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Coronal magnetic resonance imaging of three-dimensional fast-field echo with water-selective excitation improves the sensitivity and reliability of identification of extraforaminal lumbar disc herniation

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Abstract

Objective: The complete view of the nerve root, including the extraforaminal zone, can be displayed by coronal magnetic resonance imaging (MRI) of three-dimensional (3D) fast-field echo with water-selective excitation (CMRI). However, its sensitivity, specificity, and reliability for the diagnosis of extraforaminal lumbar disc herniation are unclear. We compared the sensitivity, specificity, and reliability of conventional MRI, CMRI, and 3D MRI for the identification of extraforaminal lumbar disc herniation.

Methods: This study involved 140 patients (68 with extraforaminal lumbar disc herniation and 72 with paramedian disc herniation). Their mean age was 44.57 ± 14.59 years. Conventional MRI, CMRI, and 3D MRI of all patients were evaluated by five experts. The reliability, sensitivity, and specificity of the three imaging techniques for identification of extraforaminal lumbar disc herniation were compared using kappa statistics and the chi-squared test.

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Results: CMRI showed higher agreement (0.843) than conventional MRI (0.671) and 3D MRI (0.771) for the identification of extraforaminal lumbar disc herniation. CMRI demonstrated higher sensitivity (95.6% vs. 91.2%) than conventional MRI (85.3% vs. 70.6%) and 3D MRI (92.6% vs. 86.7%) regardless of whether performed by junior or senior surgeons.
Conclusions: CMRI is helpful for identification of extraforaminal disc herniation by junior and senior orthopedic surgeons.

Keywords
Extraforaminal herniation, magnetic resonance imaging, sciatica, sensitivity, specificity, reliability

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Introduction

Disc herniation is one of the most common causes of lower back and leg pain[1] and occurs most commonly in the paramedian location.[2] Extraforaminal, or far lateral, lumbar disc herniation refers to protrusion or extrusion of a vertebral disc lateral to the bony foramina and accounts for 3% to 11% of all herniated discs.[3] Herniation lateral to the foramen, however, will most often compress the exiting nerve root at the corresponding level. This compression results in significant radicular leg pain in the distribution of the affected nerve.

Conventional magnetic resonance imaging (MRI) is an effective tool for the diagnosis of lumbar disc herniation. Accurate preoperative evaluation of the position of the disc herniation is vitally important for surgeons to choose the most appropriate surgical approach.[4] However, visualization of the nerve root beyond the foramen may be difficult, as in patients with extraforaminal lumbar disc herniation. Lumbar disc herniation sometimes coexists with spinal canal stenosis or spondylolisthesis, which can obscure the diagnosis of extraforaminal lumbar disc herniation. The limited slice thickness in the horizontal and sagittal planes can also result in a missed diagnosis. Observation of the disc morphology at the L5–S1 level is particularly difficult because of the overlapping bony structures, such as the sacral ala or iliac bone, and severe decreases in disc height because of degeneration.[4] Osborn et al.[5] reported that one-third of far-lateral herniations were initially misdiagnosed. Byun et al.[6] pointed out that extraforaminal herniated discs may not be readily visible and may be overlooked using conventional techniques. In several studies, extraforaminal disc herniation was misdiagnosed as a neurinoma.[7,8]

Unlike conventional MRI, coronal MRI of three-dimensional (3D) fast-field echo with water-selective excitation (CMRI) can provide a complete view of the nerve root, including the extraforaminal region.[6,9,10] The coronal image is reconstructed using software and can clearly show the 3D space location between the herniated disc and nerve root.[10,11] Symptomatic disc herniation and spinal cord and nerve root compression have recently been diagnosed by CMRI and 3D MRI.[9–12] However, the sensitivity, specificity, and reliability of CMRI and 3D MRI for the diagnosis of extraforaminal lumbar disc herniation have not been adequately addressed.

The present study was performed to compare the sensitivity, specificity, and reliability of conventional MRI, CMRI, and 3D MRI for the identification of

extraforaminal lumbar disc herniation. We also assessed the sensitivity, specificity, and reliability of conventional MRI, CMRI, and 3D MRI for the identification of extraforaminal lumbar disc herniation between senior and junior doctors. Extraforaminal lumbar disc herniation was confirmed by intraoperative observations.

Materials and methods

Study design

This retrospective study was performed at the Second Affiliated Hospital of Nanchang University. This research was approved by the Medical Ethics Committee and Internal Review Board of our hospital, and informed consent was obtained from the patients.

From March 2016 to September 2018, a coronal MRI fast-field echo sequence with water-selective excitation was added to conventional two-dimensional (2D) sequences in our hospital when patients were suspected to have degenerative spinal disease or intervertebral disc herniation of the lumbar spine based on clinical examination, radiography, or computed tomography. Next, 3D images were reconstructed using maximum-intensity projection and a volume-rendering technique on ADW version 4.6 software (GE Healthcare, Chicago, IL, USA). All patients underwent lumbar spine MRI, including a 3D MRI sequence at 3T, to evaluate degenerative spinal disease or intervertebral disc herniation.

Five experts, including two senior orthopedic surgeons (Jingyu Jia and Xigao Cheng), two junior orthopedic surgeons (Tianlong Wu and Dingwen He), and 1 radiologist (Wugen Li), evaluated conventional MRI, CMRI, and 3D MRI of all patients to determine the reliability, sensitivity, and specificity of each imaging method for the detection of extraforaminal lumbar disc herniation (Figures 1–3). A single-blind design was used during these evaluations, and the statistical analysis was performed by two authors (Xijuan Liu and Xi Xiong).

Statistical analysis

Statistical analysis was performed using SPSS version 17.0 for Windows (SPSS Inc., Chicago, IL, USA). Interobserver agreement was analyzed using kappa statistics. A kappa value of 0.00 to 0.20 indicates slight agreement, a value of 0.21 to 0.40 indicates fair agreement, a value of 0.41 to 0.60 indicates moderate agreement, a value

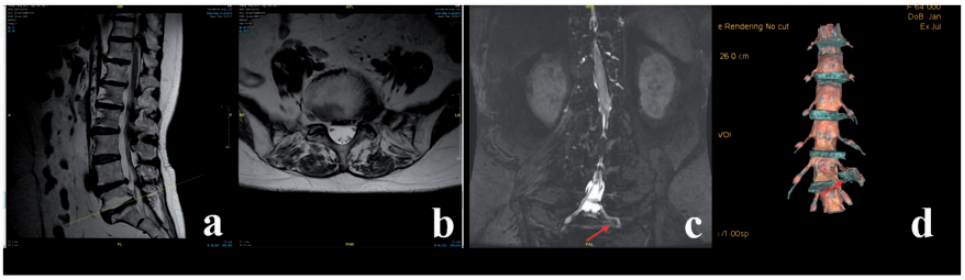

Figure 1. (a) T2-weighted MRI in the sagittal plane was used to aid in localization of L5/S1, (b) T2-weighted images in the axial plane revealed a mass in the extraforaminal region of L5/S1, (c) CMRI confirmed that the extraforaminal disc (red arrow) compressed the nerve root of L5 and (d) Three-dimensional MRI also clearly showed that the extraforaminal disc compressed the nerve root of L5. MRI, magnetic resonance imaging; CMRI, coronal magnetic resonance imaging of three-dimensional fast-field echo with water-selective excitation.

of 0.61 to 0.80 indicates substantial agreement, a value of 0.81 to <1.00 indicates almost perfect agreement, and a value of 1.00 indicates perfect agreement.[13] Accuracy of the identification of extraforaminal disc herniation was compared among conventional MRI, CMRI, and 3D MRI using the chi-squared test. The reliability of conventional MRI, CMRI, and 3D MRI for the identification of extraforaminal lumbar disc herniation between senior and junior doctors was also compared. A P value of <0.05 was considered statistically significant. The MRI scans were performed as in our previous study.[8]

Results

Among 1226 patients aged >18 years who underwent lumbar spine MRI, we identified 292 patients with radicular leg pain who had subsequently undergone spine surgery for lumbar disc herniation with a description of the intraoperative findings regarding the foraminal canals, spinal canal, and spinal nerves. All patients reported improvement in symptoms after surgery. Sixty-eight patients were confirmed to have a diagnosis of extraforaminal lumbar disc herniation, and 224 patients were diagnosed with paramedian disc herniation. We randomly selected 72 patients among the 224 patients with paramedian disc herniation for inclusion in the study. Patients with a history or imaging evidence of previous spine surgery were excluded. Therefore, this study involved 140 patients, including 68 with extraforaminal lumbar disc herniation with 107 levels of involvement and 72 patients with paramedian disc herniation with 126 levels of involvement. The mean patient age was 44.57 ± 14.59 years (range, 19–82 years), and the patients comprised 85 men (mean age, 45.33 ± 14.54 years; range, 19–82 years) and 55 women (mean age, 43.42 ± 14.72 years; range, 19–82 years).

All 68 cases of extraforaminal lumbar disc herniation were confirmed according to the standard that the exiting nerve root was compressed by disc herniation in the extraforaminal region via gross examination during the operation and improvement of radicular symptoms after the operation. The disc herniation was located in the extraforaminal region in 51 patients and in the foraminal and extraforaminal regions in 17 patients. Although the exiting nerve root was compressed in all 68 patients, the dorsal root ganglion was compressed in only 28 patients because of superior migration of the disc fragment. The mean visual analog scale score decreased from 7.97 ± 1.26 to 2.43 ± 1.25 at 1 week postoperatively. In 72 patients, paramedian disc herniation was identified by intraoperative observation and the improvement of radicular symptoms. The mean visual analog scale score decreased from 7.49 ± 1.28 to 2.23 ± 1.21 at 1 week postoperatively.

Analysis of interobserver agreement for identification of extraforaminal lumbar disc herniation using conventional MRI showed substantial agreement of 0.671 with a 95% confidence interval of 0.552 to 0.798 ($P = 0.001$). Likewise, 3D MRI showed substantial agreement of 0.771 with a 95% confidence interval of 0.666 to 0.871 ($P = 0.001$). CMRI showed almost perfect agreement of 0.843 with a 95% confidence interval of 0.755 to 0.928 ($P = 0.001$).

Among the junior surgeons, CMRI demonstrated significantly higher sensitivity (91.2%) and specificity (90.3%) than conventional MRI (70.6% and 76.3%, respectively; $P = 0.001$) (Figures 1–3). CMRI also showed higher sensitivity (91.2%) and specificity (90.3%) than 3D MRI (86.7% and 86.1%, respectively) among the junior surgeons (Figure 3), but this difference was not statistically significant.

Similarly, among the senior surgeons, CMRI demonstrated higher sensitivity (95.6%) and specificity (94.4%) than

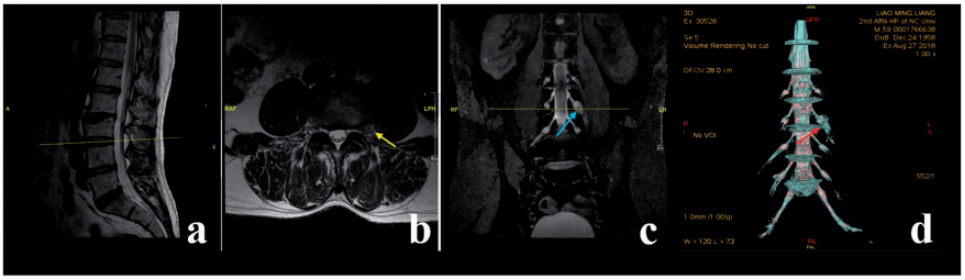

Figure 2. (a) T2-weighted MRI in the sagittal plane was used to aid in localization of L3/L4, (b) The junior surgeon did not find the extraforaminal disc herniation (yellow arrow) in the axial plane of the T2-weighted images, (c) However, the junior surgeon accurately diagnosed the extraforaminal disc herniation (blue arrow) using CMRI and (d) Three-dimensional MRI also clearly showed that the extraforaminal disc (red arrow) compressed the nerve root of L3. MRI, magnetic resonance imaging; CMRI, coronal magnetic resonance imaging of three-dimensional fast-field echo with water-selective excitation.

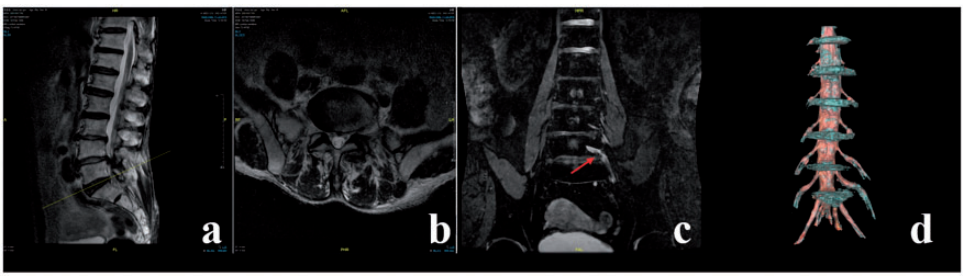

Figure 3. (a) T2-weighted MRI in the sagittal plane was used to aid in localization of L5/S1, (b) Neither the junior surgeon nor senior surgeon found the extraforaminal disc herniation in the axial plane of T2-weighted images, (c) However, both accurately diagnosed the extraforaminal disc herniation (red arrow) using CMRI and (d) The extraforaminal disc herniation (red arrow) was not found using 3D MRI because the imaging details were lost after the original images were reconstructed using 3D maximum-intensity projection and volume-rendering techniques. MRI, magnetic resonance imaging; CMRI, coronal magnetic resonance imaging of three-dimensional fast-field echo with water-selective excitation.

conventional MRI (85.3% and 84.7%, respectively; $P = 0.001$) (Figures 1–3). CMRI also showed higher sensitivity (95.6%) and specificity (94.4%) than 3D MRI (92.6% and 91.7%, respectively) among the senior surgeons, but this difference was not statistically significant.

Finally, using conventional MRI, the senior surgeons showed higher sensitivity (85.3%) in identifying extraforaminal lumbar disc herniation than the junior surgeons (70.6%, $P = 0.039$). Using CMRI, however, the sensitivity of identifying extraforaminal lumbar disc herniation was not significantly different between the senior surgeons (95.6%) and junior surgeons (91.2%).

Discussion

Conventional MRI can readily show paramedian and foraminal disc herniation, but extraforaminal herniated discs are easily overlooked using this technique. Moon et al.[4] evaluated the dependability of MRI for identification of symptomatic

extraforaminal disc herniation in the lumbar spine. They found that conventional MRI is a more reliable tool for identifying focal eccentricity of the disc. However, extraforaminal disc herniation was incorrectly diagnosed in cases in which the acquisition of axial images was not parallel to the disc, the disc profile was asymmetric, the nerve roots were of different sizes, or the nerve roots were asymmetric without disc herniation.[4] Although oblique coronal lumbar MRI can show the nerve roots in the foraminal and extraforaminal regions, Heo et al.[14] found that it was not helpful in the diagnosis of extraforaminal disc herniation in patients with spinal deformities, such as scoliosis or severe lordosis.

In contrast to conventional MRI, 3D MRI and CMRI can provide the complete view of the nerve root, including the extraforaminal area. The coronal image is reconstructed using software and can clearly show the location of the 3D space location between the herniated disc and nerve root. To date, most studies using 3D MRI for spine imaging have been feasibility studies. For example, Shen et al.[10] found that 3D MRI could better demonstrate the normal anatomy and variants of the lumbar dorsal root ganglion. Grasso et al.[9] and Shen et al.[10] suggested that 3D MRI can provide more information about symptomatic disc herniation than can other techniques, supporting the detection of morphologic changes of the nerve root, dorsal root ganglion, and spinal nerve. Additionally, 3D magnetic resonance lumbosacral radiculography using the principle of selective excitation technique demonstrated excellent visualization of the nerve roots. Moreover, Byun et al.[6] reported that 3D MRI showed satisfactory outcomes in the diagnosis of symptomatic extraforaminal disc herniation. CMRI and 3D MRI demonstrate some advantages over conventional MRI in the diagnosis of lumbar disc herniation and spinal cord and nerve root compression. However, the sensitivity, specificity, and reliability of CMRI and 3D MRI for the diagnosis of extraforaminal lumbar disc herniation have not been adequately addressed.

Lee et al.[15] compared an isotropic 3D T2-weighted (T2W) turbo spin-echo sequence (TSE-SPACE) with standard 2D T2W TSE imaging for the evaluation of lumbar neural foraminal stenosis, central spinal stenosis, and nerve compression on 3.0T MRI. They found that 3D T2W TSE demonstrated better interobserver agreement than 2D TSE-SPACE. However, extraforaminal disc herniation was not evaluated in their study. In 2017, Sung et al.[12] compared isotropic 3D T2W TSE-SPACE with 2D T2W TSE for the detection of foraminal stenosis, central spinal stenosis, and nerve compression. Their study included 37 patients with diagnoses of posterior disc herniation, lateral recess stenosis, neural foraminal stenosis, and extraforaminal disc herniation. Although good interobserver agreement was observed, there was no significant difference in the sensitivity or specificity for the identification of symptomatic extraforaminal disc herniation between 3D T2W TSE-SPACE and 2D T2W TSE. This may be attributed to the small sample size of patients with extraforaminal disc herniation. Therefore, we further analyzed the sensitivity, specificity, and reliability of 3D MRI in 140 patients (68 patients with extraforaminal disc herniation and 72 control individuals). We also evaluated the sensitivity, specificity, and reliability of conventional MRI, CMRI, and 3D MRI for the identification of extraforaminal lumbar disc herniation between senior and junior doctors. To our knowledge, no such data have been previous reported.

Unlike the study by Sung et al.,[12] the present study showed that the sensitivity and specificity of CMRI and 3D MRI for the identification of extraforaminal disc

herniation were superior to those of conventional MRI regardless of whether performed by junior or senior doctors. This demonstrates that CMRI and 3D MRI are very helpful tools for the identification of extraforaminal lumbar disc herniation by both junior and senior doctors. Moreover, we observed that although the senior surgeons showed higher sensitivity in identifying extraforaminal lumbar disc herniation than the junior surgeons using conventional MRI, the sensitivity was not significantly different between the senior and junior surgeons using CMRI. This indicates that CMRI seems to be a more effective strategy for junior surgeons to improve the accuracy of identifying extraforaminal lumbar disc herniation. We also found that CMRI demonstrated higher agreement than 3D MRI and conventional MRI. In fact, CMRI showed higher sensitivity than3D MRI (91.2% vs. 86.7%, respectively).

3D MRI can perfectly demonstrate the spatial location between the herniated disc, nerve root, dorsal root ganglion, and dura mater. In some cases, however, imaging details are lost after the original images are reconstructed using 3D maximum-intensity projection and volume-rendering techniques. The current 3D MRI reconstruction technique cannot provide satisfactory accuracy. We believe that CMRI can provide more helpful data to surgeons than can 3D MRI.

This study had two main limitations. First, selection bias could not be completely excluded because of the retrospective design. Second, this was a single-center study. The outcomes of the present study require further confirmation through performance of a multicenter study with a larger sample.

Conclusion

CMRI and 3D MRI demonstrated higher sensitivity and specificity than conventional MRI for the detection of symptomatic extraforaminal disc herniation. However, CMRI seemed to be more helpful than 3D MRI in the identification of extraforaminal disc herniation. Given the extra costs associated with MRI, longer scan time, and unsatisfactory accuracy of 3D MRI, CMRI can be considered a helpful tool when surgeons, especially junior doctors, cannot identify symptomatic disc herniation.

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Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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