV: Field of view; CSF: Cerebrospinal fluid; LSC: Lateral spinal canal; AP: Antero-posterior; IBM: International Business Machine; SPSS: Statistical Package for Social Sciences; SD: Standard deviation; IQR:

Interquartile range; *n*: Number; Max: Maximum; Min: Minimum; RC: Root compression; Rt: Right; Lt: Left; rs: Coefficient of Spearman's rank-order correlation.

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Author contributions
AF, CZ, AA, BN and AS carried out the work. AF participated in the study's idea, design, patients' selection, data interpretation, data collection, statistical analysis, references collection, manuscript writing, revision and final approval. CZ participated in patients' selection, data interpretation, data collection, references collection, manuscript writing, revision and final approval. AA participated in patients' assessment and inclusion, imaging interpretation, references collection and manuscript writing and final approval. BN participated in design, patients' selection, data interpretation, data collection, statistical analysis, references collection, manuscript writing, revision and final approval. AS participated in the study's idea, design, patients' selection, data interpretation, data collection, statistical analysis, references collection, manuscript writing, revision and final approval.

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The data supporting the results of this article are included within the article.

Declarations

Ethics approval and consent to participate
The authors obtained permission to conduct this study that was approved by the Research Ethics Committee, Federal Wide Assurance (FWA), Faculty of Medicine- Tanta university (FWA 00100834, IRB 0010038, approval code: 34952/10/21). All patients gave written agreement. The procedures followed were in accordance with our protocol. We recruited 100 patients from Outpatient clinics of Neurology and neurosurgery departments of Tanta University Hospitals.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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