A comparison of angled sagittal MRI and conventional MRI in the diagnosis of herniated disc and stenosis in the cervical foramen

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Abstract The object of this study is to demonstrate that angled sagittal magnetic resonance imaging (MRI) enables the precise diagnosis of herniated disc and stenosis in the cervical foramen, which is not available with conventional MRI. Due to both the anatomic features of the cervical foramen and the limitations of conventional MR techniques, it has been difficult to identify disease in the lateral aspects of the spinal canal and foramen using only conventional MRI. Angled sagittal MRI oriented perpendicular to the true course of the foramina facilitates the identification of the lateral disease. A review of 43 patients, who underwent anterior cervical discectomy and interbody fusion, is presented with a herniated disc and/or stenosis in the cervical foramen. They all had undergone conventional MRI and angled sagittal MRI. Fifty levels were surgically explored for evidence of foraminal herniated disc and stenosis. The results of each test were correlated with what was found at each explored surgical level. The sensitivity, specificity, and accuracy of both examinations for making the diagnosis of foraminal herniated disc and stenosis were compared. During the diagnosis of foraminal herniated disc, the sensitivity, specificity, and accuracy of angled sagittal MRI were 96.7, 95.0, and 96.0%, respectively, compared with 56.7, 85.0, and 68.0% for conventional MRI. In making the diagnosis of foraminal stenosis, the

sensitivity, specificity, and accuracy of angled sagittal MRI were 96.3, 95.7, and 96.0%, respectively, compared with 40.7, 91.3, and 66.0% for conventional MRI. In the above groups, the difference between the tests for making the diagnosis of both foraminal herniated disc and stenosis was found to be statistically significant in sensitivity and accuracy. Angled sagittal MRI was a more accurate test compared to conventional MRI for making the diagnosis of herniated disc and stenosis in the cervical foramen. It can be utilized for the precise diagnosis of foraminal herniated disc and stenosis difficult or ambiguous in conventional MRI.

Keywords Angled sagittal MRI ·
Foraminal herniated disc · Foraminal stenosis ·
Cervical spine

Introduction

The cervical foramen form an angle of approximately 45° with the anterior–posterior axis of the spine and 10–15° caudal inclination on a horizontal axis (Fig. 1) [2, 10]. However, conventional MR images are not optimally oriented along this oblique course. Due to both the anatomic features of the cervical foramen and the limitations of conventional techniques, it is difficult to identify disease in the lateral aspects of the spinal canal and foramen using only conventional MRI (Fig. 2a).

On the other hand, there were some articles in which an MR image oriented perpendicular to the true course of the cervical foramen considering such anatomic features of the cervical foramen (such MR images used in previous articles were frequently referred to as “oblique MRI”; however, “oblique” was not well defined, and “angled

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Fig. 1 Anatomic features of the cervical foramen. **a** Axial T₂-weighted images at the C4–5 disc level. The cervical foramen is directed anterolaterally at approximately a 45° angle with respect to the coronal plane through the foramen. **b** Anteroposterior image of 3D reconstructive CT. The cervical foramina are directed downward 10–15° with respect to the axial plane

sagittal”, was therefore used instead) might be useful. It was found that such angled sagittal MRI could provide a clearer view of certain anatomic structures not available in conventional MRI [4, 7, 16] (Fig. 2b).

However, articles that used angled sagittal MRI were conducted mainly to investigate the anatomic character of the cervical foramen and the nerve root. Moreover, available information from related articles is 15–20 years old and is no longer useful as a backing discussion of the role of MR imaging. Therefore, it has not been reported that angled sagittal MRI is superior to conventional MRI in the diagnosis of symptomatic patients who have a herniated disc and stenosis in the cervical foramen.

Nevertheless, in the past, the authors occasionally conducted additional angled sagittal MRI with patients who had no clear lesions as confirmed from previous conventional MRI but had clear cervical-related symptomatology. Through this method, it was possible to confirm the presence of a lesion in some cases. However, owing to absence of systematic study and the difficulty of surgical confirmation, it was questioned as to whether angled sagittal MRI was contributing significantly enough to clinical management to warrant its use.

Thus, the present study was performed to demonstrate, through surgical confirmation, that angled sagittal MRI enables the precise diagnosis of a herniated disc and stenosis in the cervical foramen by providing valuable information regarding the cervical foramen, which is not available with conventional MRI.

Clinical materials and methods

While conventional MRI was conducted with patients with neck pain and radicular arm pain who visited the hospital involved with the study between October 2005 and June 2007, angled sagittal MRI was conducted without any additional expense, as a total of 1,351 patients were retrospectively analyzed. Among them, a group with pure foraminal lesions able to be surgically confirmed and who would be easy to compare by image were selected as the subjects of this study. Patients were included in the study if all of the following were present: (1) a herniated disc and/or stenosis in the cervical foramen, (2) a lesion documented by positive radiographic findings of either conventional MRI or angled sagittal MRI, (3) failed conservative care, (4) operative treatment with ACDF. Patients were excluded from the study if any of the following conditions were present: (1) non-operative treatment, (2) a lesion including the disc located on the central or paracentral side, (3) cervical operations except ACDF (total disc replacement, laminoplasty, corpectomy, foraminotomy, tumor removal, etc.), (4) the use of conventional MRI performed at another hospital, (5) instability, (6) previous cervical surgery, (7) deformities including kyphosis, (8) skeletal dysplasia, (9) a history of arthritis, (10) neoplasm, (11) osteoporosis, and (12) a trauma-related lesion. A total of 43 patients fit the inclusion criteria.

Twenty men and 23 women participated. They ranged in age from 31 to 64 years (mean 42.3 years). Fifty levels were documented by positive radiographic findings on either conventional MRI or angled sagittal MRI. The positive radiographic findings were consistent with clinical findings. Each level was surgically explored for evidence of both foraminal herniated disc and stenosis. There was no exploration above two levels in a patient.

Fig. 2 Comparison of conventional MRI and angled sagittal MRI. The images were obtained in a 27-year-old woman who has not been diagnosed with cervical disease. **a** Identification of the lateral aspects of the cervical canal and foramen is difficult because the routine parasagittal images are not optimally oriented. **b** Angled sagittal MRI images are oriented perpendicular to the true course of the neural foramen. As compared with conventional MRI, a clearer foraminal contour and nerve root can be seen using angled sagittal MRI. The *circle* indicates the intervertebral foramen between C4 and C5

Conventional and angled sagittal MRI were performed with a 1.5 T superconducting system (GE Medical System; Signa excite; Milwaukee, WI, USA) using an eight-channel spinal coil. During the examinations, all patients were scanned in a supine position with the neck in neutral position. Conventional MRI included sagittal T1-weighted images (Pulse sequence—T1 Fast spin echo, repetition time (TR) 500 ms, echo time (TE) 10 ms, Matrix 320×224 , Echo train length 3, field of view (Fov) 240 mm, and number of excites (NEX) 4) and sagittal T2-weighted images (Pulse sequence—T2 Fast spin echo, TR 3,500 ms, TE 110 ms, Matrix 320×224 , Echo train length 30, Fov 240 mm, and NEX 4) with a slice thickness of 3.0 mm and a space of 0.5 mm. Additional axial T1-weighted images (Pulse sequence—T1 Fast spin echo, TR 550msec, TE 14msec, Matrix 256×192 , Echo train length 3, Fov 160 mm, and NEX-2) and axial T2-weighted images (Pulse sequence—T2 Fast spin echo, TR 4,000 ms, TE 110 ms, Matrix 320×224 , Echo train length 18, Fov 160 mm, and NEX 4) were obtained with a 3.0 mm slice thickness and a 0.5 mm space; these images were disc-angled. In angled sagittal MRI, the medial edge of the foramen was identified and images were taken progressing laterally through the foramen in 40° – 45° angled sagittal projections for obtaining MR images oriented perpendicular to the true course of the neural foramen (3.0 mm slice thickness, 0.1 mm space; Pulse sequence—T2 Fast spin echo, TR 3,500 ms, TE

115 ms, Matrix 384×256 , Echo train length 30, Fov 240 mm, and NEX 4; the scan time for one side was 2.5 min). The images included the medial margin of each pedicle (entrance zone), the isthmus (mid zone), and the lateral edge of the foramen. In conventional MRI and angled sagittal MRI, a fat suppression technique was not used.

Each of the two tests was evaluated independently by two experienced neuroradiologists who had no knowledge of the relevant preoperative history or clinical findings and who were not provided with information from previous diagnostic tests. When a discrepancy occurred, consensus was reached by discussion. The radiographical criteria for a foraminal herniated disc involved a focal extension of the disc margin beyond the vertebral margin in the foramen, with resulting nerve root or foraminal fat displacement. Radiographically, the criteria for a foraminal stenosis were (a) a distortion or paucity of foraminal fat, or (b) a diminution of the overall size of the neural foramina. However, stenosis that formed only as a result of a pure disc in the foramen was not included in the criteria for foraminal stenosis. Some levels were found to have both foraminal herniated disc and stenosis. When positive data existed, regarding a foraminal herniated disc and/or stenosis from conventional MRI or angled sagittal MRI, surgical exploration was performed.

The charts were then reviewed independently by a neurosurgeon and the operative reports were evaluated.

The findings at each explored surgical level were recorded in a similar fashion for each diagnostic study as to the presence of disc pathology or stenosis in the cervical foramen. A foraminal herniated disc was felt to be present if the herniated disc was sought in the foramen, and the disc fragments could be coaxed out from the foraminal space using a microprobe. The microprobe bent on tip was used. The bent part of the tool was 3 mm in length and 1 mm in diameter. A foraminal stenosis was felt to be present if there was difficulty in passing the bent part of the microprobe into the foramen.

The interpretations of both studies were then compared with the findings at the time of surgery. Each individual test at each level was then recorded as being a true or false positive or a true or false negative. From this, the sensitivity, specificity, and accuracy of each study could be tabulated. The data were then analyzed using χ^2 analysis.

Operative technique

The operation was performed according to the standard Smith and Robinson method. The disc and osteophyte were removed under a microscope. In particular, for foraminal stenosis with posterior osteophyte, a high-speed drill and a microcurett were used to decompress the osteophyte and the area around the foramen. The dura mater was exposed by complete resection of the posterior longitudinal ligament. Afterward, in one level discectomy, a Solis cage filled with the cancellous fragments of autologous iliac bone was inserted in the discectomy site. Otherwise, in a consecutive two-level discectomy, a tricortical block of autologous iliac bone was inserted in the discectomy site, and an anterior cervical plate (ACP) system, consisting of a plate and screw was implanted.

Results

A summary of the demographic, radiologic, and operative data for a foraminal herniated disc and foraminal stenosis in 43 patients who had 50 levels explored is compiled in Table 1. A lesion was located at C3–4 in 1 level, at C4–5 in 9 levels, at C5–6 in 24 levels, and at C6–7 in 16 levels. Seven cases included two levels, each. In all of these cases, the two levels were consecutive. In these cases, there was no level documented by negative operation findings for both foraminal herniated disc and foraminal stenosis. A discrepancy between conventional MRI and angled sagittal MRI interpretation for foraminal herniated disc occurred at 18 levels (Fig. 3, Fig. 4 C5–6). Conventional MRI was incorrect at 16 levels, and angled sagittal MRI was in error at two levels. Discrepancy between conventional MRI and

Table 1 Summary of demographic, radiographic, and operative data for 43 patients with foraminal disc and/or stenosis who underwent ACDF

Case		Conventional MRI		Angled sagittal MRI		Operative Finding	
No.	Level	Fd	Fs	Fd	Fs	Fd	Fs
1	C5–6	N	P	P	P	P	P
2	C5–6	N	P	N	P	N	P
2	C6–7	N	N	N	P	N	P
3	C5–6	N	N	P	N	P	N
4	C6–7	P	P	N	P	N	P
5	C4–5	N	N	N	P	N	P
6	C5–6	N	P	P	P	P	P
7	C6–7	N	N	N	P	N	P
8	C5–6	P	N	P	N	P	N
9	C4–5	N	N	N	P	N	P
9	C5–6	N	N	N	P	N	P
10	C5–6	N	N	P	N	P	N
11	C6–7	N	P	N	P	N	P
12	C5–6	P	N	N	N	P	N
13	C5–6	N	N	P	P	P	P
13	C6–7	P	N	P	P	P	P
14	C5–6	N	N	P	N	P	N
15	C6–7	N	N	N	P	N	P
16	C6–7	N	N	P	N	P	N
17	C5–6	P	N	N	P	N	P
17	C6–7	N	P	N	P	N	P
18	C4–5	P	N	P	N	P	N
19	C5–6	P	N	P	P	P	N
20	C5–6	P	N	P	N	P	N
21	C4–5	P	P	P	P	P	P
22	C3–4	P	N	P	N	P	N
22	C4–5	P	N	P	N	P	N
23	C6–7	N	P	P	P	N	P
24	C5–6	N	N	P	N	P	N
25	C5–6	P	P	N	P	N	P
26	C6–7	P	N	P	N	P	N
27	C5–6	N	N	N	P	N	P
28	C5–6	P	N	P	N	P	N
29	C4–5	N	N	N	P	N	P
29	C5–6	N	P	N	P	N	P
30	C4–5	P	N	P	N	P	N
31	C5–6	N	N	N	P	N	P
31	C6–7	N	P	N	N	N	P
32	C6–7	P	N	P	N	P	N
33	C5–6	N	N	P	P	P	P
34	C5–6	P	N	P	N	P	N
35	C5–6	N	P	P	N	P	N
36	C4–5	P	N	P	N	P	N
37	C6–7	N	N	N	P	N	P

Table 1 continued

Case		Conventional MRI		Angled sagittal MRI		Operative Finding	
No.	Level	Fd	Fs	Fd	Fs	Fd	Fs
38	C5–6	P	N	P	N	P	N
39	C6–7	P	P	P	N	P	N
40	C5–6	N	N	P	N	P	N
41	C6–7	N	N	N	P	N	P
42	C4–5	N	N	P	P	P	P
43	C6–7	N	N	P	N	P	N
Total: 50 levels							

The results of conventional and angled sagittal MRI which were consistent with the operative finding were indicated in bold

Fd foraminal herniated disc, *Fs* foraminal stenosis, *P* positive, *N* negative

angled sagittal MRI interpretation for foraminal stenosis occurred at 20 levels (Fig. 4 C5–6, C6–7). Conventional MRI was incorrect at 18 levels, and angled sagittal MRI was in error at 2 levels.

After a comparison of the findings of conventional and angled sagittal MRI with the operative finding in Table 1, the results were classified into categories: true positive/negative and false positive/negative. In addition, the sensitivity, specificity, and accuracy of both examinations in the diagnoses of a foraminal herniated disc and stenosis were calculated and compared, as shown in Table 2. In the diagnosis of a foraminal herniated disc, the sensitivity, specificity, and accuracy of angled sagittal MRI were 96.7, 95.0, and 96.0, respectively, compared with 56.7, 85.0, and 68.0% for conventional MRI. Angled sagittal MRI was overall a more accurate, sensitive, and specific test

Fig. 3 Case 6. A 52-year-old woman complained of right arm pain and neck pain. **a** Conventional T2-weighted MRI showed a low-intensity mass and suspected stenosis in the right foraminal space of C5–6. However, the presence of a herniated disc in the foramen could not be established. **b** The herniated disc and stenosis were visible clearly in the foraminal space using angled sagittal MRI

Fig. 4 Case 13. A 46-year-old man complained of left arm pain and neck pain. **a** Although conventional MRI showed what was suspected to be herniated disc in the left foraminal space of C6–7, other pathology was not documented in the left foramina. **b** Angled sagittal MRI definitely revealed C5–6 and C6–7 lesions with foraminal herniated disc and stenosis

Table 2 Results of foraminal herniated disc and foraminal stenosis

	Fd				Fs			
	Conventional MRI		Angled sagittal MRI		Conventional MRI		Angled sagittal MRI	
	P	N	P	N	P	N	P	N
Operative finding								
P	17	13	29	1	11	16	26	1
N	3	17	1	19	2	21	1	22
Sensitivity	17/30 (56.7%)		29/30 (96.7%)		11/27 (40.7%)		26/27 (96.3%)	
Specificity	17/20 (85.0%)		19/20 (95.0%)		21/23 (91.3%)		22/23 (95.7%)	
Accuracy	34/50 (68.0%)		48/50 (96.0%)		33/50 (66.0%)		48/50 (96.0%)	

Fd foraminal herniated disc, Fs foraminal stenosis, P positive, N negative

compared to conventional MRI. In the above group, the difference between the tests was found to be statistically significant in terms of sensitivity ($P < 0.05$) and accuracy ($P < 0.05$) when χ^2 analysis was used. However, the difference between the tests was not found to be statistically

significant in terms of specificity ($P = 0.292$). In the diagnosis of foraminal stenosis, the sensitivity, specificity, and accuracy of angled sagittal MRI were 96.3, 95.7, and 96.0%, respectively, compared with 40.7, 91.3, and 66.0% for conventional MRI. These data also show that angled

sagittal MRI was overall a more accurate, sensitive, and specific test compared to conventional MRI. Once again, the difference between the tests was found to be statistically significant in terms of sensitivity ($P < 0.05$) and accuracy ($P < 0.05$) when χ^2 analysis was used. Additionally, the difference between the tests was not found to be statistically significant in terms of specificity ($P = 0.550$) in this case as well.

Discussion

An ongoing debate over the use of computed tomography (CT) versus MR imaging exists as to which imaging modality provides optimal data in terms of herniated disc and stenosis in the cervical foramen. In a comparison of various imaging modalities, Bischoff et al. [1], determined that myelo-CT was the most sensitive and accurate test for diagnosing herniated nucleus pulposus and spinal stenosis, whereas myelography was the most specific. MR imaging provided comparable results in most instances; combined with its noninvasive methods and lack of side effects, it is the procedure of choice for detecting spinal abnormalities. Additionally, Schnebel et al. [13] reported a 96.6% level of agreement between MR and contrast CT in the diagnosis of spinal stenosis. It was found that the two methods were comparable in detecting spinal stenosis, and that MR imaging was more sensitive in detecting disc degeneration. Perneckzy et al. [11] determined that if MR imaging is used on the basis of clinical signs, its diagnostic accuracy matches that of myelography. It was also found that MR imaging detected substantially more multilevel abnormalities.

However, previous studies have shown that MR images tend to overestimate medial compression and that lateral disc fragments may be missed. Kelft et al. [5] showed that MRI on axial view was noted to have low specificity for foraminal lesions. It was reported that delineation of disease in the lateral aspects of the spinal canal and foramen on sagittal images is more difficult due to the oblique course of the foramen with respect to the sagittal plane [7]. The dimensions of the cervical foramen are of clinical importance in the diagnosis of foraminal herniated disc and stenosis. Anatomic studies have described the cervical neural foramen as a 4–5 mm long bony canal through which the cervical nerve root passes anterolaterally at approximately a 45° angle with respect to the coronal plane and downward 10–15° with respect to the axial plane [2, 10]. The ventral and dorsal nerve roots are located in the inferior portion of the neural foramen at or below the disc level. Thus, routine parasagittal MR images are not optimally oriented, which forces one to rely on the axial images of MR, a circumstance in which the disadvantage of the thicker 4 mm section becomes more apparent.

Due to both the anatomic features of the cervical foramen and the limitations of conventional techniques, the use of reformatted angled sagittal images has recently gained acceptance [4]. The additional acquisition of angled sagittal MR images oriented perpendicular to the true course of the neural foramina facilitates the identification of disease laterally by providing a second orthogonal imaging plane in relationship to the diseased area. Various studies have reported that an angled sagittal MR scan can provide information that is otherwise available using conventional techniques [12, 15, 17]. Yenerich et al. [16] reported that the advantages of angled sagittal MR imaging of the cervical spine for patients with radiculopathy. It was found that MR imaging provided excellent visualization of the nerve roots and foramen. Pech et al. [9] demonstrated that surface-coil MRI images in a plane perpendicular to the cervical nerve roots allowed their relationship to intraforaminal structures and the boundary of the foramen to be determined. This visual integration of angled sagittal and axial images decreases the problem of partial volume averaging and the potential problem created by an interspace gap; it allows one to distinguish disc from bone, accurately, and to determine the relationship of both to the neural structures. Without the use of contrast agents or ionizing radiation, the nerve roots, foramen borders, uncovertebral joints, and facet joints are visualized in the same image.

The angled sagittal plane can be oriented to include all of the cervical neural foramina on the symptomatic side, but it must be interpreted on contiguous images as the foramina do not all lie in the same superoinferior plane. Angled sagittal MR images are easily obtained and accurately angled to any particular area of interest. Their use has been clearly outlined in other anatomic areas [3, 6, 8, 14]. Their major disadvantage is that they increase the examination time. The total acquisition time for angled sagittal sequence we used on one side is 2.5 min.

The angled sagittal images obtained in this study provide data concerning the foramen that is unavailable when using conventional MR techniques, as the reformatted angled sagittal images are oriented perpendicular to the course of the cervical neural foramen. Facet overgrowth, herniated lateral disc, and uncinate process osteophyte that may induce foraminal stenosis is more easily detectable in angled sagittal MRI.

There are several limitations of this study. The sample size is relatively small and the retrospective design increases the potential for selection bias. However, it was possible to take advantage of the practice of the primary surgeon in that angled sagittal MRI was also conducted for all new patients with neck pain and radicular arm pain who had received conventional MRI during the period of study collection. This was done in an effort to evaluate this practice. Additionally,

related to selection bias, the final decision of two experienced neuroradiologists concerning evidence of foraminal abnormalities on MR images was respected. In addition, consideration of symptoms that were sufficiently severe to warrant surgery was determined through the consistency of clinical findings with positive findings on MRI and failed conservative treatment. The severity of foraminal abnormalities has a wide spectrum; some patients require no treatment at all, some require nonoperative treatment such as medication and/or injections, and others need surgical intervention due to severe symptoms.

An important strength in this study is the fact that it was initially proved through surgical confirmation that angled sagittal MRI is superior to conventional MRI in the diagnosis of symptomatic patients who have a herniated disc and stenosis in the cervical foramen. Therefore, the authors believe that this study can represent a foundation of clinical use over theoretical and basic utilization of angled sagittal MR image.

Subsequent to this study, the authors have reserved the use of angled sagittal MR images for patients who have definite clinical evidence of cervical radiculopathy and in whom routine sagittal or axial images have failed to disclose or characterize adequately an abnormality at the level where it is suspected.

Conclusions

Inaccurate radiographic diagnosis may be a major cause of poor surgical outcomes. Any surgical decision should be based on symptoms firmly supported by radiographic evidence. This study showed that angled sagittal MRI was a more accurate test compared to conventional MRI for making the diagnosis of herniated disc and stenosis in the cervical foramen. Therefore, when the physician's clinical examination is suggestive of cervical radiculopathy and when conventional MR imaging is nondiagnostic, angled sagittal MRI may augment conventional MRI for the precise diagnosis of herniated disc and stenosis in the cervical foramen.

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