Original Article

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대한영상의학회지

The Relationship between Neural Foraminal Stenosis and Imaging Features of Lumbar Spine MRI in Patients Older Than 60 Years with Lumbar Radiculopathy

요추신경근병증이 있는 60세 이상의 환자에서 신경공 협착과 자기공명영상 평가를 통한 인자와의 상관관계

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Purpose To investigate the MRI features associated with neural foraminal stenosis (NFS) in patients older than 60 years with lumbar (L) radiculopathy.

Materials and Methods This study included 133 retrospectively selected patients older than 60 years with lumbar radiculopathy who had undergone a lumbar spine MRI (from January 2018 to April 2018). For L4/L5 and L5/sacral (S)1 levels, NFS was reviewed blindly by two radiologists. Spondylolisthesis, retrolisthesis, disc height loss, disc bulging/herniation/central canal stenosis, ligamentum flavum thickening, and facet hypertrophy were evaluated separately for the NFS and non-NFS groups, and they were compared using univariate and multivariate analyses.

Results The univariate analysis revealed that disc height loss (p = 0.006) was associated with NFS for L4/L5. For L5/S1, both spondylolisthesis (p = 0.005) and facet hypertrophy (p = 0.006) were associated with NFS. The multivariate logistic analysis revealed that disc height loss was associated with NFS for L4/L5 [odds ratio (OR) = 4.272; 95% confidence interval (CI) 1.736–10.514]. For L5/S1, spondylolisthesis (OR = 3.696; 95% CI 1.297–10.530) and facet hypertrophy (OR = 6.468; 95% CI 1.283–32.617) were associated with NFS.

Conclusion Disc height loss was associated with NFS for L4/L5 and spondylolisthesis and facet hypertrophy were associated with NFS for L5/S1.

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Index terms Stenosis; Radiculopathy; Magnetic Resonance Imaging; Intervertebral Disc Degeneration; Spondylolisthesis

INTRODUCTION

Neural foraminal stenosis (NFS) is the narrowing of the nerve root exit caused by multiple factors such as anterior or posterior slippage of the superior vertebra, decrease in the height of an intervertebral disc, bulging or herniation of the disc, central canal stenosis, osteoarthritic changes in the facet joints, and buckling of the ligamentum flavum (1, 2). NFS in the lumbar spine can cause radiating pain to the lower extremities, tingling, numbness or muscle weakness affecting the lower extremities, stiffness, muscle spasms, a limited range of motion, and in severe cases, bowel or bladder disturbances (3). Clinically, the NFS grade is not always proportionate to the degree of the patient's symptoms. However, in correlation with the patient's symptoms, determination of factors which are associated with NFS could be helpful for the diagnosis of patients with lumbar radiculopathy.

NFS occurs most frequently at the lumbar (L4/L5) level, followed by L5/sacral (S1) (4). To our knowledge, there have been no comprehensive studies to evaluate the most effective factors for the prediction of NFS or which factor is the most important for NFS at the most frequently involved lumbar levels in patients with lumbar radiculopathy.

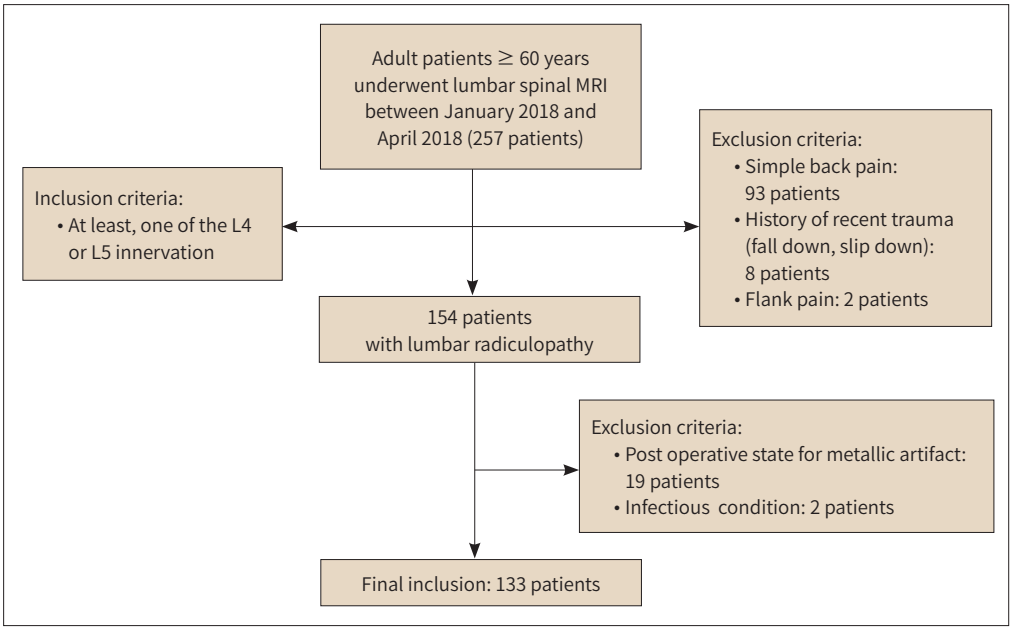
Therefore, this study aimed to perform MRI evaluation of the effects of spondylolisthesis, retrolisthesis, disc height loss, disc bulging/herniation/central canal stenosis, ligamentum flavum thickening, facet hypertrophy on the development of NFS in patients over 60 years of age with lumbar radiculopathy, for L4/L5 and L5/S1.

MATERIALS AND METHODS

PATIENT SELECTION

This retrospective study was approved by our Institutional Review Board, and the requirement for informed consent was waived (IRB No. 05-2019-194). It was performed only at our institute, which is a tertiary academic hospital. From January 2018 to April 2018, we searched the lumbar spinal MRI datasets for a total of 257 patients aged greater than 60 years that contained at least one of the L4 or L5 nerve innervations in the electronic medical records. After reviewing the electronic medical records, we excluded 103 patients who reported simple back pain (n = 93), had a history of recent trauma such as falling or slipping down (n = 8) and had flank pain (n = 2). We selected 154 patients with lumbar radiculopathy. After initially reviewing the selected MRI, we excluded postoperative state patients (n = 19) for metallic artifact and infectious condition (n = 2). The remaining 133 patients were finally selected for inclusion in this study (Fig. 1). The clinical information regarding age and sex of these selected patients were assessed.

Fig. 1. Flow diagram shows patient selection.



MRI ACQUISITION

All patients underwent lumbar spinal MRI scans on a single high field strength system (1.5 Tesla, Avanto or 3.0 Tesla, Skyra, Siemens Healthcare, Erlangen, Germany) with a multichannel phased array spine surface coil. The patients were placed in the supine position. A standardized protocol was used for all patients, which included T1-weighted spin-echo sagittal and axial images and T2-weighted fast spin-echo sagittal and axial images. All sequences had a thickness of 4 mm and an inter-slice space of 1 mm. Sagittal sequences used a 280-mm field of view (FOV) and axial sequences used a 150-mm FOV.

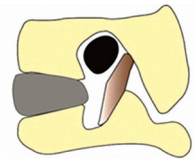
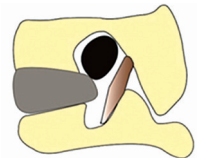
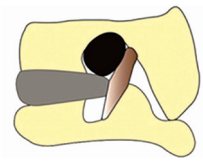
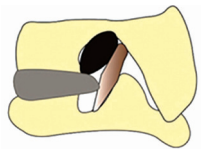
MRI EVALUATION

L4/L5 and L5/S1 of lumbar spinal MRI were retrospectively analyzed on a Picture Archiving and Communication System workstation independently by one experienced musculoskeletal radiologist with 6 years of experience and by a fourth-year resident trainee radiologist. Both radiologists were blinded to the patient's clinical history.

NFS was graded by the type of stenosis, the amount of fat obliteration, and the presence of nerve root compression or deformity, as suggested by Lee at al. (2). A normal state referred to the absence of foraminal stenosis. Mild foraminal stenosis indicated perineural fat obliteration surrounding the nerve root in either the transverse or vertical direction. Moderate foraminal stenosis referred to perineural fat obliteration surrounding the nerve root in both transverse and vertical directions. Severe foraminal stenosis implied nerve root collapse or deformity (Fig. 2). We selected the side of NFS in correlation with patient's clinical history. NFS was evaluated simultaneously. We considered mild, moderate, or severe NFS as a positive finding regardless of the grade.

Spondylolisthesis and retrolisthesis were assessed using the Meyerding system. The distance from the posterior edge of the superior vertebral body to the posterior edge of the adja-

Fig. 2. Illustration of neural foraminal stenosis.

Normal	Absence of foraminal stenosis	
Mild	Perineural fat obliteration surrounding nerve root in either transverse or vertical direction	
Moderate	Perineural fat obliteration surrounding nerve root on both transverse and vertical direction	
Severe	Nerve root collapse or deformity	

cent inferior vertebral body was calculated for assessment of spondylolisthesis. Likewise, the distance from the anterior edge of the superior vertebral body to the anterior edge of the adjacent inferior vertebral body was calculated for assessment of retrolisthesis. These were then reported as percentages of the total superior vertebral body length. Grade 1 slips occurred when less than 25% of the diameter of the vertebral body slipped forward or backward relative to the one below it. Grade 2 slips involved slippage of 26–50% of the diameter of the vertebral body. The corresponding values for grade 3 and 4 slips were 51–75% and 76–100%, respectively. Slips greater than 100% were referred to as grade 5 slips (5). In this study we considered anything greater than grade 1 spondylolisthesis or retrolisthesis as a positive finding regardless of the grade. Additionally, we evaluated the type of spondylolisthesis such as isthmic spondylolisthesis or degenerative spondylolisthesis.

Disc height was measured by determining the length of the vertical line between the inferior and superior boundaries of the vertebral bodies without consideration of the degenerative changes in the signal intensity of the disc. There were no definite criteria for disc height, and the heights were compared in the respective MR images (5). Based on the findings from Ong et al. (6), disc height loss was categorized as normal or reduced (with the severity being graded 1 or 2). Reduced disc height loss was defined as an intervertebral disc with a grossly reduced height in comparison with the discs immediately above and below (7). Since the threshold values have not been previously defined, we measured the disc height as normal or reduced. Additionally, we regarded grade 4 and grade 5 disc degeneration, evaluated based on the Pfirrmann grading system (8), as a positive finding for disc height loss. If the patients had scoliosis, we measured the disc height along the lowest lateral margin of the adjacent

vertebral bodies.

Disc bulging was defined as circumferential symmetric extension of the disc beyond the interspace, according to the definition used by Jensen et al. (9). There was no distinction between disc protrusion and extrusion. Both were considered a disc herniation (10).

Lumbar central canal stenosis was defined as when the anterior cerebrospinal fluid (CSF) space was obliterated. This was divided into four grades; grade 0: no central canal stenosis as the anterior CSF space was not obliterated, grade 1: mild stenosis with clear separation of each cauda equina, grade 2: moderate stenosis with some cauda equina aggregation and grade 3: severe stenosis with the entire cauda equina as a bundle. In this study we considered anything greater than grade 1 central canal stenosis as a positive finding regardless of the grade (11).

Ligamentum flavum thickening was measured on the axial T1-weighted image (T1WI) that was perpendicular to the spinal canal axis and parallel to the lamina, where ligamentun flavum was seen along their entire length (12). There are no existing definite criteria for ligamentum flavum thickening. In this study we used the thickness criteria adopted from Safak et al. (13) with the right and left L4/L5 of 3.41 mm and 3.46 mm, right and left of 3.55 mm and 3.61 mm, respectively.

Facet hypertrophy was measured by digitally drawing a line along the joint and then measuring the narrowest point on the axial T2WI (14). We use the facet joint space thickness criteria of 1.6 mm based on the findings from An et al. (14). We also use the criteria for osteoarthritis of the facet joints adopted from Pathria et al. (15). After measuring the axial T1WI, we evaluated the sagittal T1WI to determine the correlation with NFS and the observed facet hypertrophy.

STATISTICAL ANALYSIS

We divided the selected patients into the NFS and non NFS groups. The NFS group included patients with mild to severe degree of steonsis. We compared spondylolisthesis, retrolisthesis, disc height loss, disc bulging or herniation, ligamentum flavum thickening and facet hypertrophy between the two groups using Fisher's exact tests. A multivariable stepwise logistic regression model was used to determine the factors associated with NFS. Additionally, odds ratio (OR) as estimates of relative risk with 95% confidence intervals (CIs) were obtained for each of the imaging features. Interreader agreement was assessed by using the simple k coefficient. The level of agreement was interpreted as poor when k was less than 0, slight when k was greater than or equal to 0 and less than or equal to 0.2, fair when k was 0.2–0.4, moderate when k was 0.4–0.6, substantial when k was 0.6–0.8, and almost perfect when k was greater than 0.8. Variables with p values less than 0.05 were considered statistically significant. All statistical analyses were performed using commercially available software (version 26.0; IBM Corp., Armonk, NY, USA).

RESULTS

STUDY POPULATION

In total, 133 patients were included in this study. For L4/L5, the mean NFS patient age (± stan-

dard deviation) was 71.65 years ± 6.85 and 19 (43.2%) of the 44 patients were male. The mean non NFS patient age was 69.85 years ± 7.18 and 33 (37.0%) of the 89 patients were male. For L5/S1, the mean NFS patient age was 70.82 years ± 6.55 and 21 (33.8%) of the 62 patients were male. The mean non NFS patient age was 70.12 years ± 7.60 and 31 (43.6%) of the 71 patients

Table 1. Imaging Features for Each NFS Group for L4/L5 and L5/S1

	L4/L5			L5/S1		
	NFS Group (*n* = 44, %)			NFS Group (*n* = 62, %)		
	Mild	Moderate	Severe	Mild	Moderate	Severe
Spondylolisthesis						
Yes	18 (40.9)	-	-	17 (27.4)	-	-
Grade 1	10 (22.7)	-	2 (4.5)	7 (11.2)	1 (1.6)	4 (6.4)
Grade 2	2 (4.5)	-	3 (6.8)	1 (1.6)	1 (1.6)	2 (3.2)
Grade 3	-	-	1 (2.2)	-	-	1 (1.6)
No	26 (59.0)	-	-	45 (72.5)	-	-
	19 (43.1)	4 (9.0)	3 (6.8)	33 (53.2)	3 (4.8)	9 (14.5)
Retrolisthesis						
Yes	5 (11.3)	-	-	23 (37.0)	-	-
Grade 1	4 (9.0)	1 (2.2)	-	19 (30.6)	1 (1.6)	3 (4.8)
Grade 2	-	-	-	-	-	-
Grade 3	-	-	-	-	-	-
No	39 (88.6)	-	-	39 (62.9)	-	-
	27 (61.3)	3 (6.8)	9 (20.4)	31 (50.0)	2 (3.2)	6 (9.6)
Disc height loss						
Yes	16 (36.3)	-	-	18 (29.0)	-	-
	8 (18.1)	2 (4.5)	6 (13.6)	14 (22.5)	1 (1.6)	3 (4.8)
No	28 (63.6)			44 (70.9)		
	23 (52.2)	2 (4.5)	3 (6.8)	36 (58.0)	2 (3.2)	6 (9.6)
Ligamentum flavum thickening						
Yes	22 (50.0)	-	-	8 (12.9)	-	-
	16 (36.3)	2 (4.5)	4 (9.0)	6 (9.6)	-	2 (3.2)
No	22 (50.0)	-	-	54 (87.0)	-	-
	15 (34.0)	2 (4.5)	5 (11.3)	44 (70.9)	3 (4.8)	7 (11.2)
Disc bulging/herniation/central canal stenosis						
Yes	31 (70.4)	-	-	46 (74.1)	-	-
	22 (50.0)	3 (6.8)	6 (13.6)	38 (61.2)	2 (3.2)	6 (9.6)
No	13 (29.5)	-	-	16 (25.8)	-	-
	9 (20.4)	1 (2.2)	3 (6.8)	12 (19.3)	1 (1.6)	3 (4.8)
Facet hypertrophy						
Yes	9 (20.4)	-	-	11 (17.7)	-	-
	7 (15.9)	1 (2.2)	1 (2.2)	8 (12.9)	1 (1.6)	2 (3.2)
No	35 (79.5)	-	-	51 (82.2)	-	-
	24 (54.5)	3 (6.8)	8 (18.1)	42 (67.7)	2 (3.2)	7 (11.2)

Data are presented as numbers and proportions.
NFS = neural foraminal stenosis

were female.

We summarized the number of imaging features for patients with NFS in L4/L5 and L5/S1, based on the NFS grade in Table 1.

UNIVARIATE ANALYSIS FOR IMAGING FEATURES ASSOCIATED WITH NFS FOR L4/L5 AND L5/S1

The results of univariate analysis to determine the imaging features associated with NFS for L4/L5 and L5/S1 are shown in Table 2. For L4/L5, disc height loss was significantly associated with NFS (p = 0.006). For L5/S1, both spondylolisthesis and facet hypertrophy were significantly associated with NFS (p = 0.005, p = 0.006, respectively). However, when we considered spondylolisthesis above grade 2 as positive finding, there was a result showed positive correlation between spondylolisthesis and NFS at both L4/L5 (p = 0.015) and L5/S1 (p = 0.020).

Table 2. Univariate Analyses of the Imaging Features in Each NFS Group for L4/L5 and L5/S1

Features	L4/L5			L5/S1		
	NFS Group (n = 44, %)	Non NFS Group (n = 89, %)	p-Value*	NFS Group (n = 62, %)	Non NFS Group (n = 71, %)	p-Value*
Spondylolisthesis						
Yes	18 (40.9)	23 (25.8)	0.109	17 (27.4)	6 (8.5)	0.005
Grade 1	12 (27.2)	21 (23.5)		12 (19.3)	6 (8.5)	
Grade 2	5 (11.3)	2 (2.2)		4 (6.4)	-	
Grade 3	1 (2.2)	-		1 (1.6)	-	
No	26 (59.1)	66 (74.2)	-	45 (72.6)	65 (91.5)	-
Retrolisthesis						
Yes	5 (11.3)	10 (11.2)	0.999	23 (37.1)	16 (22.5)	0.085
Grade 1	5 (11.3)	9 (10.1)		23 (37.1)	16 (22.5)	
Grade 2	-	1 (1.1)		-	-	
Grade 3	-	-		-	-	
No	39 (88.7)	79 (88.8)	-	39 (62.9)	55 (77.5)	-
Disc height loss						
Yes	16 (36.3)	13 (14.6)	0.006	18 (29.0)	17 (23.9)	0.556
No	28 (63.7)	76 (85.4)	-	44 (71.0)	54 (76.1)	-
Ligamentum flavum thickening						
Yes	22 (50.0)	30 (33.7)	0.089	8 (12.9)	5 (7.0)	0.380
No	22 (50.0)	59 (66.3)	-	54 (87.1)	66 (93.0)	-
Disc bulging/herniation/central canal stenosis						
Yes	31 (70.4)	70 (78.6)	0.389	46 (74.1)	54 (76.0)	0.842
No	13 (29.5)	19 (21.3)	-	16 (25.8)	17 (23.9)	-
Facet hypertrophy						
Yes	9 (20.4)	8 (9.0)	0.095	11 (17.7)	2 (2.8)	0.006
No	35 (79.6)	81 (91.0)	-	51 (82.3)	69 (97.2)	-

Data are presented as numbers and proportions.
*Results of Fisher's exact test.
NFS = neural foraminal stenosis

MULTIVARIABLE LOGISTIC REGRESSION ANALYSIS FOR IMAGING FEATURES ASSOCIATED WITH NFS FOR L4/L5 AND L5/S1

The result of the multivariable logistic analysis to determine the imaging features associated with NFS for L4/L5 and L5/S1 are shown in Table 3. For L4/L5, disc height loss (Fig. 3) was significantly associated with NFS (OR = 4.272; 95% CI 1.736–10.514). For L5/S1, not only spondylolisthesis (Fig. 4) (OR = 3.696; 95% CI 1.297–10.530) but also facet hypertrophy (Fig. 5) (OR = 6.468; 95% CI 1.283–32.617) was significantly associated with NFS.

ASSOCIATION BETWEEN THE TYPE OF SPONDYLOLISTHESIS AND NFS FOR L4/L5 AND L5/S1

Table 4 shows the types of spondylolisthesis in patients with or without NFS for L4/L5 and L5/S1. For L4/L5, isthmic type spondylolisthesis was not associated with NFS. However, for L5/S1, isthmic type spondylolisthesis was significantly correlated with NFS (p = 0.012).

INTERREADER AGREEMENT

For L4/L5, there was almost perfect agreement between readers for spondylolisthesis (k = 0.87), retrolisthesis (k = 0.89), disc height loss (k = 0.91) and ligamentum flavum thickening (k = 0.87). Additionally, there was substantial agreement in disc bulging/herniation/central canal stenosis (k = 0.77) and facet hypertrophy (k = 0.71). For L5/S1, there was almost perfect agree-

Table 3. Multivariate Logistic Regression Analyses of the Imaging Features in Each NFS Group for L4/L5 and L5/S1

Features	L4/L5			L5/S1		
	p-Value	Multivariate OR	95% CI	*p*-Value	Multivariate OR	95% CI
Spondylolisthesis						
Yes	0.163	1.891	0.773–4.623	0.014	3.696	1.297–10.530
No	-	1	Reference	-	1	Reference
Retrolisthesis						
Yes	0.808	0.844	0.216–3.303	0.145	1.887	0.803–4.430
No	-	1	Reference	-	1	Reference
Disc height loss						
Yes	0.002	4.272	1.736–10.514	0.922	0.956	0.392–2.335
No	-	1	Reference	-	1	Reference
Ligamentum flavum thickening						
Yes	0.237	1.686	0.710–4.005	0.216	2.198	0.632–7.641
No	-	1	Reference	-	1	Reference
Disc bulging/herniation/central canal stenosis						
Yes	0.379	0.648	0.246–1.705	0.823	1.106	0.456–2.681
No	-	1	Reference	-	1	Reference
Facet hypertrophy						
Yes	0.158	2.395	0.713–8.052	0.024	6.468	1.283–32.617
No	-	1	Reference	-	1	Reference

CI = confidence interval, NFS = neural foraminal stenosis, OR = odds ratio

Fig. 3. Disc height loss associated with NFS.
A. A 72-year-old female patient with radiating pain in the thigh and knee shows disc height loss at L4/L5 with severe NFS (arrow) on sagittal T1-weighted image.
B. The illustration shows NFS caused by disc height loss.
NFS = neural foraminal stenosis

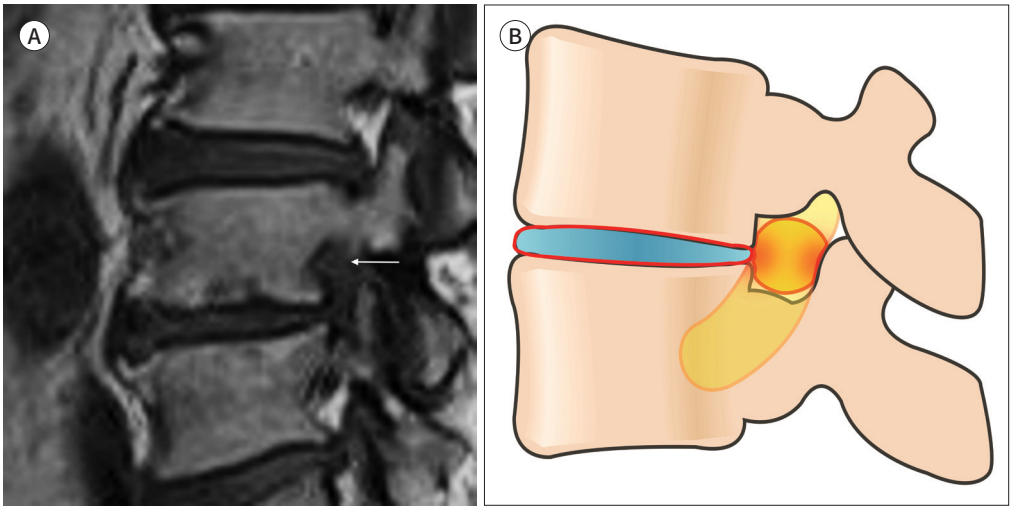
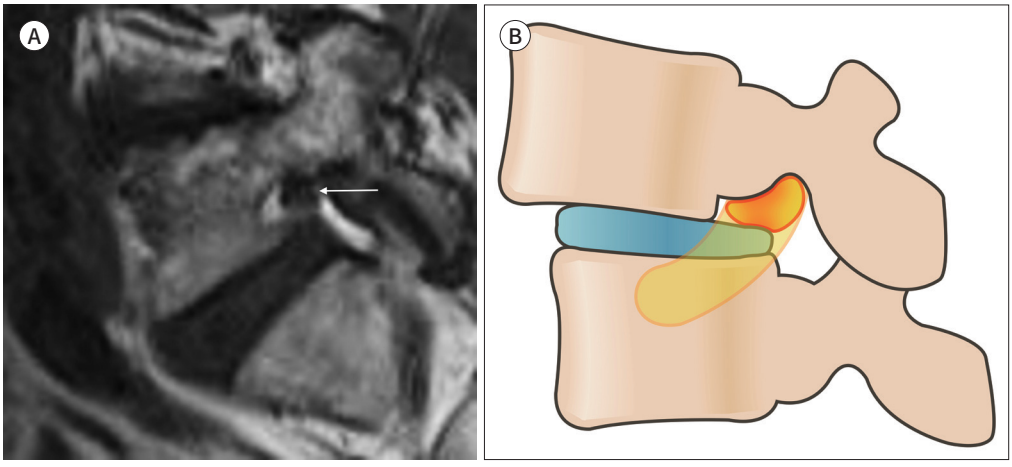


Fig. 4. Spondylolisthesis associated with NFS.
A. A 70-year-old male patient with radiating pain in the foot shows spondylolisthesis at L5/S1 with severe NFS (arrow) on sagittal T1-weighted image.
B. The illustration shows NFS caused by spondylolisthesis.
NFS = neural foraminal stenosis



ment between readers for retrolisthesis (k = 0.84), disc height loss (k = 0.84) and facet hypertrophy (k = 0.82). Additionally there was substantial agreement in spondylolisthesis (k = 0.76), ligamentum flavum thickening (k = 0.77) and disc bulging/herniation/central canal stenosis (k = 0.77).

DISCUSSION

This study aimed to assess the effect of imaging features in L4/L5 and L5/S1 on NFS for patients with lumbar radiculopathy.

Fig. 5. Facet hypertrophy associated with NFS.
A. A 78-year-old female patient with numbness of the bilateral lower extremities shows facet hypertrophy at L5/S1 with severe NFS (arrow) on sagittal T1-weighted image. Additionally, severe NFS is shown at L4/L5.
B. The illustration shows NFS caused by facet hypertrophy.
NFS = neural foraminal stenosis

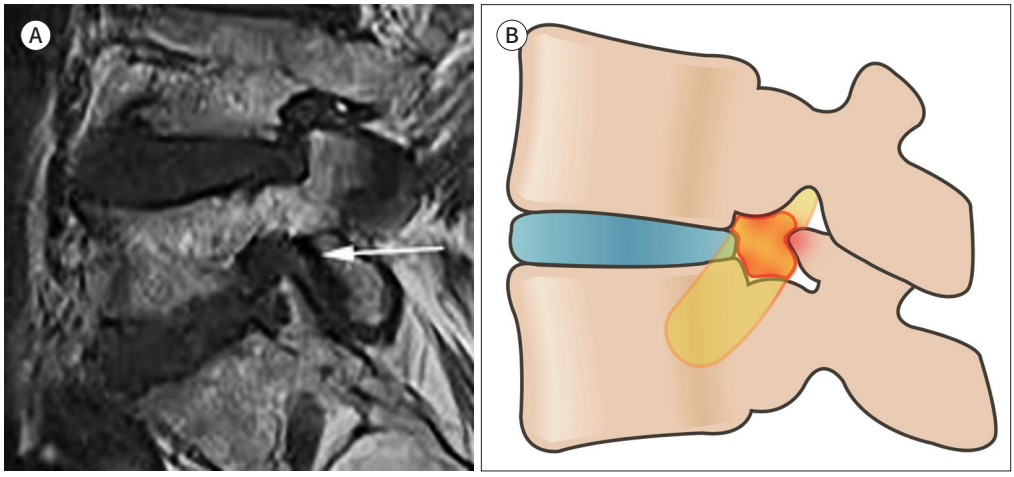


Table 4. Association between the Type of Spondylolisthesis and NFS for L4/L5 and L5/S1

Features	L4/L5			L5/S1		
	NFS Group (*n* = 44, %)	Non NFS Group (*n* = 89, %)	*p*-Value*	NFS Group (*n* = 62, %)	Non NFS Group (*n* = 71, %)	*p*-Value*
Spondylolisthesis						
Isthmic type	1 (2.2)	1 (1.1)	0.999	8 (12.9)	1 (1.4)	0.012
Degenerative type	43 (97.7)	88 (98.8)	-	54 (87.0)	70 (98.5)	-

Data are presented as numbers and proportions.
*Results of Fisher's exact test.
NFS = neural foraminal stenosis

Upon analysis of the imaging features associated with NFS at L4/L5, disc height loss was found to be significantly associated with NFS. This is presumed to be related to the stability of the anterior and posterior longitudinal ligaments, interspinous ligament, supraspinous ligament, intertransverse ligament, and facet capsular ligament supporting the lumbar spine. L4/L5 level ligamentous laxity, which showed the highest degree of lordosis in the erect position, is likely to have increased, possibly causing degenerative change. According to Lee et al. (16), the posterior longitudinal ligament and interstitial ligament stability is lowest at the L4 level. The autopsy study by Rissanen (17) reported that L4/L5 interstitial ligament rupture or degenerative change after 40 years of age occurred in over 90% of the cases. For this reason, L4/L5 is affected by craniocaudal factor such as disc height loss rather than transverse factor such as spondylolisthesis or retrolisthesis. Additionally, degenerative discs have a lower water concentration and loss of proteoglycan than normal age matched discs (18). It can cause consequential loss of elasticity of the disc, which can affect the rapid loss of disc height in degenerative discs (19). Narrowing of the disc space due to degenerative change and downward displacement of the inferior articular process results in a bilobal shape of the foramen. This may explain the narrowing of the foramen.

At the level L5/S1, spondylolisthesis was significantly associated with NFS. The developmental mechanisms underlying spondylolisthesis and retrolisthesis differ. Spondylolisthesis usually develops from lumbar lordosis, while retrolisthesis develops from the compensatory mechanisms to move the gravity axis posteriorly for the correction of lumbar spinal sagittal imbalance (20). According to Shipley (21), in cases involving spondylolisthesis, anterior subluxation of the superior vertebral lamina and facets can cause narrowing in the central and lateral recess regions of the canal, respectively. The foramen becomes distorted from the normal vertical oval shape to a figure-of-eight or keyhole shape, and the exiting nerve root becomes trapped between the pedicle of the subluxated vertebra above and the disc below. Spondylolisthesis results in application of shear forces to the intervertebral disc. Such forces are likely to result in changes in disc structure and water content with secondary degeneration (22).

Spondylolisthesis involves pseudobulging of the disc itself, which causes the ligamentum flavum to be pulled to the interior aspect and narrows the foramen. Moreover, the inferior articular process of the superior vertebral body comes down, making the foramen narrower. Kim et al. (23) demonstrated that anterior displacement of the vertebral body causes the vertical axis of the neural foramen to be pulled closer to the horizontal axis. Retrolisthesis also shows downward motion of the inferior articular process of the superior vertebral body, there is no actual evidence of pulling of the ligamentum flavum or pseudobulging of the disc itself. This results in a weaker effect on NFS in comparison with that of spondylolisthesis.

Facet hypertrophy was also significantly associated with NFS at L5/S1. Anteroposterior stenosis results from the superior articular process and posterior vertebral body transversely (1, 24). The axis of the superior articular process of S1 shows a much more horizontal tendency, compared to the superior articular process of L5, which appears to have more vertical tendency. It can cause compression of neural foramen with transverse direction, resulting in NFS at L5/S1. Additionally, disc bulging and osteophyte are generated simultaneously in most cases.

This study had several limitations. First, we did not analyze a large number of subjects, which can lead to bias in our results. Second, we included only patients who were aged greater than 60 years of age. NFS usually caused by degenerative change, so we focused imaging features associated with age related degenerative change which is commonly observed among patients greater than 60 years of age, rather than theoretical factors associated with NFS. Third, we did not include other factors that can affect the NFS such as foraminal body spur or lateral recess stenosis. These can be major influencing factors especially for the patients with degenerative scoliosis. Fourth, the patient selection only accounted for lumbar radiculopathy related to nerve symptoms. Therefore, there were no clear exclusion criteria based on clinical tests or symptoms due to the patient's past medical history. However, to address this limitation, this study included cases showing lumbar radiculopathy as well as numbness, tingling sensations, or leg, calf, ankle, or foot pain along the L4 and L5 spinal nerve dermatome. Cases with mere back pain were excluded in an attempt to overcome this limitation. Fifth, most patients showed mild degree of NFS in this study. For mild degree NFS, it exhibited only one method of fat obliteration which was associated with disc height loss only. This could be a selection bias. Sixth, we regarded grade 1 spondylolisthesis as a

positive finding. However, when we regarded spondylolisthesis greater than grade 2 as a positive finding, there was a positive correlation between spondylolisthesis and NFS. This different result was significant for the association between the grade of spondylolisthesis and the degenerative change of the facet joint. Seventh, there were only two patients who showed isthmic spondylolisthesis at L4/L5. Since there were such small numbers, it is difficult to draw conclusions regarding the relationship between the type of spondylolisthesis and NFS for L4/L5. Eighth, we were not able to consider other factors which can cause similar symptoms associated with L4 or L5 nerve innervation. For example, varicose veins in the lower extremities can cause tingling sensations, numbness, or pain in the thigh, calves or foot. Additionally, piriformis syndrome could also lead to the development of similar symptoms, which is caused by compression of the sciatic nerve. Ninth, we measured radiological variables using sagittal and axial MR images, which were obtained in the supine position. The supine position involves non-axial loading and may not show the actual foraminal size when standing or walking, since lumbar spinal stenosis is a dynamic phenomenon that typically worsens in the upright, weight-bearing, and extended position. Evaluation of flexion on plain radiographs in the standing position and dynamic images during extension may have allowed for more accurate grading in comparison with differences in the degree.

The present study demonstrated the relationship between NFS and other imaging features such as spondylolisthesis, retrolisthesis, disc height loss, disc bulging/herniation/central canal stenosis, ligamentum flavum thickening and facet hypertrophy for the elderly patients with lumbar radiculopathy. For L4/L5, disc height loss was significantly associated with NFS. For L5/S1, both spondylolisthesis and facet hypertrophy were significantly associated with NFS. Currently, simple plain radiography or computed tomography is not a sufficient tool for the diagnosis of NFS. The findings from this study might be helpful in guiding the diagnosis of NFS.

Author Contributions

Conceptualization, L.K., J.H.S.; data curation, L.K., J.H.S.; formal analysis, P.C.; investigation, R.H.; methodology, R.J.; project administration, Y.J.A.; resources, K.J.H.; software, K.T.U.; supervision, J.H.S.; validation, all authors; visualization, K.M.; writing—original draft, L.K.; and writing—review & editing, all authors.

Conflicts of Interest

Chang Ho Jeon has been an Editorial Board Member of Journal of the Korean Society of Radiology since 2021; however, he was not involved in the peer reviewer selection, evaluation, or decision process of this article. Otherwise, no other potential conflicts of interest relevant to this article were reported.

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요추신경근병증이 있는 60세 이상의 환자에서 신경공 협착과 자기공명영상 평가를 통한 인자와의 상관관계

이계영[1] · 정희석[1*] · 박찬규[1] · 김매란[1] · 류화성[1] · 노지은[1] · 염정아[1] · 김진혁[1] · 김태언[1] · 전창호[2]

목적 요추신경근병증이 있는 60세 이상의 환자의 신경공 협착에 영향을 줄 수 있는 인자를 자기공명영상 평가를 통해 알아보고자 하였다.

대상과 방법 요추신경근병증이 있는 60세 이상의 환자 133명이 본원에서 시행 받은 2018년 1월부터 4월까지의 요추 자기공명영상을 대상으로 하였다. 제4/5 요추간과 제5 요추/제1 천추간에서 신경공 협착이 있는 군과 없는 군으로 나눈 후 척추전방전위증, 척추후방전위증, 추간판 간격 감소, 추간판탈출증, 중심성 척추관 협착, 황색인대비후, 척추후관절 비후 여부를 2명의 판독자가 분석한 후 단변량 및 다변량 로지스틱 회귀분석을 시행하였다.

결과 단변량 분석에서 제4/5 요추간에 대해 추간판 간격 감소(p = 0.006), 제5 요추/제1 천추간에 대해서는 척추전방전위증(p = 0.005)과 척추후관절 비후(p = 0.006)가 신경공 협착과 유의한 연관성을 보였다. 다변량 분석에서는 제4/5 요추간에 대해 추간판 간격 감소[odds ratio (이하 OR) = 4.272; 95% confidence interval (이하 CI) 1.736~10.514]가 신경공 협착과 관련된 인자였다. 제5 요추/제1 천추간에서는 척추전방전위증(OR = 3.696; 95% CI 1.297~10.530)과 척추후관절 비후(OR = 6.468; 95% CI 1.238~32.617)가 이와 관련된 인자였다.

결론 제4/5 요추간에서는 추간판 간격 감소가, 제5 요추/제1 천추간에서는 척추전방전위증과 척추후관절 비후가 신경공 협착과 관련된 인자였다.

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