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Evaluation of sclerosis in Modic changes of the spine using susceptibility-weighted magnetic resonance imaging

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ABSTRACT

Purpose: To evaluate the diagnostic performance of susceptibility-weighted magnetic resonance imaging (SWMR) for the differentiation of sclerotic and non-sclerotic Modic changes (MC) of the spine compared to computed tomography (CT) and radiographs.
Materials and methods: The Institutional Ethics-Review-Board approved this prospective study in advance. Written consent was obtained from all subjects. SWMR and standard T1/T2 MR of the cervical (n = 21) and/or lumbar spine (n = 34) were performed in 54 patients. 21 patients served as control. 18 patients were evaluated with CT; in all other patients radiographs were available. 67 Modic changes were identified on T1/T2 MR. On SWMR changes were classified as sclerotic and non-sclerotic based on signal intensity measurements. The sensitivity and specificity of SWMR and T1/T2 MR for differentiating between sclerotic and non-sclerotic Modic changes were determined with CT and radiographs as reference standard.
Results: On SWMR, signal measurements between sclerotic and non-sclerotic Modic changes differed significantly ($p < 0.01$). On T1- and T2-weighted MR no significant difference ($p > 0.05$) was measured. On SWMR, a reliable differentiation between sclerotic and non-sclerotic Modic changes could be achieved, with a sensitivity of 100% and specificity of 95%. In contrast, the combination of T1-/T2-weighted MR yielded a significantly lower sensitivity to detect sclerosis (20%).
Conclusion: SWMR allows a reliable detection of sclerosis in Modic changes with a higher accuracy compared to standard spine MR sequences, using radiographs and CT as reference standard.

1. Introduction

In 1988 Modic et al. [1,2] were the first to classify pathological changes of the endplates and the adjacent bone marrow of vertebral bodies into tree types, using magnetic resonance imaging (MRI). Based on T1- and T2-weighted MR, they differentiated between lesions with edema and hypovascularity (type I), a conversion from red into yellow bone marrow (type II) and sclerosis (type III) [3]. Type I Modic changes show signs of acute inflammation and are frequently associated with back pain, whereas type III changes are considered to represent the stable stage and are less likely to be associated with pain. Modic type II represents the transitional stage, which can transform into either Modic I or III [3]. Besides type I, II and III, there are mixed types ranging from hypo- to hyperintense signal on T1- and T2-weighted MR [4]. In clinical practice, additional radiographs or computed tomography (CT) with associated ionizing radiation are often performed. These imaging modalities allow a reliable detection of bone sclerosis and enable a further discrimination between the different subtypes of Modic changes. This is of clinical relevance as this additional information can help to determine whether the affected vertebral body could be the source of a local bone marrow edema with associated back pain or whether a different reason for back pain should be considered because the Modic change is a sclerosed stable state.

The signal derived from susceptibility-weighted magnetic resonance imaging (SWMR) is based on magnetic susceptibility and

Abbreviations: MRI, magnetic resonance imaging; MC, Modic change; CT, computed tomography; GRE, gradient echo; SWMR, susceptibility-weighted magnetic resonance imaging; TSE, turbo spin echo; TE, time to echo; TR, time to repeat; MEDIC, multi-echo data imaging combination; VB, vertebral body; ROC, receiver operating characteristics; CI, confidence interval.

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is sensitive to materials, which distort the local magnetic field. SWMR is based on a gradient echo (GRE) imaging technique and was shown to enable the reliable differentiation between e.g. calcifications and haemorrhage. So far, SWMR was mainly used in neurovascular imaging, e.g. to differentiate bleedings from calcifications, to identify intracranial veins or to detect thromboembolism [5].

The aim of this study was to evaluate the potential of SWMR for the detection of sclerosis in Modic changes compared to standard T1/T2 sequences, with computed tomography and radiographs as reference standard.

2. Material and methods

2.1. Study population

This prospective study was initiated after approval by the Institutional-Ethics-Review-Board of the Charité University Hospital, Berlin. Written informed consent was obtained from all patients. Between July 2013 and March 2016 a total of 54 patients (28 male, 26 female; mean age 56 ± 17 years; age range 19–89 years) were included. Patients only participated if they fulfilled the inclusion criteria of having a clinical spinal pain syndrome and an indication for MRI, being able to give written informed consents and being 18 years or older. Exclusion criteria were malignant vertebral neoplasms e.g. metastasis and a contraindication for MRI. All patients underwent MR of the spine (cervical/thoracal spine n = 21; lumbar spine n = 34) with T1-, T2- and susceptibility-weighted sequences. As a reference standard, 53 of the patients were examined with radiographs and in 18 patients an additional CT-scan was performed. In one patient only a CT and no radiograph was available. All vertebral bodies were evaluated on radiographs or CT as a reference standard to determine whether sclerosis was present. In 33 of the included patients, Modic changes were detected. Overall, a total of 67 Modic changes were identified (cervical spine n = 13; thoracic spine n = 5; lumbar spine n = 49).

2.2. Imaging protocol

All patients were examined on a 1.5 T MRI (Avanto, Siemens Medical Solutions, Erlangen, Germany), using a standard neck coil for the cervical and a standard body coil for the lumbar spine. For the lumbar spine, sagittal T1 TSE, T2 TSE and axial T2 TSE sequences were acquired with the following imaging parameters: T1 TSE: field of view 280 mm^2, matrix 448, TR/TE = 726/13 ms, 150° flip angle and 3 mm slice thickness; T2 TSE: field of view 280 mm^2, matrix 384, TR/TE = 3300/88 ms, 150° flip angle and 3 mm slice thickness. The examination of the cervical spine included sagittal T1 TSE, T2 TSE and axial T2 MEDIC sequences with the following imaging parameters: T1 TSE: field of view 240 mm^2, matrix 448, TR/TE = 803/21 ms, 150° flip angle and 3 mm slice thickness; T2 TSE: field of view 240 mm^2, matrix 448, TR/TE = 2800/77 ms, 150° flip angle and 3 mm slice thickness. Additionally, a 3D-fast low-angle gradient-echo sequence (SWMR) was performed for the cervical and lumbar spine. The SWMR magnitude image derives from a velocity-compensated 3D-GRE sequence, which is part of the SWMR. 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, SWMR also includes the reconstruction of phase information [6,7]. To reduce artifacts, a standard ventral saturator was used. For SWMR of the cervical and lumbar spine we used a TR/TE = 49/14 ms, a flip angle of 15° and a slice thickness of 3 mm. The matrix and field of view were adjusted to the performed standard T1/T2 spine sequences. Afterwards magnitude images and phase images were reconstructed [8]. Acquisition time of the SWMR sequence was 5 min and 11 s. SWMR images were reconstructed in an automated fashion as provided by the vendor.

2.3. Imaging analysis

All image analysis was carried out on PACS workstations (Centricity Radiology RA1000, GE Healthcare, Little Chalfont, UK). Two readers (4 and 2.5 years of experience in radiology) identified Modic changes on T1/T2-weighted MR sequences and classified them as Modic I (hypointens in T1- and hyperintense in T2-weighted MR), Modic II (hyperintense in T1- and T2-weighted MR) and Modic III (hypointense in T1- and T2-weighted MR). The readers were blinded to radiographs and CTs and analysed the images independently on two different workstations. Clinical information was not included in the valuation of the two readers. Hyperintense signal on inversed SWMR magnitude images in combination with a hyperintense surface on SWMR phase images in the area of the identified Modic changes on T1/T2-weighted images was defined as be sclerosed. Sclerotic Modic changes were rated as Modic III and non-sclerotic as Modic I and II. As reference standard radiographs and/or CT were evaluated to differentiate between sclerotic and non-sclerotic Modic changes. To assess intermodality correlation two readers measured the maximal diameter of the sclerotic Modic changes on SWMR, radiographs and/or CT. Inversed SWMR were used because the contrast of the inversed SWMR magnitude images is similar to the contrast of CT and radiographs. The readers were more accustomed to this contrast to detect a sclerosis. Afterwards a quotient was calculated between the signal intensity of the Modic change and a normal vertebral body (MC/VB). This quotient should show the alteration of the signal in the Modic change compared to a normal vertebral body.

The sensitivity and specificity to differentiate between sclerotic and non-sclerotic Modic changes were calculated for the combinations: T1-weighted MR, T2-weighted MR, SWMR; T1-weighted MR, T2-weighted MR without SWMR. As reference standard the combination T1-weighted MR, T2-weighted MR and radiographs/computed tomography was used.

2.4. Statistical analysis

Sensitivities and specificities of the qualitative analysis of Modic changes on SWMR and T1- and T2-weighted MR were computed, using CT and radiographs as reference standard. For a quantitative analysis ROC analysis was used to determine the optimal cut-off value to distinguish sclerosed from non-sclerosed Modic changes on SWMR. The difference of the quotient MC/VB between sclerotic and non-sclerotic Modic changes was determined by the Student's *t*-test. A Bonferroni correction was used to correct for multiple or repeated comparisons. The level of significance was set at alpha < 0.05. Linear regression was used to determine the relationship between diameter measurements of sclerotic Modic changes on T1-, T2-weighted MR, SWMR, CT and radiographs. The correlation between MR and CT was also analysed using linear regression. To evaluate interobserver agreement, Bland-Altman plots were computed.

3. Results

3.1. Qualitative assessment for the detection of sclerosis in Modic changes

With the combination of T1-, T2-weighted MR and CT or radiographs as reference standard, 46 sclerotic and 21 non-sclerotic Modic changes could be identified. Blinded to CTs and radiographs, the combination of SWMR with T1- and T2-weighted MR