Imaging Appearance of Magnetic Resonance Myelography in Normal Population: Employing Three-dimensional Sampling Perfection with Application Optimized Contrasts Using Different Flip-angle Evolutions (3D-SPACE) Sequence

Chuan-Han Chen, Hung-Chieh Chen, Jyh-Wen Chai, Clayton Chi-Cheng Chen

ABSTRACT

Characterizing the normal distribution of cerebrospinal fluid (CSF) in the spine is crucial for an accurate assessment of CSF leakage and other abnormalities. Magnetic resonance myelography (MRM) is a noninvasive diagnostic method that is commonly used to evaluate the spinal distribution of CSF. Our aim was to evaluate the anatomical distribution of CSF in the spine of healthy individuals, by MRM using the three-dimensional sampling perfection with amplification-optimized contrasts using flip-angle evolutions (3D-SPACE) sequence.

Twenty-one healthy volunteers underwent whole-spine MRM imaging using the 3D-SPACE sequence. MRM images were reconstructed with 5-mm axial multiplanar reconstruction (MPR) and maximum intensity projection (MIP) at each spine level. Two radiologists evaluated CSF distribution from the spinal canal in the MPR and MIP images, using 7-point (types A–G) and 3-point (grades 0–3) classification systems, respectively. Inter-reader agreement was calculated with the kappa coefficient (κ).

Reader 1/reader 2 evaluated 46/53, 67/57, 4/6, 0/0, 0/7, and 2/5 cervical spine (C-spine)-level MPR images corresponding to types A–G, respectively (κ = 0.74). Numbers at the thoracic spine (T-spine) level were 185/186, 41/44, 8/5, 0/0, 0/0, 16/11, and 2/6, respectively (κ = 0.69), and at the lumbar spine (L-spine) level were 46/58, 25/23, 9/5, 0/0, 0/0, 19/13, and 6/6, respectively (κ = 0.50). Inter-reader agreement for MPR images at the whole-spine level was considered good (κ = 0.69). Reader 1/reader 2 evaluated 0/0, 13/13, 8/8, and 0/0 MIP images at the C-spine level corresponding to grades 0–3, respectively (κ = 0.80). Numbers at the T-spine level were 10/14, 8/5, 3/2, and 0/0, respectively (κ = 0.67), and at the L-spine level were 5/2, 10/8, 6/11, and 0/0, respectively (κ = 0.26). Inter-reader agreement for MIP images at the whole-spine level was considered good (κ = 0.61).

In conclusion, T2-weighted MRM with 3D-SPACE sequence imaging can be a useful technique to detect the normal distribution of CSF in the spinal canal. Understanding the normal distribution of CSF in the spinal canal is necessary to achieve an accurate diagnosis of CSF leakage.

Spontaneous cerebrospinal fluid (CSF) leakage most frequently happened at spine level with the principal symptom as an orthostatic headache. Identifying CSF leakage as the cause of headaches presents a considerable clinical challenge among patients without a history of trauma or lumbar puncture. If left untreated, CSF leakage may result in several complications, such as subdural hemorrhage, brain herniation, and death. Therefore, diagnosing CSF leakage early and accurately is of crucial importance for the successful treatment of this disease.

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Imaging modalities that have been used to detect CSF leakage in the spine include computed tomographic (CT) myelography, radioisotope cisternography, and magnetic resonance myelography (MRM). As a radiation-free and noninvasive imaging method, MRM is the most frequently used of these approaches to diagnose CSF leakage. Commonly reported MRM imaging findings indicative of CSF leakage include a triangular-shaped expansion of the neural sleeve, an irregular linear signal lateral to the neural sleeve, distended spinal epidural veins, and extradural fluid collection [1, 2]. Axial multiplanar reconstruction (MPR) images are used in conjunction with maximum intensity projection (MIP) images for an accurate determination of the CSF leakage site.

However, MRM imaging has some disadvantages. In particular, there is considerable inter-reader variability in the interpretation of MRM images obtained using different pulse sequences. Furthermore, the normal population may also present MRM images showing abnormalities mimicking CSF leakage. This ambiguity is a potential source of confusion.

Here, we aimed to determine whether MRM with a newly developed pulse sequence, three-dimensional sampling perfection with application optimized contrasts (3D-SPACE), could be used for effectively detecting the CSF distribution in the spinal canal of normal individuals. To our knowledge, this is the first study examining the spinal distribution of CSF in a normal population using MRM with the 3D-SPACE sequence.

RESULTS

For MPR images at the C-spine level, reader 1 categorized 46 as type A (36.5%), 67 as type B (53.2%), 4 as type C (3.2%), 0 as type D (0.0%), 0 as type E (0.0%), 7 as type F (5.5%), and 2 as type G (1.6%), whereas reader 2 categorized 53 as type A (42.1%), 57 as type B (45.2%), 6 as type C (4.7%), 0 as type D (0.0%), 0 as type E (0.0%), 5 as type F (4.0%), and 5 as type G (4.0%). For MPR images at the T-spine level, reader 1 categorized 185 as type A (73.4%), 41 as type B (16.3%), 8 as type C (3.2%), 0 as type D (0.0%), 0 as type E (0.0%), 16 as type F (6.3%), and 2 as type G (0.8%), whereas reader 2 categorized 186 images as type A (73.8%), 44 as type B (17.4%), 5 as type C (2.0%), 0 as type D (0.0%), 0 as type E (0.0%), 11 as type F (4.4%), and 6 as type G (2.4%). For MPR images at the L-spine level, reader 1 categorized 46 as type A (43.8%), 25 as type B (23.8%), 9 as type C (8.6%), 0 as type D (0.0%), 0 as type E (0.0%), 19 as type F (18.1%), and 6 as type G (5.7%), whereas reader 2 categorized 58 as type A (55.2%), 23 as type B (21.9%), 5 as type C (4.8%), 0 as type D (0.0%), 0 as type E (0.0%), 13 as type F (12.4%), and 6 as type G (5.7%). These data are summarized in Table 1. Inter-reader agreements for the interpretation of MPR images at the C-, T-, L-, and whole-spine levels were good (κ = 0.74), good (κ = 0.69), moderate

MATERIALS AND METHODS

This study was approved by the Institutional Review Board (IRB) of Taichung Veterans General Hospital.

Subjects

Twenty-one healthy adults (10 males, 11 females; age range, 20–50 years; mean age, 28.0 ± 9.7 years) without any history of headaches or known spinal disease were recruited.

Magnetic resonance myelography

Subjects underwent MRM imaging of the whole spine using the 3D-SPACE sequence. The parameters used for MRM were as follows: TR of 3000 ms, TE of 560 ms, fat suppression, isotropic voxel size of 0.9 mm, matrix size of 320 × 320, and field of view (FOV) of 200 mm. The generalized autocalibrating partially parallel acquisitions (GRAPPA) imaging reconstruction technique with an acceleration factor of 2 was used with the 3D-SPACE sequence. 3D-SPACE sequence images were acquired in the coronal plane. Axial whole spine MPR images were obtained as 5-mm slices and MIP images were reconstructed at the cervical, thoracic, and lumbar spine levels.

Image evaluation

To evaluate the CSF distribution and spinal canal morphology, the MRM images were reconstructed by MPR and MIP processing. We used the modified MIP image grading scale proposed by Yoo et al. [4], which we considered to be more applicable to a normal population (Fig. 1). Additionally, we created a classification system to categorize MPR images (Fig. 2), based on our experiences to interpret spinal magnetic resonance (MR) images. To our knowledge, there are no reports characterizing the MR imaging profile of the spine in a normal population. We also did not find any studies examining the imaging profile of CSF distribution in a normal population using CT myelography, which could be used as a reference. Two radiologists (with 4 and 9 years of experience, respectively) independently evaluated the MRM images for each level of the spine.

The image quality and contrast were evaluated by 3-point scale, as follows: grade 3 – minimal noise and above-average image contrast; grade 2 – presence of noise, but sufficiently clear for a diagnosis to be made, and average image contrast; and grade 1 – presence of significant noise levels that impaired image interpretation and poor image contrast.

Statistical analysis

The results of two readers were analyzed and the inter-reader agreement between two readers was evaluated with the kappa coefficient (κ).
MR myelography in normal population

MIP images were categorized according to CSF expansion from the spinal canal using a 4-point grading system (grades 0–3). For MIP images at the C-spine level, reader 1 categorized 0 as type 0 (0.0%), 13 as type 1 (61.9%), 8 as type 2 (38.1%), and 0 as type 3 (0.0%), whereas reader 2 categorized 0 as type 0 (0.0%), 13 as type 1 (61.9%), 8 as type 2 (38.1%), and 0 as type 3 (0.0%). For MIP images at the T-spine level, reader 1 categorized 10 as type 0 (47.6%), 8 as type 1 (38.1%), 3 as type 2 (14.3%), and 0 as type 3 (0.0%), whereas reader 2 categorized 14 as type 0 (66.7%), 5 as type 1 (23.8%), 2 as type 2 (9.5%), and 0 as type 3 (0.0%). For MIP images at the L-spine level, reader 1 categorized 5 as type 0 (23.8%), 10 as type 1 (47.6%), 6 as type 2 (28.6%), and 0 as type 3 (0.0%), whereas reader 2 categorized 2 as type 0 (9.5%), 8 as type 1 (38.1%), 11 as type 2 (52.4%), and 0 as type 3 (0.0%). The data are summarized in Table 2. Inter-reader agreements for the interpretation of MIP images at the C-, T-, L-, and whole-spine levels were considered good (κ = 0.80), good (κ = 0.67), fair (κ = 0.26), and good (κ = 0.61), respectively.

Figure 1. Schematic drawing of the 7-type classification of the imaging appearance of CSF on axial MPR images.

<table>
<thead>
<tr>
<th>Type A</th>
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<tr>
<td><img src="image1" alt="Type A" /></td>
<td><img src="image2" alt="Type B" /></td>
<td><img src="image3" alt="Type C" /></td>
<td><img src="image4" alt="Type D" /></td>
<td><img src="image5" alt="Type E" /></td>
<td><img src="image6" alt="Type F" /></td>
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Figure 2. Schematic drawing of the 4-point scale grading system used to categorize the CSF distribution in the spine using MIP images. Grade 0: no CSF expansion from the CSF space. Grade 1: unilateral or bilateral triangular-shaped expansion of the CSF space around the nerve root sleeve. Grade 2: a high-intensity signal stripe along the nerve root sleeve, with the stripe length not exceeding the thecal sac width. Grade 3: a high-intensity stripe arising from a unilateral or bilateral triangular-shaped expansion of the CSF space around the nerve root sleeve, with the stripe length exceeding the thecal sac width.

Table 1. Numbers of MPR images categorized as types A–G according to the spinal distribution of CSF

<table>
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<tr>
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<td>C spine</td>
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<td>L spine</td>
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<td>Total</td>
<td>277</td>
<td>297</td>
<td>133</td>
<td>124</td>
<td>21</td>
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Overall, no images were assessed as type D or E using the MPR classification system, and no images were categorized as grade 3 on the MIP grading system. Epidural fluid collection was not reported by either reader in any subject. Both readers categorized the image quality and contrast of the MRM images as type 3 (Table 3).

Figure 3 shows MRM images from a normal 33-year-old male, including image reconstructions by MPR (panels a–c) and MIP (panel d). The MIP images were categorized as grade 1 at the T-spine level and grade 2 at the L-spine level. The MPR images were categorized as type F, which was determined to indicate the presence of perineural cysts.

**DISCUSSION**

MRM is commonly used to diagnose spinal abnormalities by demonstrating the CSF distribution in the spinal canal. This imaging method is considered an effective tool for diagnosing spinal abnormalities, especially in cases where other imaging modalities are not feasible or reliable.
for accurately detecting the site of spinal CSF leakage [4], especially when used in conjunction with axial MPR [5]. Numerous studies using MRM have provided detailed imaging profiles of the spinal distribution of CSF in patients with CSF leakage [1, 2-6]. However, to our knowledge, there are no studies characterizing the imaging profile of CSF distribution in the spinal canal of the normal population. The goal of our study was to evaluate the effectiveness of MRM with the 3D-SPACE sequence in determining the CSF distribution in the spinal canal.

The two readers most frequently categorized the MPR images as type A (about 57–61%), followed by type B (about 25–27%). Thus, nearly 85% of the axial MPR images in normal individuals were either type A or B; the remaining images were categorized as type C, F, or G. Types F and G, which likely indicate the presence of perineural cysts, accounted for about 10% of all images. When images were analyzed at each spine level separately, types A and B accounted for 87–90% of images at the C- and T-spine levels. There was more variability in the interpretation of MPR images at L-spine than at C- and T-spine levels, likely due to the confounding effects of engorged epidural vessels and the oblique direction of neural sleeves that are typically observed at these levels. Images categorized as types F and G were more frequently seen at the L-spine level (18–23%) than at the C- or T-spine level (<8%).

Most of the MIP images at the C-spine level were categorized as grade 1 (61%), and images at T-spine level were primarily categorized as grade 0 (47–66%). MIP images categorized as grade 2, indicating probable CSF leakage [4], accounted for 26–33% of all evaluations. Inter-reader agreement was less consistent when evaluating the MPR and MIP images at the L-spine level (κ = 0.50 and κ = 0.26, respectively). MIP images were reformatted from 3D data by projection of the voxels using an MIP that was perpendicular to the visualization plane. Loss of image detail and the relatively high signal intensity of nearby structures (e.g., blood vessels) may frustrate attempts to detect the CSF distribution in MIP images. Thus, caution is recommended when diagnosing CSF leakage based on a grade 2 assessment of MIP images.

None of the subjects had MIP images that were classified as grade 3, which would represent a finding of definite CSF leakage [4]. Similarly, no MPR images were classified as type D or E, which would indicate the presence of spinal canal abnormalities. There were no abnormal findings indicative of CSF leakage or epidural fluid collection in any of the subjects.

We used a T2-weighted 3D-SPACE pulse sequence for MRM imaging to evaluate the CSF distribution in the spine. The 3D-SPACE sequence consists of variable flip angle pulses less than 180°, allowing for long echo trains and short echo spacing. When combined with a parallel imaging technique, such as GRAPPA, the image acquisition time can be further reduced. The 3D-SPACE sequence allows volumetric acquisition of the spinal canal in a reasonable time period, by using thin axial scans and isotropic voxels. This approach can provide very thin and high-resolution multiplanar or oblique reformatted slices with the help of isotropic acquisition [7]. Thus, we can obtain 3D images and other reformatted images with a high spatial resolution and relatively low acquisition times from one coronal acquisition using a large FOV.

Tins et al. reported that the 3D-SPACE sequence combines high spatial resolution and reasonable contrast resolution with a high resilience to artifacts. These characteristics allow high-resolution isotropic reformating with a large FOV, and the method performs very well in otherwise difficult circumstances, such as the imaging of complex anatomy [8]. In our study, the quality and contrast of images of the CSF distribution in the spine were assessed as grade 3. As such, the signal corresponding to the CSF distribution could always be distinguished from signals of nearby fat or blood vessels. By using 3D imaging techniques, it is possible to differentiate discrete structures adjacent to the spinal canal, such as perineural cysts, which is not possible when using conventional 2D-MRM.

There are some limitations in our study. The small number of subjects analyzed may lead to errors in the data distribution. In addition, this was not a blinded or controlled study, which may result in the introduction of bias from the two readers. Due to our limited experience, subtle abnormalities may not have been detected when interpreting the images. Also, the classification system may not have been adequate to categorize all of the variations of CSF distribution in the spine.

In conclusion, T2-weighted MRM with 3D-SPACE sequence imaging can be a useful technique to detect the normal distribution of CSF in the spinal canal. Understanding the normal distribution of CSF in the spinal canal is necessary to achieve an accurate diagnosis of CSF leakage.
REFERENCES