ORIGINAL ARTICLE

Differentiation of Osteophytes and Disc Herniations in Spinal Radiculopathy Using Susceptibility-Weighted Magnetic Resonance Imaging

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Objective: The aim of this study was to evaluate the diagnostic performance of susceptibility-weighted magnetic resonance imaging (SW-MRI) for the differentiation of osteophytes and disc herniations of the spine compared with that of conventional spine MR sequences and radiography.

Materials and Methods: This study was approved by the local ethics review board; written consent was obtained from all subjects. Eighty-one patients with suspected radiculopathy of the spine were included prospectively. Radiography, T1/T2, and SW-MRI of the cervical/lumbar spine were performed. As reference standard, 93 osteophytes (n = 48 patients) were identified on radiographs in combination with conventional T1/T2 images. One hundred fourteen posterior disc herniations (n = 60 patients) were identified on T1/T2 in combination with radiography excluding osteophytes. For this study, 2 observers independently assessed the presence of osteophytes and disc herniations on T1/T2 and SW-MRI, with radiographs excluded from the analysis. In a subgroup of patients (n = 19), additional computed tomography images were evaluated. Sensitivity, specificity, and interobserver agreement were calculated.

Results: Most osteophytes (n = 92 of 93) and disc herniations (n = 113 of 114) could be identified and differentiated on SW-MRI magnitude/phase images, if radiographs were excluded from analysis. Susceptibility-weighted magnetic resonance imaging achieved a sensitivity of 98.9% and specificity of 99.1% for the identification of osteophytes. Conventional T1/T2 spine MR sequences achieved a sensitivity and specificity of 68.6% and 86.5%, respectively, if radiographs were excluded from analysis. Regarding the size of osteophytes, SW-MRI showed a strong correlation with computed tomography (R² = 0.96) and radiography (R² = 0.95). In addition, SW-MRI achieved a higher interobserver agreement compared with conventional MR.

Conclusions: Susceptibility-weighted magnetic resonance imaging enables the reliable differentiation of osteophytes and disc herniations in patients with spinal radiculopathy with a higher sensitivity and specificity compared with conventional T1/T2 MR sequences.

Key Words: magnetic resonance imaging, susceptibility-weighted MRI, spinal radiculopathy, osteophytes, disc herniations

(W)ith increasing age, a relatively large proportion of the population shows radiological signs of spinal degeneration, usually located in the cervical or lumbar spine.1 If surgical intervention is required due to radiculopathy or myelopathy, cross-sectional imaging is important to localize the site and degree of spine disease and to differentiate between disc herniations, nerval compression due to osteophytes, and other abnormalities.2,3 Commonly used imaging modalities include magnetic resonance imaging (MRI), radiography, and computed tomography (CT). Radiography is a widely available and inexpensive method to visualize osteophytes, facet and uncovertebral arthritis, and narrowing of disc space. Functional radiographs can be useful for the 2-dimensional assessment of the spine, including instability. A precise 3-dimensional (3D) evaluation of osseous changes can be achieved by using CT. This technique is, however, associated with radiation4 and a limited diagnostic performance for the identification of disc herniations due to a relatively low soft tissue contrast.5 Therefore, it is not routinely performed in all patients.

Magnetic resonance imaging provides a great range of information with a focus on soft tissue structures and has developed into the method of choice to assess the involvement of spinal nerves and damage to the spinal cord.6 However, a major limitation of spine MRI is that osseous degenerative changes such as osteophytes cannot reliably be distinguished from disc herniations, as both structures can appear hypointense on T1- and T2-weighted images. Because of this limitation, additional radiography and CT are often acquired for preoperative planning.

The development of susceptibility-weighted MRI (SW-MRI) enables the MR-based differentiation of calcified structures from soft tissues based on their magnetic susceptibility. The potential of SW-MRI has so far mainly been investigated for the identification of calcifications in the brain.6–15

The aim of this study was to evaluate the diagnostic performance of SW-MRI for the differentiation of osteophytes and disc herniations of the spine compared with that of conventional MR sequences and radiography.

MATERIALS AND METHODS

Study Population

This study was prospectively approved by the local ethics review board. Written consent was obtained from all subjects before they underwent the study protocol. In all investigated 81 subjects with suspected radiculopathy of the cervical or lumbar spine, a clinical MRI scan was required. As part of the study protocol, an additional sequence (susceptibility-weighted imaging) was performed. Overall, we investigated 14 subjects without degenerative changes of the spine and a total of 67 patients with degenerative changes, osteophytes, and/or posterior disc herniations of the cervical/lumbar spine prospectively using a standardized imaging protocol. The 14 subjects without osteophytes and/or posterior disc herniations presented with clinical symptoms, suggesting radiculopathy of the spine. The scan, however, did not show degenerative or inflammatory changes of the spine. The study population included 41 male (50.6%) and 40 female (49.4%) patients who visited our institution and underwent MRI of the spine between July 2013 and February 2016. Sixty-seven patients were diagnosed with degenerative changes of the cervical/lumbar spine (36 male patients, mean age 59.4 ± 17.0 years; 31 female patients, mean age 55.0 ± 17.5 years,

Received for publication March 21, 2016; and accepted for publication, after revision, June 17, 2016.

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Conflicts of interest and sources of funding: none declared.

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ISSN: 0200-9966/17/5202–0075
DOI: 10.1097/RLI.0000000000000314

Received: 2016-03-21; Accepted: 2016-06-17.

INVESTIGATIVE RADIOLOGY • VOLUME 52, NUMBER 2, FEBRUARY 2017 www.investigativeradiology.com | 75

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P > 0.05) based on the detection of osteophytes and posterior disc herniations on radiographs in combination with conventional spine MRI scans in at least 1 vertebral segment. Fourteen patients (6 male patients, mean age 45.0 ± 18.3 years; 8 female patients, mean age 43.6 ± 16.7 years) without degenerative changes on radiographs and conventional spine MRI scans were used as a reference group. Susceptibility-weighted magnetic resonance imaging, conventional cervical/lumbar spine T1/T2 MR sequences, and radiography were performed in all patients. For a subgroup of patients (n = 19 of 67), additional CT scans of the cervical/lumbar spine were available.

**Imaging Protocol**

Magnetic resonance imaging was performed on a Siemens 1.5 T scanner (Avanto; Siemens Medical Solutions, Erlangen, Germany) in a standardized supine position with a standard neck coil for the cervical and a standard body coil for the lumbar spine. The following spine MRI protocol, which is routinely used in our department for the diagnosis of cervical/lumbar spine lesions, was applied: sagittal T1 turbo spin-echo (TSE), T2 TSE, and axial T2 TSE (lumbar) or T2 MEDIC (cervical). Cervical spine [T1 TSE: field of view 240 × 240 mm², matrix 448 × 448, TR/TE = 803/21 milliseconds, 150-degree flip angle, and 3-mm slice thickness; T2 TSE: field of view 240 × 240 mm², matrix 448 × 448, TR/TE = 2800/77 milliseconds, 150-degree flip angle, and 3-mm slice thickness], lumbar spine [T1 TSE: field of view 280 × 280 mm², matrix 448 × 448, TR/TE = 726/13 milliseconds, 150-degree flip angle, and 3-mm slice thickness; T2 TSE: field of view 280 × 280 mm², matrix 448 × 448, TR/TE = 3300/88 milliseconds, 150-degree flip angle, and 3-mm slice thickness]. In addition, a 3D fast low-angle gradient-echo sequence (SW-MRI) was performed. A standard ventral saturator was used to minimize artifacts. The SW-MRI magnitude image derives from a velocity-compensated 3D-gradient-recalled echo (GRE) sequence, which is part of the SW-MRI. This sequence is comparable to standard GRE sequences for the detection of T2* time-shortening lesions. In addition to the velocity-compensated 3D-GRE sequence, SW-MRI includes phase information. Imaging parameters of the SW-MRI sequence, which was automatically aligned to the sagittal T1/T2-weighted sequences, included the following: TR/TE = 49/14 milliseconds, 15-degree flip angle, and 3-mm slice thickness. Field of view and matrix were adapted to the respective T1 and T2 TSE sequences. Acquisition time for SW-MRI was 5 minutes and 11 seconds in average. After the acquisition, SW-MRI magnitude and phase images were reconstructed.

**Imaging Analysis**

All images were analyzed using PACS workstations (Centricity Radiology RA1000; GE Healthcare, Little Chalfont, United Kingdom). As reference standard, osteophytes were identified on radiographs in combination with conventional T1/T2 spine MRI scans. Osteophytes were visually detected on sagittal radiographs and sagittal conventional T1/T2 spine MRI scans based on their cortical and medullary continuity with the vertebral body and based on their specific shape. On conventional T1/T2-weighted spine MRI scans, osteophytes display accordingly an isointense signal to the vertebra. Off-center marginal osteophytes of the end plates were excluded from the analysis as their detection is limited on radiographs. On SW-MRI scans, osteophytes were identified based on the following properties: hyperintense on inverse SW-MRI magnitude images with a hyperintense surface on SW-MRI phase images. Sizes of osteophytes were measured on SW-MRI magnitude, T1- and T2-weighted MRI scans, and radiographs to assess intermodality correlations. Regarding posterior disc herniations, the combination of T1/T2-weighted MRI scans with radiographs excluding osteophytes served as reference standard. Posterior disc herniations were identified on MRI scans as herniations in the spinal canal with contiguous connection to the intervertebral disc. The herniation showed a hypointense signal to the adjacent disc on T1-weighted and an isointense to hyperintense signal on T2-weighted images, depending on the degree of disc hydration. Radiographs were additionally reviewed to exclude that posterior osteophytes were present at that location.

Disc herniations were identified on inverse SW-MRI magnitude images as hypointense or without signal on SW-MRI phase images. For this study, all MRI scans were reviewed independently by 2 experienced radiologists with 4 and 8 years of diagnostic experience in musculoskeletal MRI. Both readers were blinded to radiographs. Osteophytes were visually detected based on their specific shape and signal intensity. The maximal extend of the osteophyte was measured. No grading system was used.

**Computed Tomography**

For a subgroup of patients (n = 19 of 67) additional CT scans of the cervical/lumbar spine were available. Correlations of size measurements between SW-MRI, conventional radiography, and CT were evaluated. Diameters of spondylophyes were measured manually on susceptibility-weighted magnitude images and radiographs to assess intermodality correlations. Clinical standard CT scans were performed by using a 64-section Aquilion system (Toshiba Medical Systems, Otawara, Japan).

**Contrast-to-Noise Measurements**

The signal(osteophyte), signal(intervertebral disc), and the signal(noise) was assessed by manually drawing a region of interest in intervertebral discs, osteophytes, and noise in standard T2-weighted and inverse susceptibility-weighted magnitude images. Noise refers to the mean signal in a region of air dorsal to the spine. Contrast-to-noise ratio (CNR) was calculated by subtracting the signal measured in the osteophyte by the signal measured in the intervertebral disc and dividing the difference by the signal measured in the noise.

**Statistical Analysis**

Variables are reported as mean ± standard deviation. Sensitivities and specificities of SW-MRI compared with that of T1/T2-weighted MRI scans in combination with radiographs were computed. To display the spread of data and the limits of agreement, interobserver/intraobserver agreement was assessed using Bland-Altman plots. The relationship between size measurements on SW-MRI, T1- and T2-weighted MRI scans, and radiographs was determined using linear regression. A P < 0.05 was considered statistically significant.

**RESULTS**

**Sensitivity and Specificity for the Detection of Osteophytes**

As reference standard, 93 osteophytes (in 48 patients) were identified on conventional T1/T2 MR in combination with radiographs confirming osteophytes. If radiographs were excluded from the analysis, the majority (n = 92 of 93) of osteophytes could be identified on inverse SW-MRI magnitude images with a hyperintense surface on susceptibility-weighted phase images (Figs. 1, 2). Susceptibility-weighted magnetic resonance imaging achieved a sensitivity of 98.9% and a specificity of 99.1% for the identification of osteophytes with a 95% confidence interval of 93.4% to 99.9% and 94.4% to 99.9%, respectively (Figs. 1B3-B4, Figs. 2A3-A4). If radiographs were excluded from the analysis, it was in some cases difficult to distinguish osteophytes from disc herniations and surrounding tissues (e.g., ligaments) on standard T1/T2-weighted MR sequences. Therefore, only 69 lesions (72.6%) could be delineated (Figs. 1B1-B2, Figs. 2A1-A2). Standard spine MR sequences achieved a sensitivity of 68.6% and a specificity of 86.5% for the identification of
osteophytes with a 95% confidence interval of 56.2% to 78.9% and 79.9% to 91.3%, respectively.

Sensitivity and Specificity for the Detection of Posterior Disc Herniations

As reference standard, 114 posterior disc herniations (in 60 patients) were identified on conventional T1/T2 MR in combination with radiographs excluding osteophytes. If radiographs were excluded from the analysis, the majority (n = 113 of 114) of discal herniations were identified on SW-MRI magnitude images (Figs. 1A3-A4, Figs. 2B3-B4). Susceptibility-weighted magnetic resonance imaging achieved a sensitivity of 99.1% and a specificity of 98.9% for the identification of disc herniations with a 95% confidence interval of 94.4% to 99.9% and 93.4% to 99.9%, respectively.

If radiographs were excluded from the analysis, conventional T1/T2 spine MR sequences achieved a sensitivity of 86.5% and a specificity of 68.6% for the identification of disc herniations with a 95% confidence interval of 79.9% to 91.3% and 56.2% to 78.9%, respectively (Figs. 1A1-A2, Figs. 2B1-B2).

Assessment of Size of Osteophytes

Size measurements revealed a close correlation for osteophytes between SW-MRI and radiographs ($R^2 = 0.95, P < 0.05$). There was no significant difference of size measurements between SW-MRI and radiographs (6.3 ± 4.0 mm vs 6.4 ± 4.2 mm). Conventional T2-weighted MR spine sequences showed a moderate correlation ($R^2 = 0.82, P < 0.05$) compared with radiography-based size measurements of osteophytes. Conventional T1-weighted MRI scans showed a lower moderate correlation ($R^2 = 0.62, P < 0.05$) compared with radiography-based size measurements of osteophytes. In T2-weighted sequences, the size of calcifications was underestimated compared with radiographs ($5.8 ± 4.0$ mm vs $7.2 ± 4.5$ mm). In 19 of 81 patients, a total of 33 osteophytes were detected on CT images. All of these could be identified on susceptibility-weighted magnitude images. Size measurements revealed a close correlation for osteophytes between CT and SW-MRI ($R^2 = 0.96, P < 0.05$) as well as for CT and radiographs ($R^2 = 0.92, P < 0.05$). There was no significant difference of size measurements between SW-MRI and CT (6.0 ± 3.7 vs 6.2 ± 3.8 mm) as well as radiographs and CT (6.7 ± 3.9 vs 6.8 ± 3.8 mm).

Signal (osteophytes) to Signal (intervertebral disc) Ratio (CNR)

On T2-weighted images, a CNR of $35.5 ± 17.1$ was measured. On inverse susceptibility-weighted magnitude images, the size of calcifications was underestimated compared with radiographs ($5.8 ± 4.0$ mm vs $7.2 ± 4.5$ mm). In 19 of 81 patients, a total of 33 osteophytes were detected on CT images. All of these could be identified on susceptibility-weighted magnitude images. Size measurements revealed a close correlation for osteophytes between CT and SW-MRI ($R^2 = 0.96, P < 0.05$) as well as for CT and radiographs ($R^2 = 0.92, P < 0.05$). There was no significant difference of size measurements between SW-MRI and CT (6.0 ± 3.7 vs 6.2 ± 3.8 mm) as well as radiographs and CT (6.7 ± 3.9 vs 6.8 ± 3.8 mm).

Interobserver Correlation

Between both readers, there was a close correlation of interobserver agreement regarding size measurements ($R^2 = 0.97$) in SW-MRI with only a minimum difference in mean (0.01) (Fig. 3, A–B). The
95% confidence intervals ranged from −1.26 to 1.24 in Bland-Altman plots. Interobserver correlation for size measurements in conventional T2-weighted MR sequences showed a moderate correlation of measurements ($R^2 = 0.94$) with a small difference in mean (0.2) (Fig. 3, C–D). In Bland-Altman plots, 95% confidence intervals ranged from −3.54 to 3.26.

**DISCUSSION**

This study demonstrated that SW-MRI enables the differentiation of osteophytes and posterior disc herniations in patients with spinal radiculopathy with a higher sensitivity and specificity compared with conventional T1/T2-weighted MR sequences.

**Current Clinical Imaging Assessment of Osteophytes and Posterior Disc Herniations**

Radiography is the most frequently used technique for the detection of osteophytes and osseous changes of the degenerative spine. Computed tomography imaging of the spine provides more detailed information about the dimension of osseous changes but is associated with a significant radiation dose. Magnetic resonance imaging is usually performed as the first-line imaging study in patients with progressive neurologic symptoms and especially if plain radiography films are negative. With its superior soft tissue resolution, MRI provides excellent anatomic detail. Changes in signal intensity, disc structure, disc height, and distinction between nucleus and annulus are usually evaluated on T2-weighted sagittal images. Guidelines for a more consistent description of disc herniations were released. Especially, the differentiation of dorsal osteophytes and disc herniations can be challenging on conventional T1/T2 MR sequences, as both structures can appear hypointense on T1- and T2-weighted MRI scans. Therefore, radiography and CT are currently used as additional imaging modalities for the visualization of these changes.

**Susceptibility-Weighted MRI**

Currently, the interpretation of conventional MRI of the spine is based on the magnitude information of the image. Because of phase
artifacts, it has been challenging in the past to extract useful phase information for further tissue characterization. Susceptibility-weighted imaging is based on a high-resolution 3D gradient-echo sequence. It makes use of magnitude and filtered phase information separately and in combination with each other during image acquisition to create new sources of contrast.\textsuperscript{11,13,22} Diamagnetic (e.g., calcified lesions), paramagnetic (e.g., hemosiderin), and ferromagnetic (e.g., iron) compounds interact with the local magnetic field and therefore alter the phase of local tissues.\textsuperscript{22,23} Calcified structures appear with a hyperintense signal on inverse magnitude images and with a strong hyperintense signal on SW-MRI filtered phase images. Phase artifacts, for example, on tissue interfaces, appear dark on magnitude as well as on SW-MRI phase images.\textsuperscript{15,22,24} The main challenge for MRI with standard T1/T2 sequences is the differentiation between calcified spondylophytes and other lesions that cause a signal loss in T1/T2 sequences. The most important information for the differentiation of these lesions can be derived from the phase image. Phase images are, however, more prone to artifacts, for example, minor motion artifacts. In these cases, it can be difficult to clearly differentiate small spondylophytes from tissue artifacts. Susceptibility-weighted magnetic resonance imaging sequences have been previously used mainly for brain imaging to visualize venous vasculature\textsuperscript{11,12,22,25} and to distinguish between intracerebral hemorrhage, calcifications, and changes in iron content in, for example, stroke, neurodegenerative disorders, trauma, and tumors.\textsuperscript{6,12,22,23,26–29} In addition, it was shown that SW-MRI can be useful for the identification of plaque calcifications in atherosclerosis\textsuperscript{30} and the distinction between calcifications and hemorrhagic lesions in patients with prostatic cancer.\textsuperscript{10}

**SW-MRI for the Differentiation of Osteophytes and Posterior Disc Herniations of the Spine**

In this study, SW-MRI enabled the reliable identification of osteophytes and disc herniations in the cervical and lumbar spine with a higher sensitivity and specificity compared with conventional T1/T2 MR sequences. In addition, the interobserver agreement and agreement for the size measurement of osteophytes was higher for SW-MRI compared with that for conventional T1/T2 MR. This could be explained by 2 features of SW-MRI. First, SW-MRI allows the differentiation of diamagnetic calcified lesions from surrounding structures, based on the magnitude and phase information. Second, the contrast (CNR) between osteophytes and disc herniations was significantly higher on SW-MRI compared with that on conventional MR sequences.

In a clinical setting, the analysis of the additional sequences can be based on a visual assessment of the additional magnitude and phase images and therefore is not time-consuming. The analysis directly adds to the clinical and surgical decision tree as it provides the differentiation between spondylophytes and disc herniations without the need for further radiographs or CT imaging. Especially for preoperative planning, it is important to determine whether discectomy is sufficient or if osteophytes have to be removed additionally for successful treatment. Based on the cause of spinal radiculopathy, surgery can be performed with an anterior, posterior, or even combined approach. A prospective study demonstrated that surgical decompression arrests progression and improves neurological outcomes, functional status, and quality of life; therefore, surgery is increasingly recommended as the standard treatment for patients with degenerative myelopathy.\textsuperscript{31}

In addition, SW-MRI can provide important information about the dimension and the precise spatial localization of osteophytes, which can be challenging based on 2-dimensional radiography. Therefore, it can help to plan the dimension of anterior decompression preoperatively, for example, if a resection of spondylophytes cranially or caudally is sufficient enough or if even a corpectomy as a wide decompression needs to be taken into account. Because SW-MRI shows a good performance in detecting these changes, it should also be a future goal to reduce the use of ionizing radiation, especially in young patient collectives.

In future studies, the applicability of SW-MRI for the assessment of other types of calcifying musculoskeletal diseases such as calcifying bone lesions, bone tumors, and calcifying soft tissue tumors should be examined.

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**FIGURE 3.** Interobserver correlation and agreement of size measurements of osteophytes. A and B. Size measurement showed a strong correlation and interobserver agreement for SW-MRI. C and D. For conventional T2 images, a moderate correlation with a wider 95% confidence interval was measured. Bland-Altman plots: centerline, mean absolute difference central line; upper and lower line, limits of agreement (95% confidence intervals).
Limitations

One limitation of the current study was that CT was not available in all patients, as it was not clinically required and the additional radiation dose was therefore not justified. As the diagnosis of off-center marginal osteophytes of the end plates is limited on radiographs, this type of osteophyte was excluded from our analysis.

No correlation analysis of SW-MRI findings with symptoms of patients was performed. Future studies are needed for further evaluation of the potential of SW-MRI in a larger patient collective. Susceptibility-weighted magnetic resonance imaging artifacts from local field inhomogeneity due to metallic implants are seen as concentric rings of hyperintensity and hypointensity and result in limited assessment of the affected region.

CONCLUSIONS

Susceptibility-weighted magnetic resonance imaging enables the differentiation of osteophytes and disc herniations in patients with spinal radiculopathy with a higher sensitivity and specificity compared with conventional T1/T2 MR sequences. This is of relevance for routine MRI of the spine, as an additional SW-MRI sequence may avoid further workup with CT imaging or radiography for assessing osseous structures.

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