DIAGNOSTIC ACCURACY OF THE MRI IN LUMBAR SPINAL STENOSIS AND LUMBAR DISK HERNIATION.

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ABSTRACT

PURPOSE: To evaluate the diagnostic accuracy of MRI in lumbar spinal stenosis and disk herniation in symptomatic patients by using surgery as the comparison method.

MATERIALS AND METHODS: Sagittal T1-weighted, sagittal and axial T2-weighted MR images were obtained in 32 patients with lumbar spinal stenosis and 18 patients with lumbar disk herniation. All patients underwent surgery. The MR images were evaluated with regarding to intervertebral disk abnormalities, stenosis of the spinal canals, facet joint hypertrophy, ligamentum flavum hypertrophy and nerve root compression. The MR findings were compared with the surgical findings.

RESULTS: The accuracy of MRI in diagnosis of disk protrusion, extrusion, and sequestration was 89%, 83% and 89% respectively. Its diagnostic accuracy in detection of herniation location was 86%, 87%, and 89% respectively for central canal, centrolateral location and lateral recess. There was no negative surgical finding in this study. Nerve root compression was 80% accurately diagnosed by MRI. For the 11 cases in which disagreement between MRI and surgical findings, the breakdown was as follows. In 2 patients the MRI and diagnosis was that of disk protrusion but the surgical findings were those of extrusion. In one case, MR diagnosed disk extrusion but the surgery revealed a protruded disk. In one case, there was a sequestrated disk, while MR was interpreted as an extruded disk, and vice versa. About the location of herniation, MR was read as centrolateral location but the surgery showed only lateral location in one case. MR missed 2 cases of centrolateral disk herniation by being interpreted as lateral herniation. Concerning nerve root compression, MR over diagnosed one case of nerve root compression in a surgically proven nerve root deviation. However, MR missed one case of nerve root compression by being read as no compression. The accuracy of MRI in detection of central, centrolateral and lateral recess stenosis was 90%, 89%, and 83% respectively. Its diagnostic accuracy in facet joint hypertrophy, ligamentum flavum hypertrophy and nerve root compression was 83%, 84% and 82% in order. The disagreement between MRI interpretation and surgical findings did occur. Among these 10 patients, MRI showed one patient with centrolateral stenosis but surgery demonstrated only central canal stenosis, and vice versa. In one case, the facet joints were noted as unremarkable during surgery while MRI suggested hypertrophy. In contrary, MRI missed one case of surgically proven facet joint hypertrophy. In one case, MRI was read as ligamentum flavum hypertrophy, while surgery demonstrated normal size. MRI was not able to detect hypertrophy of ligamen-

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tum flavum in two cases. MRI over diagnosed one case of nerve root compression in a surgically proven normal nerve root while it missed one case of nerve root compression.

CONCLUSION: MRI is proven to be highly accurate in diagnosis of lumbar disk herniation and lumbar spinal stenosis. However, there is some disagreement on the diagnosis of disk protrusion, extrusion and sequestration; location of herniated disk, and lumbar stenosis; nerve root compression; facet joint hypertrophy and ligamentum flavum hypertrophy.

Low back pain is one of the leading causes of absence from work and disability.[1] Deyo et al[7] estimated that as many as 80% of all adults have low back pain at sometimes of their lives. Both lumbar spinal stenosis and lumbar disk herniation are the major causes of low back pain. A number of imaging methods are available for assessment of such abnormalities. MRI remains the noninvasive method of choice for assessment of the low back pain.[1] The sensitivity and specificity of MR imaging of intervertebral disk abnormalities are relatively well known.[1] However, there is less information about the value of MR imaging in the assessment of facet joints and ligamentum flavum.

The purpose of this study is to evaluate the diagnostic accuracy of MRI in lumbar spinal stenosis and disk herniation in symptomatic patients by using surgery as the comparison method.

MATERIALS AND METHODS

Patient Population

This cross-sectional study enrolled fifty patients with lumbar spinal stenosis or disk herniation who underwent lumbar spinal surgery at Department of Orthopaedics Surgery, Siriraj Hospital, Mahidol University during August- October, 2001. Written informed consent was obtained from all patients. The patients were operated on by the same orthopaedic surgeon (V.J.). All of them had lumbar MRI scanned before surgery.

32 patients had lumbar spinal stenosis, including 12 men and 20 women with 52-79 years old (mean, 61 years). 18 patients had lumbar disk herniation, including 13 men and 5 women with 28-54 years old (mean, 42 years).

The patients suffered from low back pain and/ or radicular pain. The relevant clinical history and physical findings were collected. The patients with spinal tumor, infection or previous spinal surgery were excluded.

MR Imaging

The MR imaging was performed with a 1.5 -T ACS-NT scanner (Philips, Best, The Netherlands.) with a body coil. The protocol included sagittal T1-weighted (253/12 [repetition time msec/ echo time msec]) and T2-weighted (2588/120) turbo spin-echo imaging of the entire lumbar spines with the following sequence parameters: matrix, 256 X 180; field of view, 280 mm; section thickness 3 mm, intersection gap 0.5 mm. In addition, axial T2-weighted (3900/100) turbo spin-echo images of all lumbar intervertebral spaces (four sections per disc level from L1-S1) were obtained with the following sequence parameters: matrix, 256 X 210; field of view, 180 mm; section thickness, 4 mm; intersection gap, 0.5 mm.

Image Analysis

The imaging studies in all 50 patients were analyzed independently by one experienced neuroradiologist (P.C.). The three separate MR acquisitions were interpreted in the following manner. The sagittal T1-weighted images were evaluated for disk-space height; canal compression; presence and configuration of epidural fat and nerve root in the neural foramina in the parasagittal plane; disk position and configuration; vertebral body signal; and upper lumbar neural canal, including the conus. The signal intensity of the disk and adjacent vertebral endplates were evaluated on T2-weighted sagittal image. In addition, the CSF-extradural interface was examined for the presence or absence of herniated disk and canal stenosis.

The presence of following abnormalities were recorded: spondylolisthesis, loss of normally high signal intensity of the disk on T2-weight image, loss of disk height, disk bulging, disk herniation (protrusion, extrusion and sequestration), thecal sac compression, nerve root compression, hypertrophy of facet joint, and hypertrophy of ligamentum flavum.

With regard to the disk abnormalities,[1] the following terms were used: normal, bulging, protrusion, extrusion, and sequestration.

Normal disk. The disk was considered to be normal when it did not reach beyond the borders of the adjacent vertebral bodies (Fig 1A).

Bulging disk. This diagnosis was made when a smooth, more or less circular extension of the disk margin was noted beyond the margins of the vertebral endplates. Bulging disk may be generalized, that was, be along the entire circumference of the vertebral endplate; in symmetric fashion with the smooth outline paralleling the contour of the vertebra endplate; or eccentric. Generally, a bulging disk was considered to be associated less with sciatica than disk herniation[3] (Fig 1B).

Disk protrusion. Protrusion was defined as a focal or asymmetric extension of the disk beyond the vertebral border, with the disk origin broader than any other dimension of the protrusion (Fig 1A).

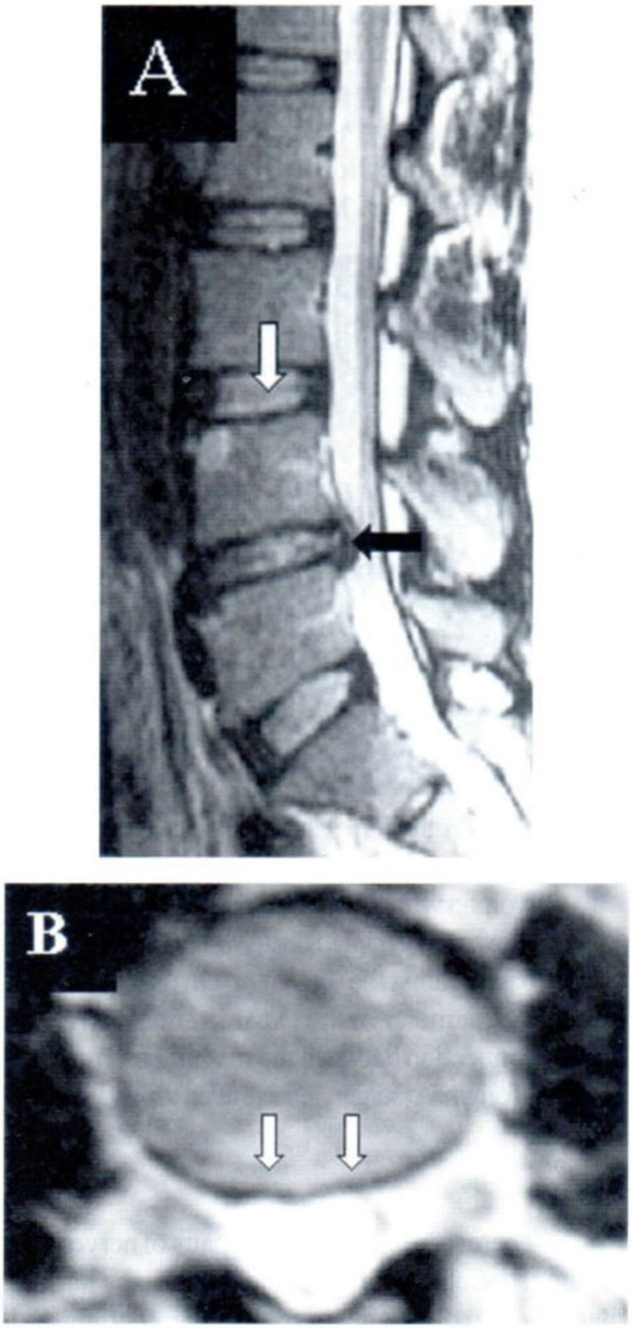

Fig. 1 Normal disk, bulging disk and disk protrusion. (**A**) Sagittal T2-weighted SE MR image of the lumbar spine in a 37 year-old man with low back pain showed normal L3-4 disk configuration (white arrow) and L4-5 disk protrusion (black arrow). (**B**) Axial T2-weighted SE MR image of the L3-4 intervertebral disk in another patient demonstrated a bulging disk (white arrow).

Disk extrusion. Extrusion was determined as a more extreme extension of the disk beyond the vertebral border, with the base against the disk of origin narrower than the diameter of the extruded material and a connection between the material and the disk of origin (Fig 2).

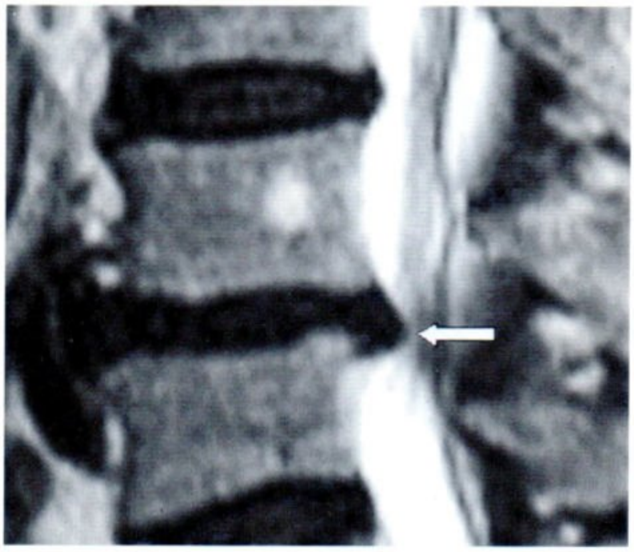

Fig. 2 Disk Protrusion. Sagittal T2-weighted SE MR image of the lumbar spine in a 28 year-old woman with low back pain and radicular pain showed a herniated disk(white arrow) with the base against the disk of origin narrower than the diameter of the extruded material and a connection between the material and the disk of origin. At surgery, an extruded disk was found.

Disk sequestration. Sequestration was defined as a free disk fragment that was distinct from the parent disk and had an intermediate signal intensity on T1-weighted images but an increased signal intensity on T2-weighted images (Fig 3).

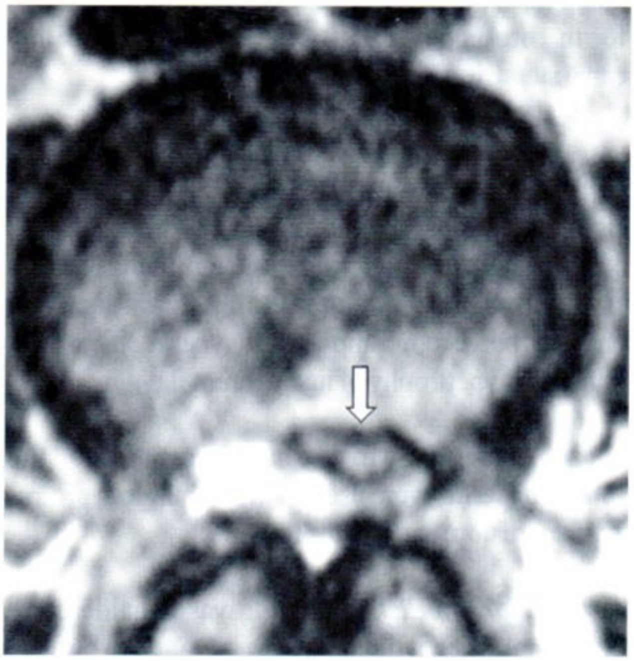

Fig.3 Disk sequestration. Axial T2-weighted SE MR image of the lumbar spine in a 40 year-old man with low back pain, severe radicular pain and positive straight leg raising test showed a free disk fragment (white arrow).

There were ordinarily two pairs of nerves that may be associated with the pathology of each lumbar intervertebral disk. These included descending and exiting nerves.[3]

Descending nerve. At each lumbar intervertebral disk, there was usually only one spinal nerve root outside the dural sac in the spinal canal descending behind the intervertebral disk to exit below the pedicle of the vertebral body forming the lower surface of the disk. At the L4-L5 intervertebral disk, for example, the descending nerve would be the L5 nerve root.

Exiting nerve. The exiting nerve was the nerve leaving the spinal canal through the top of the neural foramen below the pedicle of the vertebral body sitting on the top of the disk. At the L4-L5 disk, for example, the exiting nerve would be the L4 nerve, which usually left the dural sac at about the level of the lower part of the body of L3, descended behind the L3-L4 disk, and exited the spinal canal below the pedicle of L4 through the top of L4-L5 foramen.

The relationship of the nerve roots with the adjacent disks was described as no compression or nerve root compression. An impression of thecal sac was diagnosed as either present or absent.

The endplates and adjacent bone marrow were graded according to the system of Modic et al [13] as follows: no abnormality, low signal intensity on T1-weighted images, and high signal intensity on T2-weighted images when compared to normal fatty bone marrow: type I, high signal intensity with both sequences: type II, and low signal intensity with both sequences: type III. When two different grades were present on both sides of intervertebral disk space, only one diagnosis was applied (first priority, type I; second priority, type II; last priority, type III).

Spinal canal. Spinal canal was divided in the axial plane into four zones: central canal zone, lateral recess or subarticular zone, foraminal zone and extraforaminal zone.[14] Criteria for spinal canal stenosis on MR images were 1) a distortion or paucity of epidural fat either in the neural foramina, lateral recess, or posteriorly between the ligamentum flavum (Fig 4), and 2) a diminution in the overall size of the neural foramina, neural canal, and/ or thecal sac. An attempt was made to determine the contribution of the hypertrophied facet joints and bony overgrowth as well as hypertrophy of ligamentum flavum.[4]

Facet joints. Facet joints were diathrodial joints formed by articulation of the superior articular process and inferior articular process. The shape and size of the facet joints were analyzed on axial images. The hypertrophy of facet joints[8] was defined as narrowing of the nerve root exit zones caused by superior or inferior facet bone growth (Fig 4). This did not include secondary causes such as an increase in the size of the capsuloligamentous (joint capsule) structures.

Ligamentum flavum. Ligamentum flava (Fig 4) were paired ligaments extending from the anteroinferior border of lamina above to the upper posterior border of the lamina below. The thickness of ligamentum flavum was measured on the axial plane at the level of spinal lamina. The normal value of its thickness on MR images was 5.54 mm ± 1.38.[8] It was considered hypertrophy if the ligament was larger than 6.92 mm (mean + 1SD).

The description and drawing of the surgical findings were recorded at conclusion of the surgery for each patient. The MR findings were compared with the surgical findings at the level of operation.

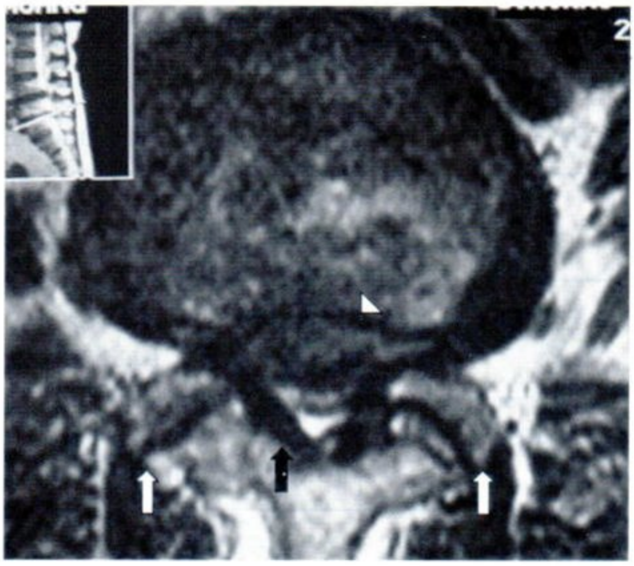

Fig.4 Axial T2-weighted SE MR image of the lumbar spine in a 68 year-old woman with low back pain, radicular pain relieved by squatting showed severe central canal stenosis due to facet joint hypertrophy (white arrow), ligametum flavum hypertrophy (black arrow) and herniated disk (white arrow head).

Statistical analysis

This study was a cross-sectional, diagnostic test. The sensitivity, specificity, positive predictive value, negative predictive value, accuracy and the 95% confidence interval of each parameter were calculated. The causes of disagreement between the MR findings and the surgical findings were analyzed.

RESULTS

Lumbar disk herniation

Table 1 listed the diagnostic values of MRI in lumbar disk herniation. These included sensitivity, specificity, positive predictive value, negative predictive value, accuracy and 95% confidence interval of each parameter.

Twenty disk explorations were performed in 18 patients. The accuracy of MRI in detection of disk protrusion, extrusion and sequestration was 89%, 83%, and 89% respectively. Its diagnostic accuracy in detection of herniation location is 86%, 87%, and 89% respectively for central canal, centrolateral location and lateral recess. There was no negative surgical finding in this study. Nerve root compression was 80% accurately diagnosed by MRI.

TABLE 1: Diagnostic Values of MRI in Lumbar Disk Herniation.

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95%CI)
Protrusion	75 (0.60,0.90)	93 (0.85,1.05)	75 (0.65,0.85)	89 (0.80,0.98)	89 (0.79,0.99)
Extrusion	83 (0.65,1.01)	83 (0.67,0.99)	71 (0.49,0.93)	91 (0.74,1.08)	83 (0.64,1.02)
Sequestration	86 (0.75,0.97)	90 (0.77,1.03)	86 (0.75,1.05)	90 (0.75,1.05)	89 (0.31,0.97)
Central	89 (0.76,1.02)	85 (0.73,0.97)	87 (0.70,0.99)	85 (0.71,0.99)	86 (0.74,0.98)
Centrolateral	83 (0.70,0.93)	91 (0.76,1.06)	85 (0.68,1.02)	88 (0.74,1.02)	87 (0.73,1.01)
Lateral recess	80 (0.61,0.99)	95 (0.82,1.02)	84 (0.75,1.01)	88 (0.75,1.01)	89 (0.75,1.03)
Nerve root compression	78 (0.63,0.93)	82 (0.68,0.96)	81 (0.64,0.99)	84 (0.65,1.03)	80 (0.67,0.93)

PPV = Positive Predictive Value, **NPV** = Negative Predictive Value

TABLE 2: Surgical and MR Results: Disagreement on Lumbar disk herniation.

MRI / Surgical Findings	Number of patients
Protrusion / Extrusion	2
Extrusion / Protrusion	1
Sequestration / Extrusion	1
Extrusion / Sequestration	1
Centrolateral / Lateral	1
Lateral / Centrolateral	2
Nerve root compression / Deviation	1
No compression / Nerve root compression	1
Total	11

Table 2 listed the disagreement between MR and the surgical findings. For the 11 cases in which disagreement between MRI and surgical findings, the breakdown was as follows. In 2 patients the MRI and diagnosis was that of disk protrusion but the surgical findings were those of extrusion. In one case, MR diagnosed disk extrusion but the surgery revealed a protruded disk. In one case, there was a sequestrated disk, while MR was interpreted as an extruded disk, and vice versa. About the location of herniation, MR was read as centrolateral location but the surgery showed only lateral location in one case. MR missed 2 cases of centrolateral disk herniation by being interpreted as lateral herniation. Concerning nerve root compression, MR over diagnosed one case of nerve root compression in a surgically-proven nerve root deviation. However, MR missed one case of nerve root compression by being read as no compression.

Lumbar spinal stenosis.

Table 3 listed the diagnostic values of MRI in lumbar spinal stenosis. These included sensitivity, specificity, positive predictive value, negative predictive value, accuracy and 95% confidence interval of each parameter.

TABLE 3: Diagnostic values of MRI in Lumbar Spinal Stenosis.

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95%CI)
Central	88 (0.74,1.02)	92 (0.85,0.99)	93 (0.86,1.04)	88 (0.79,0.97)	90 (0.82,0.98)
Centrolateral	83 (0.69,0.97)	91 (0.79,1.03)	78 (0.60,0.96)	90 (0.76,1.04)	89 (0.81,0.97)
Lateral recess	84 (0.72,0.96)	87 (0.72,1.02)	80 (0.75,0.95)	84 (0.68,1.00)	83 (0.65,1.01)
Facet joint hypertrophy	81 (0.69,0.93)	79 (0.62,0.96)	84 (0.71,0.97)	87 (0.72,1.02)	83 (0.68,0.98)
Ligamentum flavum hypertrophy	87 (0.70,1.04)	84 (0.70,0.98)	81 (0.64,0.99)	83 (0.65,1.01)	84 (0.70,0.98)
Nerve root hypertrophy	86 (0.74,0.98)	79 (0.61,0.97)	84 (0.76,1.02)	80 (0.75,0.95)	82 (0.68,0.96)

TABLE 4: Surgical and MR Results: Disagreement on Lumbar Spinal Stenosis.

MRI / Surgical Findings	Number of patients
Centrolateral / Central	1
Central / Centrolateral	1
Facet joint hypertrophy / Unremarkable	2
Unremarkable / Facet joint hypertrophy	1
Ligamentum flavum hypertrophy / Unremarkable	1
Unremarkable / Ligamentum flavum hypertrophy	2
Nerve root compression / Nerve deviation	1
No compression / Nerve root compression	1
Total	10

Forty decompressive laminectomies were performed in 32 patients with lumbar spinal stenosis. All operated levels were found stenotic as demonstrated by preoperative MR images.

The accuracy of MRI in detection of central, centrolateral and lateral recess stenosis was 90%, 89%, and 83% respectively. Its diagnostic accuracy in facet joint hypertrophy, ligamentum flavum hypertrophy and nerve root compression was 83%, 84% and 82% in order.

The disagreement between MRI interpretation and surgical findings did occur. Among these 10 patients, MRI showed one patient with centrolateral stenosis but surgery demonstrated only central canal stenosis, and vice versa. In one case, the facet joints were noted as unremarkable during surgery while MRI suggested hypertrophy.

On the contrary, MRI missed one case of surgically proven facet joint hypertrophy. In 1 case, MRI was read as ligamentum flavum hypertrophy, while surgery demonstrated normal size. MRI was not able to detect hypertrophy of ligamentum flavum in two cases. MRI over diagnosed one case of nerve root compression in a surgically-proven normal nerve root while it missed one case of nerve root compression.

DISCUSSION

MRI has been the imaging method of choice for evaluation of both lumbar disk herniation and lumbar spinal stenosis due to its high accuracy and noninvasiveness. Modic et al[4] found 82.3% agreement between MR and surgical findings for both types and location of disease.

Nevertheless, there was some disagreement between MRI and surgical findings that need to be clarified. These included disagreement on diagnosis of 1) disk protrusion, extrusion, and sequestration, 2) herniation or stenosis location, 3) nerve root compression, 4) facet joint hypertrophy, and 5) ligamentum flavum hypertrophy.

Disagreement on diagnosis of disk protrusion, extrusion and sequestration.

Both disk protrusion and extrusion can be found in asymptomatic volunteers but sequestration was rare in asymptomatic persons.[1] Boden et al[9] examined 67 asymptomatic individuals aged 20-80 years with MR images. They found at least 1 herniated disk in 20% of the individuals younger than 60 years and 36% of those older than 60 years. Jensen et al[10] reported that 98 asymptomatic individuals aged 20-80 years examined, 5% had disk bulging; 27%, protrusion; and 1%, extrusion of at least 1 disc level. Then distinction among protrusion, extrusion and sequestration was important since extrusion and sequestration seemed to cause symptoms.

In this study we used the morphologic characteristics to classify the type of herniated disks as previously mentioned in Imaging Analysis section. Disk extrusions were practically never seen at the disk level on axial sections. The large posterior displacement of the disc material beyond the margins of the intervertebral space still generally created images corresponding to the definition of a protrusion because they were outlined by the posterior longitudinal ligament. Significant migration of disk material was usually necessary to generate a typical extrusion at the disk level, was very often only possible on sagittal sections. Therefore it was sometimes confusing to diagnose either protrusion or extrusion by using morphological criteria.

Despite its apparent simplicity, only moderate interobserver and intraobserver agreement has been reported using this nomenclature in an independent study.[11]

Disagreement on diagnosis of herniation or stenosis location.

Distinction between the lateral recess stenosis and central canal stenosis was particularly important for the surgical management. A facetectomy may be necessary in addition to laminectomy and fusion in cases in which the lateral recess compromise was particularly severe.[6] Certainly, it was a little more unusual to encounter isolated lateral recess changes without some component of a central problem.

In this study we used the modified system proposed by Wiltse et al[5] in dividing the spinal canal into the central canal zone, lateral recess (subarticular zone), foraminal zone, and extraforaminal zone. The medial edge of the facet was the landmarks that separate the central zone from the subarticular zone. Unfortunately this landmark was generally not included in the axial sections at the disk level. Due to lack of visualized bony landmark on axial image, the boundary between the central and lateral recess was hard to be demarcated.

Disagreement on the diagnosis of nerve root compression.

Thornbury et al[7] suggested that adding the dimension of the nerve compression more directly impacts the treatment choice between surgical versus conservative therapy. In their study, the sensitivity of MRI in the diagnosis of disk-caused nerve compression was 91.9% and specificity is 52.4%. The low specificity implied that for MRI, the nerve root compression seem to be over diagnosed.

We found that two cases of nerve root compression were diagnosed by MRI while surgical findings revealed only nerve root deviation. All the deviated nerves in these cases were descending nerves in the thecal sac, which were more deviated or stretched rather than compressed. However, MRI missed 2 cases of surgically-proven nerve compression. The compressed nerves in these cases were exiting nerves at the foraminal zone. Retrospectively, the compressed nerves were better visualized by sagittal T2-weighted images in both cases, instead of axial views.

Disagreement on the diagnosis of facet joint hypertrophy.

Facet joint hypertrophy was a clinically significant factor of the low back pain especially when spondylolisthesis was present.[6] A single hypertrophic joint can encroach on two different nerve roots including the exiting part of the nerve root above and the descending part of the nerve root below.[5]

Weishaupt et al[1] found that mild and moderate osteoarthritis of facet joints was found in 18-22% in 60 normal volunteers; age 20-50 years. While no severe osteoarthritis was found in normal volunteers.

Our study used the increase in size of the facet joint as the criteria for diagnosing of facet joint hypertrophy. The evaluation seemed to be subjective since there was no standard reference for the average size of the normal facet joints. The discrepancy in diagnosis of facet joint hypertrophy was probably due to lack of standard size of reference and intraobserver bias.

Disagreement on the diagnosis of ligamentum flavum hypertrophy.

The bilateral ligamentum flava were the posterolateral boundaries of the spinal canal. Grenier et al[10] measured the thickness of the ligamentum flavum in axial plane at 49-53 levels in the 30 patients. The mean value was 5.54±1.38 mm. The thickness was greater than 6 mm at 14 levels. This reference value was probably greater than the actual mean value in asymptomatic Thai population.

The possible change in the thickness of ligamentum flavum dependent on load was studied in vitro by Schoenstroen and Hanssen.[5] and was found to be around 2 mm. In an already narrow spinal canal, a bulging inward of 2 mm from each side should severely affect the roots of the cauda equina, as has been shown theoretically and experimentally.[5] A thickening of the ligamentum flavum in the cranial portion of the lateral recess could affect the descending segmental root.

Since our study used Grenier's mean value of normal ligamentum flavum thickness, this probably caused underestimation of the ligament thickness in 2 cases. Nevertheless, only minor discrepancy between MRI finding and surgical results was found.

Limitation

Although every effort was made to overcome limitations in this study, certain potential flaws became apparent. First, the population size was not large enough. To achieve higher accuracy with less allowable error, approximately 140 patients were needed. Second, intraobserver bias of both radiologist and orthopedic surgeon could make this study less accurate. To alleviate this bias, two or three experts were needed to interpret the images and the surgical findings. In case of disagreement, consensus should be made before final decision. Third, the intraobserver bias in diagnosis of facet joint hypertrophy still remained. A study of facet joint measurement in asymptomatic Thai individual was needed. Forth, the application of Grenier's mean value of normal ligamentum flavum thickness would not represent mean value of the ligament in Thai persons. Therefore we needed a study of ligamentum flavum measurement in asymptomatic Thai individuals.

CONCLUSION

MRI was proven to be highly accurate in diagnosis of lumbar disk herniation and lumbar spinal stenosis. However, there was some disagreement on diagnosis of disk protrusion, extrusion and sequestration; location of herniated disk, and lumbar stenosis; nerve root compression; facet joint hypertrophy and ligamentum flavum hypertrophy.

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