ORIGINAL ARTICLE

Reliability of Cervical Neural Foramen Stenosis Grading Based on Axial Three-Dimensional Magnetic Resonance Images

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Objective: To assess the reliability of cervical neural foramen stenosis (CNFS) grading by using three-dimensional (3D) T1W, 3D T2W, and two-dimensional (2D) T2W images in axial plane.

Materials and Methods: The authors enrolled 32 patients between December 2019 and February 2020 who underwent cervical spine magnetic resonance imaging (MRI) with clinical manifestations of cervical spondylosis. Two blinded radiologists interpreted the axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images using a 4-point visual scale for CNFS grading in all cervical levels. Intra-observer agreement of CNFS grading on the three imaging pulse sequences for each observer and inter-observer agreement between both observers were analyzed using intra-class correlation coefficient (ICC).

Results: Three hundred eighty-four neural foramina were evaluated. The overall mean intra-observer agreement of CNFS grading was strong on the axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images for each observer with ICC values of 0.79 and 0.82. The overall mean inter-observer agreement for CNFS grading was strong on 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images with ICC values of 0.79, 0.79, and 0.86, respectively.

Conclusion: Axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images exhibited comparable strong reliability in the grading of cervical neural foramen stenosis without the significant benefit of 3D over 2D technique.

Keywords: Cervical spine; Neural foramen stenosis; MRI; Grading

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Cervical spondylosis is a degenerative condition that causes cervical anatomic changes in multiple structures, including bones, facet joints, uncovertebral joints, intervertebral discs, and spinal ligaments. These changes result in a narrowing of the cervical neural foramina and cause cervical radiculopathy, a common clinical manifestation of the degenerative cervical spines that lower patients' quality of life[1-8].

Magnetic resonance imaging (MRI) is the most frequently used imaging modality for evaluating cervical spinal structures such as cervical neural foramen, spinal cord, and intervertebral discs. It provides higher soft tissue contrast, thus is superior in assessing cervical pathology than other imaging modalities such as plain radiographs and computed tomography[1,2,8].

However, there have been neither standard imaging criteria nor the best MRI pulse sequences to evaluate cervical neural foramen stenosis. Discrepancies in neural foramen stenosis severity grading exist among radiologists and clinicians. There have been many prior studies on the imaging techniques for improving concordance of the image interpretation[2,5,6,9-12], and some studies were to correlate with clinical symptoms[3,10,13,14]. However, the concordance in image interpretation and clinical correlation still varies.

A three-dimensional (3D) MRI technique has shown an advantage in cervical neural foramen evaluation, especially in lower partial volume averaging and cerebrospinal fluid (CSF) flow artifacts over the conventional two-dimensional (2D) technique[1,9,13], which could help the radiologists for

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better evaluation of the cervical neural foramen.

The present study aimed to assess the reliability of the radiologists in evaluating cervical neural foramen stenosis by using 3D T1-weighted (T1W) images, 3D T2-weighted (T2W) images, and conventional 2D T2-weighted images in the axial imaging plane.

Materials and Methods

Patient selection

The present study was a prospective study approved by the local ethics committee, No. MURA2020/32, on December 09, 2019. Informed consent was obtained for all subjects included in the present study. The authors prospectively enrolled patients that underwent cervical spine MRI with clinical manifestations of cervical spondylosis between December 2019 and February 2020. Adult patients with symptoms including axial neck pain, cervical radiculopathy, paresthesia, weakness, and gait disturbance were included in the present study. The patients with a previous history of cervical spinal surgery, spinal trauma, spondyloarthropathy, and spinal tumor were excluded from the study. In the present study, the patients that met the inclusion criteria within the three months of study period were included. Finally, the present study comprised 32 patients with 384 neural foramina. The demographic data and clinical information were collected.

MRI parameters

MRI examinations were performed using a 1.5-T scanner (Ingenia; Philips Medical Systems, Best, Netherlands) with Release software version 5.4.1.1 and a 3.0-T scanner (Ingenia; Philips Medical Systems, Best, Netherlands) with Release software version 5.3.1.1. Images were routinely obtained using head and neck coil in the axial and sagittal planes using T1W and T2W turbo-spin-echo (TSE) sequences with the patients in the supine position. The axial imaging plane was set parallel to the intervertebral discs and covered all cervical spinal levels from C2 to T1. Additional axial images were acquired using 3D isotropic T1W and T2W TSE sequences. Details of the MRI protocol are described in Table 1.

Table 1. Magnetic resonance imaging parameters

Parameters	Axial 3D T1W TSE	Axial 3D T2W TSE	Axial 2D T2W TSE
1.5T Philips Ingenia			
TR/TE (msec)	600/32	2,200/120	3,000/100
Slice thickness (mm)	3.0	3.0	3.0
Gap (mm)	0	0	1.0
Flip angle (degree)	90	90	90
FOV (mm)	160×160	160×160	160×160
Matrix	200/200	228/213	240/189
Voxel size (mm)	0.80/0.80/3.00	0.70/0.75/3.00	0.66/0.66/3.00
Turbo factor	25	44	22
Parallel imaging factor	1.8	1.4	1.3
Scan time (minutes)	4	5	4
3.0T Philips Ingenia			
TR/TE (msec)	350/20	1,500/100	3,500/100
Slice thickness (mm)	3.0	3.0	3.0
Gap (mm)	0	0	1.0
Flip angle (degree)	90	90	90
FOV (mm)	150×150	150×150	160×160
Matrix	216/216	272/207	240/189
Voxel size (mm)	0.69/0.69/3.00	0.55/0.72/3.00	0.66/0.66/3.00
Turbo factor	25	44	22
Parallel imaging factor	1.8	1.4	1.3
Scan time (minutes)	4	5	4

2D=two dimensional; 3D=three dimensional; TSE=turbo spin echo; T1W=T1 weighted image; T2W=T2 weighted image; TR=repetition time; TE=echo time; FOV=field of view

Image analysis

The MR images were interpreted independently by a neuroradiologist and a second-year neuro-radiology fellow with ten years and two years of experience in spinal MRI, respectively. They were blinded to the clinical information and official radiological reports. Each observer graded the three axial image sets derived from 3D and 2D image acquisition for the severity of the cervical neural foramen stenosis (CNFS) from C2-C3 to C7-T1 levels. The authors introduced a 4-point visual scale for CNFS severity grading by adapting from the templates of Kim et al.[2] and Park et al.[5,14], based on the degree of neural foramen narrowing and perineural fat obliteration in the neural foramina. The severity grading was assigned as grade 0 for no CNFS, grade 1 for mild narrowing of the neural foramen without nerve root compromise and less than 50% perineural fat obliteration, grade 2 for moderate neural foramen stenosis with more than 50% perineural fat obliteration, and grade 3 for severe neural foramen stenosis with collapse nerve root and total obliteration of perineural fat (Figure 1-4).

Statistical analysis

The statistical analyses were performed with the Stata/IC software, version 14.0. Intra-observer agreement of the axial image-based cervical neural

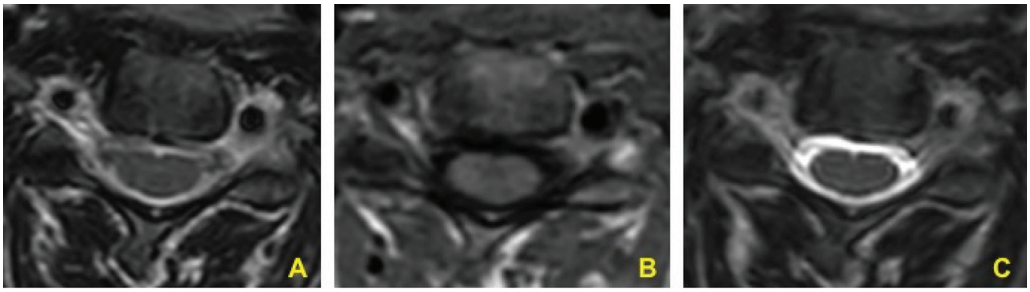

Figure 1. A 52-year-old female patient with cervical radiculopathy. MRI shows grade 0 cervical neural foramen stenosis (no CNFS) in (A) axial 2D T2W image, (B) axial 3D T1W image, and (C) axial 3D T2W image.

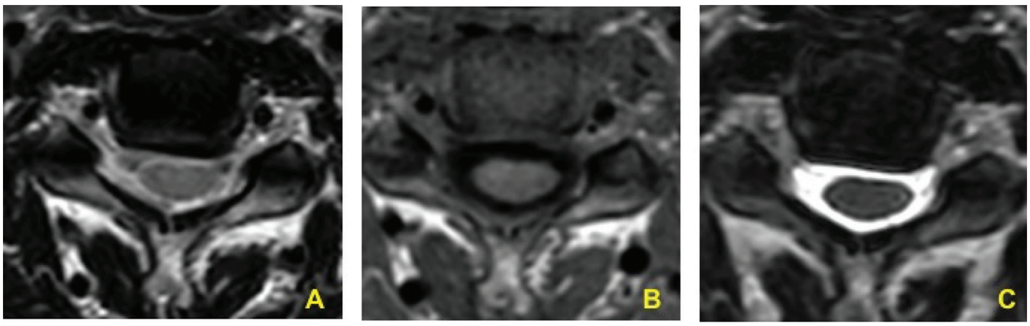

Figure 2. A 62-year-old female patient with cervical radiculopathy. MRI shows grade 1 cervical neural foramen stenosis (mild CNFS) bilaterally in (A) axial 2D T2W image, (B) axial 3D T1W image, and (C) axial 3D T2W image.

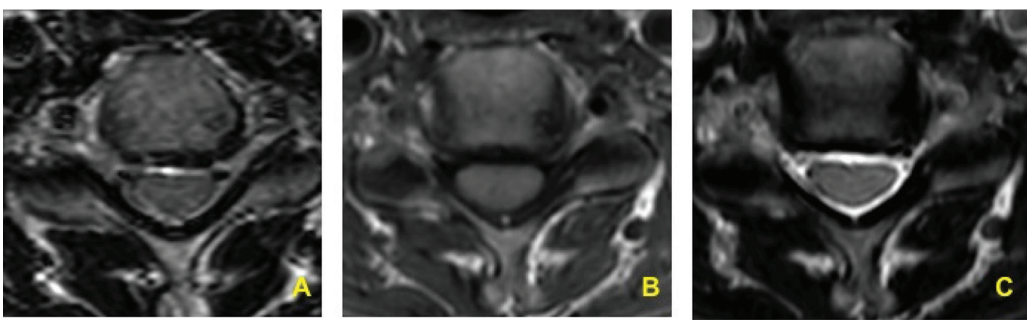

Figure 3. A 68-year-old female patient with cervical radiculopathy. MRI shows grade 2 cervical neural foramen stenosis (moderate CNFS) on the left side in (A) axial 2D T2W image, (B) axial 3D T1W image, and (C) axial 3D T2W image.

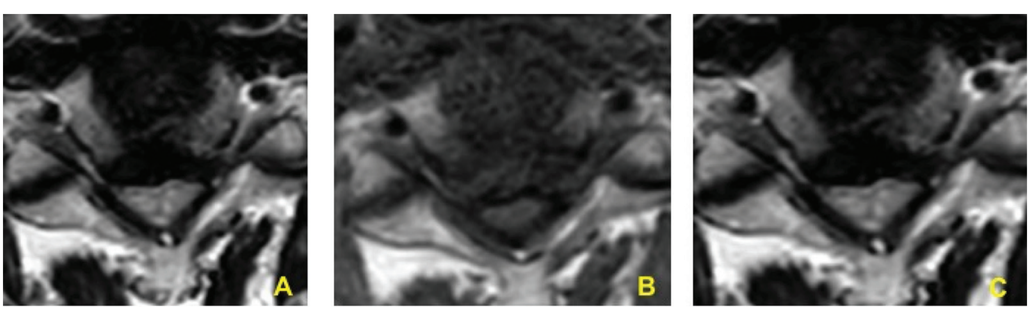

Figure 4. An 80-year-old male patient with gait disturbance. MRI shows grade 3 cervical neural foramen stenosis (severe CNFS) bilaterally in (A) axial 2D T2W image, (B) axial 3D T1W image, and (C) axial 3D T2W image.

foramen stenosis grading on the three imaging pulse sequences as 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE, for each observer and inter-observer agreement between the two observers were analyzed using intra-class correlation coefficient (ICC), ranging from 0 to 1, with p-value and 95% confidence interval (CI). According to the previous guideline for interpreting ICC values[15], the ICC values in the present study were interpreted as ICC values greater than 0.75 indicate strong agreement, values of 0.40 to 0.75 indicate moderate agreement, and values lower than 0.4 indicate poor agreement. The authors also determined the overall mean values and standard deviation of the ICC in all cervical neural foramina for each observer. A p-value less than 0.05 was considered statistically significant.

Results

The 32 patients enrolled in the present study included 11 men and 21 women, with 384 neural foramina. The age ranged from 38 to 85 years (mean age 68.13±12.35 years). There were various clinical manifestations in the patients. The details of demographic data are described in Table 2.

Table 2. Demographic data

	Total (n=32)
Age (years); mean±SD	68.13±12.35
Sex; n (%)	
Female	21 (65.6)
Male	11 (34.4)
Weight (kg); mean±SD	67.5±19.53
Height (cm); mean±SD	157.18±19.48
BMI (kg/m²); mean±SD	25.24±3.51
Symptoms; n (%)	
Axial neck pain	5 (15.6)
Radiculopathy	9 (28.1)
Paresthesia	5 (15.6)
Weakness	4 (12.5)
Gait disturbance	9 (28.1)
Cervical alignment; n (%)	
Normal cervical lordosis	4 (12.5)
Decreased cervical lordosis/straightening of the cervical spine	18 (56.3)
Reverse cervical lordosis	10 (31.3)

SD=standard deviation; BMI=body mass index

Severe neural foramen stenosis (grade 3) was more frequently observed at C5-6 and C6-7 levels, and no CNFS (grade 0) was most commonly found at the C2-3 level in three imaging pulse sequences by two observers. The overall mean value of intra-observer agreement for the axial image-based grading of cervical neural foramen stenosis using 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images of each observer showed strong agreement in both observers (ICC values of 0.79 and 0.82 for observer 1 and observer 2, respectively).

While considering each level of neural foramina, the results demonstrated moderate agreement at both sides of the C2-3 level and right C5-6 level for observer 1 (ICC values of 0.55 to 0.74), and strong agreement in the rest of the cervical levels (ICC values of 0.78 to 0.91). For observer 2, there was moderate agreement on both sides of the C7-T1 level (ICC value of 0.70 to 0.75), and strong agreement in the other cervical levels (ICC values of 0.77 to 0.91). The details of intra-observer agreement among the three MRI pulse sequences for two observers are shown in Table 3.

The overall mean inter-observer agreement for axial image-based cervical neural foramen stenosis grading was strong for inter-observer reliability on 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images (ICC values of 0.79, 0.79, and 0.86, respectively). When comparing the performance of the three imaging pulse sequences, the result mainly exhibited slightly higher agreement with the axial 2D T2W TSE, except for the right C4-5, right C5-6, and right C7-T1 levels. Complete agreement (ICC values of 1.00) in stenosis grading was shown in axial 3D T1W images at the right C2-3 level.

The results of inter-observer agreement analysis in each level based on axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE image-based grading are demonstrated in Table 4.

The reliability of stenosis grading was strong between C3-4 to C5-6 levels and right C7-T1 level on all three imaging pulse sequences (ICC values of 0.76 to 1.00, 0.84 to 0.97, and 0.78 to 0.96 on 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images, respectively). There was relatively lower reliability of grading at the right C2-3 level on 3D T2W TSE and 2D T2W TSE images with the moderate agreement (ICC values of 0.54 and 0.73, respectively), left C7-T1 level on 3D T2W images (ICC value of 0.69) and left C5-6 level with ICC values of 0.60 and 0.74 on 3D T1W TSE, and 3D T2W TSE images, respectively.

After categorization of the image-based neural foramen stenosis severity into a low grade for grade 0 to 1, and high grade for grade 2 to 3 stenosis, the overall mean value of the inter-observer agreement was slightly increased on all three imaging pulse sequences (ICC values of 0.83, 0.88, and 0.87 on 3D

Table 3. Intra-observer agreement in grading of cervical neural foramen stenosis based on axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images

Level (side)	Observer 1		Observer 2	
	ICC (95% CI)	p-value	ICC (95% CI)	p-value
C2-3 (R)	0.551 (0.193 to 0.766)	0.004	0.848 (0.727 to 0.921)	<0.001
C2-3 (L)	0.742 (0.536 to 0.865)	<0.001	0.769 (0.585 to 0.88)	<0.001
C3-4 (R)	0.807 (0.653 to 0.899)	<0.001	0.817 (0.671 to 0.905)	<0.001
C3-4 (L)	0.859 (0.747 to 0.927)	<0.001	0.859 (0.746 to 0.926)	<0.001
C4-5 (R)	0.825 (0.686 to 0.909)	<0.001	0.816 (0.668 to 0.904)	<0.001
C4-5 (L)	0.911 (0.84 to 0.954)	<0.001	0.906 (0.832 to 0.951)	<0.001
C5-6 (R)	0.734 (0.521 to 0.861)	<0.001	0.835 (0.704 to 0.914)	<0.001
C5-6 (L)	0.779 (0.603 to 0.885)	<0.001	0.879 (0.783 to 0.937)	<0.001
C6-7 (R)	0.787 (0.617 to 0.889)	<0.001	0.84 (0.712 to 0.916)	<0.001
C6-7 (L)	0.829 (0.692 to 0.911)	<0.001	0.868 (0.762 to 0.931)	<0.001
C7-T1 (R)	0.849 (0.729 to 0.921)	<0.001	0.753 (0.556 to 0.871)	<0.001
C7-T1 (L)	0.783 (0.61 to 0.887)	<0.001	0.699 (0.459 to 0.843)	<0.001
Mean±SD	0.788±0.090		0.824±0.059	

R=right; L=left; SD=standard deviation; ICC=intra-class correlation coefficient; CI=confidence interval

Table 4. Inter-observer agreement in axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE image-based cervical neural foramen stenosis grading between the two observers

Level (side)	3D T1W image		3D T2W image		2D T2W image	
	ICC (95% CI)	p-value	ICC (95% CI)	p-value	ICC (95% CI)	p-value
C2-3 (R)	1 (1.000 to 1.000)	<0.001	0.542 (0.062 to 0.776)	0.017	0.725 (0.436 to 0.866)	<0.001
C2-3 (L)	0.935 (0.867 to 0.968)	<0.001	0.751 (0.489 to 0.878)	<0.001	0.838 (0.668 to 0.921)	<0.001
C3-4 (R)	0.876 (0.745 to 0.939)	<0.001	0.886 (0.767 to 0.945)	<0.001	0.923 (0.843 to 0.962)	<0.001
C3-4 (L)	0.88 (0.754 to 0.941)	<0.001	0.862 (0.718 to 0.933)	<0.001	0.862 (0.718 to 0.933)	<0.001
C4-5 (R)	0.814 (0.620 to 0.909)	<0.001	0.852 (0.696 to 0.928)	<0.001	0.805 (0.601 to 0.905)	<0.001
C4-5 (L)	0.891 (0.777 to 0.947)	<0.001	0.963 (0.924 to 0.982)	<0.001	0.911 (0.818 to 0.957)	<0.001
C5-6 (R)	0.836 (0.665 to 0.920)	<0.001	0.954 (0.905 to 0.977)	<0.001	0.868 (0.729 to 0.936)	<0.001
C5-6 (L)	0.72 (0.425 to 0.863)	<0.001	0.902 (0.799 to 0.952)	<0.001	0.880 (0.755 to 0.942)	<0.001
C6-7 (R)	0.708 (0.402 to 0.857)	<0.001	0.887 (0.769 to 0.945)	<0.001	0.957 (0.911 to 0.979)	<0.001
C6-7 (L)	0.613 (0.207 to 0.811)	0.005	0.889 (0.773 to 0.946)	<0.001	0.933 (0.862 to 0.967)	<0.001
C7-T1 (R)	0.844 (0.681 to 0.924)	<0.001	0.967 (0.933 to 0.984)	<0.001	0.828 (0.647 to 0.916)	<0.001
C7-T1 (L)	0.856 (0.705 to 0.930)	<0.001	0.714 (0.414 to 0.860)	<0.001	0.781 (0.552 to 0.893)	<0.001
Mean±SD	0.789±0.128		0.786±0.186		0.859±0.068	

R=right; L=left; SD=standard deviation; T1W=T1 weighted; T2W=T2 weighted; ICC=intra-class correlation coefficient; CI=confidence interval

T1W TSE, 3D T2W TSE, and 2D T2W TSE images, respectively). The data analyses are presented in Table 5.

Discussion

Currently, MRI is the imaging modality for diagnosing and assessing patients with clinical suspicion of cervical spondylotic radiculopathy. However, there has been discrepancy in evaluating the severity of neural foramen stenosis. Several studies have proposed severity grading systems using conventional 2D MRI techniques[2,3,5,11], but the inter-observer agreements of those grading systems still vary.

A newer 3D MRI technique has the advantage of remarkably thinner section thickness with no section gap and thus has relatively higher spatial resolution than the conventional 2D MRI and can be post-processing multiplanar reformats, which provides superiority in the evaluation of cervical spine anatomical structures[9,13]. A study in 2017 by Kim et al.[6] used T2 sagittal view 3D MRI to evaluate the severity of neural foramen stenosis. The result has shown better reliability than a conventional axial

Table 5. Inter-observer agreement in axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE image-based cervical neural foramen stenosis grading between the two observers categorized into low grade and high grade

Level (side)	3D T1W image		3D T2W image		2D T2W image	
	ICC (95% CI)	p-value	ICC (95% CI)	p-value	ICC (95% CI)	p-value
C2-3 (R)	1 (0.891 to 1.000)	<0.001	0.969 (0.838 to 0.999)	<0.001	0.969 (0.838 to 0.999)	<0.001
C2-3 (L)	0.969 (0.838 to 0.999)	<0.001	0.969 (0.838 to 0.999)	<0.001	0.906 (0.750 to 0.980)	<0.001
C3-4 (R)	0.813 (0.636 to 0.928)	<0.001	0.844 (0.672 to 0.947)	<0.001	0.844 (0.672 to 0.947)	<0.001
C3-4 (L)	0.875 (0.710 to 0.965)	<0.001	0.75 (0.566 to 0.885)	0.002	0.813 (0.636 to 0.928)	<0.001
C4-5 (R)	0.75 (0.566 to 0.885)	0.005	0.813 (0.636 to 0.928)	<0.001	0.688 (0.500 to 0.839)	0.076
C4-5 (L)	0.781 (0.600 to 0.907)	0.001	0.969 (0.838 to 0.999)	<0.001	0.844 (0.672 to 0.947)	<0.001
C5-6 (R)	0.719 (0.533 to 0.863)	0.015	0.906 (0.750 to 0.980)	<0.001	0.938 (0.792 to 0.992)	<0.001
C5-6 (L)	0.781 (0.600 to 0.907)	0.007	0.813 (0.636 to 0.928)	0.001	0.781 (0.600 to 0.907)	<0.001
C6-7 (R)	0.75 (0.566 to 0.885)	0.003	0.844 (0.672 to 0.947)	0.001	0.969 (0.838 to 0.999)	<0.001
C6-7 (L)	0.625 (0.437 to 0.789)	0.141	0.813 (0.636 to 0.928)	0.001	0.938 (0.792 to 0.992)	<0.001
C7-T1 (R)	0.938 (0.792 to 0.992)	<0.001	1 (0.891 to 1.000)	<0.001	0.875 (0.71 to 0.965)	<0.001
C7-T1 (L)	0.938 (0.792 to 0.992)	<0.001	0.906 (0.750 to 0.980)	<0.001	0.844 (0.672 to 0.947)	<0.001
Mean±SD	0.828±0.115		0.883±0.081		0.867±0.083	

R=right; L=left; SD=standard deviation; T1W=T1 weighted; T2W=T2 weighted; ICC=intra-class correlation coefficient; CI=confidence interval

base 2D MRI. The present study used axial base 3D MRI to evaluate the neural foramen because axial base imaging is a more familiar anatomical view in clinical practice, and no post-processing reformation is needed.

According to the present study results, both axial-based 3D and 2D MRI had comparable high intra-observer agreement in all imaging pulse sequences as 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE, and equally strong inter-observer agreement in the severity grading of neural foramen stenosis. Even if the study categorized into low grade and high grade neural foramen stenosis, the results were similar with a slightly higher level of agreement. Thus, the axial-based 3D MRI technique may not provide additional benefit to the axial-based 2D MRI technique for cervical neural foramen stenosis grading.

In addition, the authors found total agreement in neural foramen stenosis grading at the right C2-3 level on axial 3D T1W images. This technique may be beneficial for the evaluation of the upper cervical levels.

The reliability of stenosis grading based on axial images was not significantly different among these pulse sequences. The 3D MRI technique is superior to the conventional 2D MRI technique due to relatively thinner slice thickness with no section gap and higher spatial resolution. It could benefit from detecting the small structures or pathology undetected in conventional 2D techniques[9,13] due to its ability to image reconstructions into multiplanar views, especially in patients with discordance between clinical manifestation and imaging findings. Additional axial 3D T1W or T2W image acquisition techniques may be the optional sequences for evaluating the cervical neural foramen, depending on the specification of the institute's MRI system and the experience and satisfaction of the radiologist in the sequences.

According to a high level of inter-observer agreement between two observers, the interpretation of the neural foramen stenosis based on these three image acquisition techniques may not depend on the experiences of the radiologists. It may provide more reproducibility in image interpretation and could be assessed in a future study by testing multiple inter-observer agreements with the various experiences.

The present study had limitations. First, the small sample size may lead to indifference in the level of agreement among the three imaging pulse sequences used in the present study despite more advantages of the 3D TSE over conventional T2W TSE from the prior studies. Second, the authors did not correlate the imaging findings with the clinical symptoms. Additional investigation is needed to demonstrate the correlation between the stenosis grading and the severity of the symptoms. Last, this comparative study had no reference standard to test the diagnostic performance and conclude the best imaging techniques for neural foramen stenosis grading.

Conclusion

Axial 3D T1W TSE, 3D T2W TSE, and 2D

T2W TSE images exhibited strong reliability in grading cervical neural foramen stenosis. There was no significant benefit of 3D over conventional 2D techniques in stenosis grading. Additional axial 3D images may be the optional sequences in evaluating the cervical neural foramen, depending on the experience and satisfaction of the radiologist.

What is already known on this topic?

There have been studies regarding reliability in evaluating cervical neural foramen stenosis using 2D or 3D MRI. Most studies have evaluated severity grading based on 2D or 3D T2W sequences. However, there has been some discrepancy in evaluating the severity grading of cervical neural foramen stenosis.

What this study adds?

The study compared reliability and concordance in evaluating the severity grading of cervical neural foramen stenosis between 3D T1W, 3D T2W, and 2D T2W images based on axial plane. There was comparable strong reliability in cervical neural foramen stenosis grading using axial 3D T1W TSE, 3D T2W TSE, and 2D T2W TSE images, with no significant benefit of 3D over conventional 2D techniques.

Conflicts of interest

The authors declare no conflict of interest.

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