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SCIENTIFIC ARTICLE

Modic changes in vertebral endplates: a comparison of MR imaging and multislice CT

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Abstract
Objective This paper aims to evaluate the presence of endplate sclerosis in different types of Modic changes and to assess the capability of MRI in detecting endplate sclerosis within these changes.
Materials and methods The lumbar spines (L3-S1) of 70 patients were retrospectively reviewed to determine Modic changes and disc degeneration from MRI and endplate sclerosis from CT. T1- and T2-weighted signal intensity and Hounsfield unit (HU) measurements of type I and II Modic changes were recorded and the association of both Modic types I and II with endplate sclerosis was analyzed with a Mann–Whitney test.
Results Altogether 82 Modic changes in 36 subjects were recorded: 13% were type I, 12% mixed type I/II, 65% type II, 9% mixed type II/III, and 1% type III. Thirty-eight percent of the endplates with Modic changes had sclerosis in CT. Of specific Modic types, mixed I/II and II/III associated significantly with endplate sclerosis. Endplate sclerosis was not detected in MRI in a quantitative analysis.
Conclusion Endplate sclerosis exists in all types of Modic changes, especially in mixed Modic types, and not only in type III changes, as previously assumed. Endplate sclerosis was not detected in MRI, which may depend on the amount of mineralization of the bone marrow.

Keywords Modic change · Degenerative disc disease · Lumbar spine · Magnetic resonance imaging · Computed tomography

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Introduction

Vertebral endplate (Modic) changes are bone marrow and endplate lesions visible in magnetic resonance imaging (MRI). They are shown to be associated with degenerative intervertebral disc disease [1, 2], and several studies have shown Modic changes as an indicator of symptomatic disc degeneration [3–9].

The classification of changes was provided by Modic et al. [1] based on 474 patients, most of whom had chronic low-back pain. The histological correlation was based on six operative specimens [1]. Type I lesions (low T1 and high T2 signals) indicated an ongoing active degenerative process and demonstrated vascularized fibrous tissue within the bone marrow. Type II lesions (high T1 and T2 signals) were more stable during a 3-year follow-up and reflected fatty replacement of the bone marrow. Type III lesions were found later (low T1 and T2 signals), and they are thought to associate with endplate sclerosis on plain film radiography [10]. The histological nature of type III changes remains undetermined.

It has been suggested that only type III Modic changes are visible on plain film radiography. In the initial report by

Modic et al. [1], type I and II changes showed no definite correlation with sclerosis in radiography. In clinical practice we have noticed that type III Modic changes are extremely rare among middle-aged patients. However, endplate sclerosis is very often seen on plain film radiography and computed tomography (CT) images.

We hypothesized that type III changes might not be the only Modic type with endplate sclerosis. Thus, the purpose of our study was to evaluate the presence of endplate sclerosis in different Modic types and to assess the capability of MRI in detecting endplate sclerosis within these changes.

Materials and methods

Study population

Seventy patients (34 (49%) men; mean age 47.7 (range 17–75) years at the time of the first imaging) who underwent lumbar CT and MRI examinations between January 2004 and December 2006 and met our inclusion criteria were included after a review of a digital database of a radiology record system. Patients were included if (a) both CT and MRI examinations were done within 6 months from the first imaging, (b) MR imaging was performed with a 1.5 T system, and (c) CT examination was performed with 16-row multislice CT in our own institution. Two patients with focal metastatic lesions and two patients with lumbar arthrodesis were excluded. Additionally, one technically suboptimal MRI study was excluded. The institutional review board did not require advance approval or individual informed consent, as we only reviewed patients' images. The research was conducted according to the principles of the Declaration of Helsinki.

MR imaging

The MRI examinations were performed at our institution using a 1.5 T unit (GE Signa Twinspeed, General Electric Medical Systems, Milwaukee, WI, USA) and a Phased Array CTL Spine Coil (USA Instruments, Aurora, OH, USA). Sagittal T2-weighted images were obtained using a fast spin-echo sequence with a repetition time (TR) of 4,000 ms, echo time (TE) of 118 ms, echo train length of 27 and the number of acquisitions of 4. The matrix size was 448×224, FOV 28×28 cm, slice thickness 4 mm, and intersection gap 1 mm. Sagittal T1-weighted images were obtained using a fluid-attenuated inversion recovery sequence with a TR of 2,060 ms, TE of 21 ms, inversion time (TI) of 860 ms, echo train length of 6 and the number of acquisitions of 4. The matrix size was 256×224, FOV 28×28 cm, slice thickness 4 mm and intersection gap 1 mm.

CT imaging

The lumbar CT imaging was performed using a 16-slice CT scanner (GE LightSpeed Pro 16; GE Healthcare, Milwaukee, WI, USA) with a detector configuration of 16×1.25 mm. A standard lumbar spine protocol with a tube voltage of 120 kV, tube current of 100–650 mA and rotation time of 0.8 s was used. Automatic tube current modulation based on patient size and X-ray attenuation was used. The slice thickness and reconstruction interval were 1.25 mm and 0.625 mm, respectively.

Qualitative image analysis

Modic changes and intervertebral disc degeneration were evaluated from the MR images and vertebral endplate sclerosis from the sagittal reconstructed CT scans. MR and CT image analysis included the three lowest lumbar levels.

Classification of Modic changes was carried out on the basis of the T1- and T2-weighted MR images based on the five midsagittal planes. Both the upper and lower endplates at each disc level were graded separately into types MI, MII, or MIII, as previously defined [1], and mixed Modic types I/II or II/III [9].

The degree of disc degeneration was graded on the T2-weighted sagittal MR images by using the grading system of Pfirrmann et al. [11]. In grade I degeneration the nucleus pulposus is homogenously hyperintense and clearly distinct from the hypointense outer annular fibers. In grade II degeneration the nucleus pulposus is inhomogeneous and horizontal hypointense bands may be present. In grade III degeneration the inner parts of the disc are inhomogeneous and have intermediate signal intensity. In grade IV degeneration the distinction between the inner and outer parts of the disc is lost, and the inner parts of the disc have intermediate or low signal intensity. In grade V degeneration the disc is collapsed.

Endplate sclerosis was visually evaluated from the CT scans by comparing the MR images and sagittal reconstructed CT scans on a workstation. The presence of endplate sclerosis was defined as yes or no.

Quantitative image analysis

The endplate signal intensity from the MR images and Hounsfield units (HU) from the CT scans were determined from affected endplates by one author (MK). The largest possible elliptical region of interest (ROI) was fitted within the area displaying a Modic change (Fig. 1). For each patient, the area of the ROI was the same in the T1- and T2-weighted MR images and the CT scans. The mean ROI was 60.4 mm^2 (range, 30–112 mm^2). To normalize the T1- and T2-weighted signal intensity and the HU values for affected endplates among the patients, the T1, T2, and HU ratios

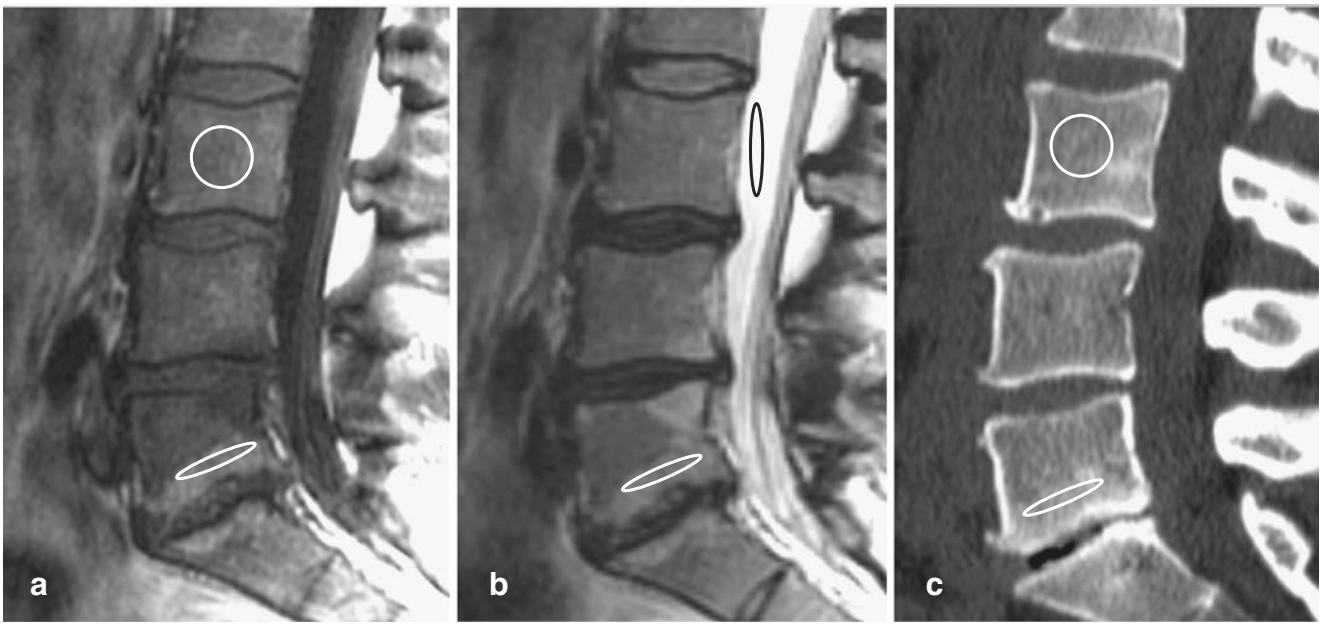

Fig. 1 A 46-year-old woman with a sclerotic type II (high T1- and T2-signals) Modic change showing the anatomical areas evaluated. **a** Sagittal T1-weighted image. To analyze T1-signal intensity, the ROI was placed at the upper endplate of L5-S1 in the region of the type II Modic change and at the normal L3 vertebra. **b** Sagittal T2-weighted image. To analyze T2 signal intensity the ROI was placed at the upper endplate of L5-S1 in the region of the type II Modic change and behind the L3 vertebra in the cerebrospinal fluid. **c** Sagittal reconstructed CT image. To analyze HU, the ROI was placed at the upper endplate of L5-S1 in the region of the type II Modic change and at the normal L3 vertebra. There is also a type II Modic change with dorsal corner sclerosis at the lower endplate of L5-S1 and a small non-sclerotic type I (low T1 and high T2 signals) Modic changes at the dorsal corners of both L4-L5 endplates

were calculated (T1 ratio=T1-weighted signal intensity for an affected endplate/T1-weighted signal intensity for a normal vertebra, T2 ratio=T2-weighted signal intensity for an affected endplate/T2-weighted signal intensity for liquor signal intensity, HU ratio=HU for an affected endplate/HU for a normal vertebra).

Nine type I and 19 type II Modic changes observed on the three midsagittal planes in the MR images were included in the quantitative analysis. If the Modic change was very thin and adjacent to the endplate, it was not possible to avoid a partial volume effect from the margins of the vertebral body or possible disc degeneration, and those changes were excluded from the quantitative analysis. Additionally, mixed Modic types were excluded as the signal intensity varied considerably within the change.

Statistical analysis

The characteristics of the Modic changes were illustrated with frequency tables. The difference in age distribution in the study population was evaluated using Student's *t* test. Variations in the T1, T2, and HU ratios were shown graphically as scatter plots (Fig. 4a–f). The significance of the difference between the T1, T2, and HU ratios for sclerotic and non-sclerotic Modic changes was determined using a Mann–Whitney test. The data were analyzed with SPSS for Windows software, version 14.0.

Results

Out of 70 patients studied, 36 (51%) were found to have Modic changes in MRI. The mean age of patients with Modic changes was 51.4 years, while the mean age of patients without changes was 43.8 years. Modic changes associated positively with age (p=0.042). Nineteen patients with Modic changes were females (53%) and 17 were males (47%).

These 36 subjects had a total of 82 Modic changes at 216 endplates (38%). Of these changes, 11 (13%) were type I, 10 (12%) mixed type I/II, 53 (65%) type II, seven (9%) mixed type II/III and one (1%) type III (Table 1). Thirty-one (38%) endplates with Modic changes in MRI had sclerosis in CT (Table 1). No sclerosis was observed in CT in the absence of Modic changes in MRI. Endplate sclerosis was adjacent to the endplate and usually localized in the same area with a Modic change. Table 1 presents the occurrence of different Modic types in MRI compared with endplate sclerosis in CT. Of specific Modic types, mixed I/II and II/III, and the only type III change were associated with sclerosis. Figures 2 and 3 demonstrate

Table 1 Number of different types of Modic changes (levels and endplates pooled; N=420) and the number (proportion) of endplate sclerosis within changes

		Sclerosis				Total
		Yes		No		
		N	%	*N*	%	
Modic	I	2	18.2	9	81.8	11
	I/II	9	90.0	1	10.0	10
	II	12	22.6	41	77.4	53
	II/III	7	100.0	0	0.0	7
	III	1	100.0	0	0.0	1
	Total	31	37.8	51	62.2	82

type II Modic changes in MRI in two different patients with (Fig. 2) and without (Fig. 3) sclerosis in CT. Modic changes were most typically sclerotic at L5-S1, 58% (19 of 33 endplates) of the changes being sclerotic at this level (Table 2).

All discs adjacent to a Modic change had at least grade III disc degeneration. Forty percent (four out of 10) of the Modic changes adjacent to a grade III disc degeneration were associated with endplate sclerosis in CT. The corresponding numbers for grade IV and V degeneration were 29% (10 out of 35) and 46% (17 out of 37), respectively.

Quantitative analysis

The variations in normalized T1- and T2-weighted signal intensity and HU values are shown as scatter plots in Fig. 4a–f. The T1- or T2-weighted signal intensities did not differ in endplates with type I or II Modic changes with or without sclerosis (Fig. 4a–d). Type II Modic changes with sclerosis had statistically higher HU values (Mean, 2.1; SD, 0.6) than did changes without sclerosis (Mean, 1.0; SD, 0.2) (p<0.001) (Fig. 4f). Additionally, sclerotic type I Modic changes tended to have higher HU values (Mean, 2.8; SD, 0.7) than did type I changes without sclerosis (Mean, 1.1; SD, 0.1) (p=0.056) (Fig. 4e).

Discussion

This is the first study to investigate Modic changes in MRI compared with multislice CT examination. It has been suggested that only type III Modic changes are visible on plain film radiography. Interestingly, the results of this study are somewhat different from those published previously. We found that not only type III changes, but also other Modic types, especially mixed Modic changes (I/II and II/III), showed endplate sclerosis in CT. However, endplate sclerosis could not be detected in MR images in the quantitative analysis.

Modic changes are bone marrow and endplate lesions adjacent to degenerative lumbar intervertebral discs. Three different Modic types (I, II and III) were initially described by Modic et al. [1, 10]. Since then, mixed Modic types (I/II and II/III) have been identified, suggesting that all Modic changes can progress from one type to another and that they all present different stages of the same pathological process [9].

The prevalence of Modic changes (51%) with type II predominance was consistent with previous findings in patient populations [1, 2]. Mixed Modic types were also identified, supporting Braithwaite's notions about the natural history of these changes [9]. Mixed Modic types are assumed to develop before conversion to one of the true Modic types [1, 12]. In the original study, Modic observed that five of six patients with a type I change converted to type II over a 14- to 36-month interval [1]. In another study of 60 sciatica patients, 14% of the Modic changes at the baseline converted to another type within the 3-year follow-up [12].

Modic changes associated positively with age (p= 0.042), suggesting their degenerative etiology. Furthermore,

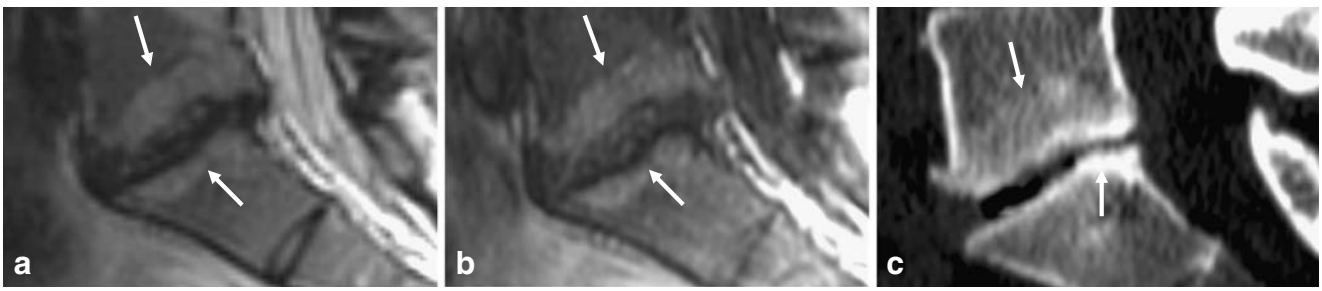

Fig. 2 A 46-year-old woman with a sclerotic type II Modic change at L5-S1. **a** Sagittal T1-weighted and **b** sagittal T2-weighted MR images show a high signal at both endplates of L4–5. **c** Sagittal reconstructed CT images show sclerosis at the upper endplate and at the dorsal corner of lower endplate of L5-S1

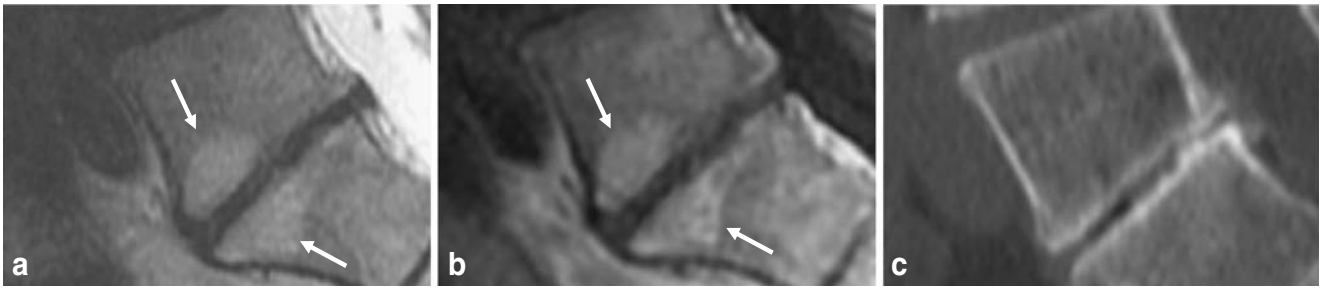

Fig. 3 A 63-year-old man with a non-sclerotic type II Modic change at L5-S1. **a** Sagittal T1-weighted and **b** sagittal T2-weighted MR images show a high signal at both endplates of L5-S1. **c** Sagittal reconstructed CT images show no sclerosis at the endplates of L5-S1

all discs adjacent to a Modic change are typically degenerated [1, 2], as observed in this study, as well. Additionally, Modic changes are found to be most common at L4-L5 and L5-S1 [9, 13]. In this study 90% of the changes were located at these two levels.

A new and important finding in our study was that 90% (nine out of 10) of mixed type I/II and all seven mixed type II/III changes in MRI showed sclerosis at the endplates in question in CT. The corresponding proportions of sclerotic endplates for type I, II and III Modic changes were 18% (two out of 11), 22% (12 out of 55) and 100% (one out of one), respectively. Modic et al. [1, 10] were the first to introduce the appearance of bone sclerosis in MRI. They suggested that type III Modic changes are presented by decreased signal intensity on both T1- and T2-weighted images, which appears to correlate with extensive bone sclerosis on plain radiographs [10]. Conversely, type I and II Modic changes showed no definite correlation with sclerosis in plain film radiography [1]. Mixed Modic types were not evaluated separately.

There have been few reports in the literature in which reactive bone sclerosis has appeared hypointense in T1-weighted and hyperintense in T2-weighted MR images. In a study on MRI features of osteoblastoma by Shaikh et al. [14], low signal intensity reactive sclerosis was observed in both T1- and T2-weighted images. A histopathological examination of reactive sclerosis with this behavior showed heavy matrix mineralization. Reactive sclerosis accompanied by marrow edema appeared hypointense in T1-weighted and hyperintense in T2-weighted images. In the histopathological examination these cases were associated with increased fibrovascular tissue within the marrow and a perivascular infiltration of lymphocytes and plasma cells. The same association is observed in inflammatory arthropathies. In an acute stage of the process, non-sclerotic low T1- and high T2-weighted signal intensity changes are seen in the anterior disco-vertebral junction [15]. As the process becomes chronic, sclerotic (shiny corners on plain film radiography) high T1- and T2-weighted signal intensity changes are seen, reflecting the healing process of the lesion. The reactive new bone formation probably occurs at previously inflamed areas.

Table 2 Total number of Modic changes at different levels (endplates pooled; $N=140$) and the number (proportion) of sclerosis within changes

	Sclerosis		
Level	Modic	*N*	%
L3-L4	8	2	25.0
L4-L5	41	10	24.4
L5-S1	33	19	57.6

In this study, endplate sclerosis observed in CT could not be detected in MR images in the quantitative analysis. The T1- or T2-weighted signal intensities did not differ in endplates with type I or II Modic changes with or without sclerosis (Fig. 4a–f). However, as assumed, the HU values of sclerotic Modic changes were higher than in those without sclerosis.

From the histopathologic point of view, osteosclerosis can be defined as a qualitative increase in bone volume. The sclerosis may be fully or partly mineralized. If the sclerosis is partly mineralized, the amount of water is increased and calcium deposition is less compared with fully mineralized sclerosis [16]. The sclerosis seen on plain radiography and in a CT of type III Modic changes is a reflection of dense mineralized bone within the vertebral body rather than the marrow elements [1]. MR signal intensity is, however, more a reflection of the vertebral body marrow elements within these trabeculae. We believe the sclerosis seen in most of the mixed Modic types and in some type I and II changes may reflect a regenerative process in the marrow with new bone formation.

The clinical importance of these findings is that there may be an association between low back pain (LBP) symptoms in patients with degenerative disc disease and

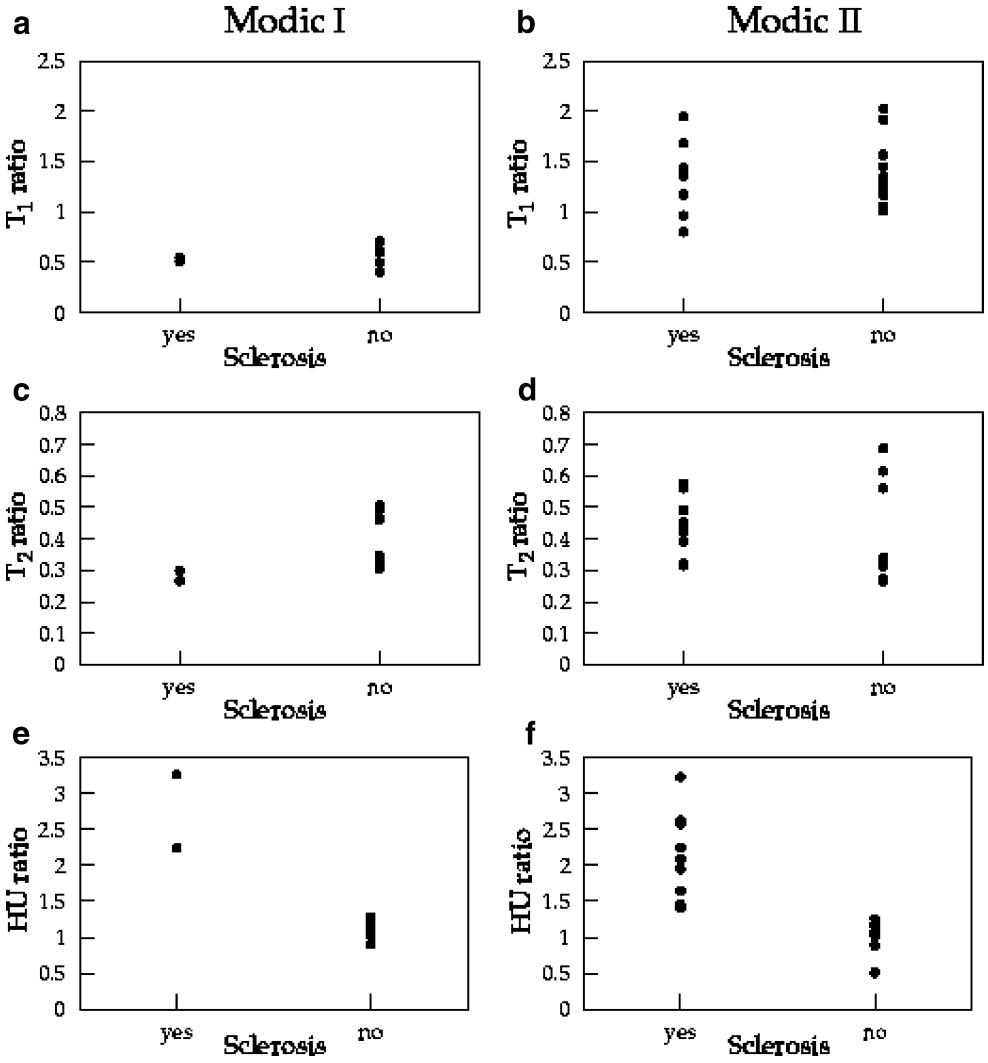

Fig. 4 Scatter plots **a**–**f** show the variation in normalized T1- and T2-weighted signal intensity and HU values at the endplates with type I or II Modic changes with or without sclerosis

Modic changes. The relationship to symptoms has been studied both clinically and in comparison with discography of the affected levels. Most authors agree that, among Modic changes, type I changes are the ones most strongly associated with LBP [5–7, 17]. However, the relationship between Modic changes and discogenic LBP remains controversial [8, 9, 18, 19]. We speculate that, the reactive sclerosis seen within Modic changes in CT in this study may reflect a healing process of the bone marrow. However, the clinical importance of this finding needs to be confirmed in further prospective studies.

A limitation of the study was its retrospective nature. The patients were referred for a variety of clinical problems and exact clinical correlation was not attempted. However, our purpose was to document and quantify this new finding with MRI and CT examinations. High-dose ionising radiation prevents application of CT in prospective studies and non-patient populations. MRI has become a first imaging modality in patients with low back pain, because it provides a non-invasive precise morphologic appraisal of the lumbar spine and permits direct relation of morphologic findings to LBP. Another limitation was that the data was not analyzed by two radiologists. However, the classification of Modic changes has already been shown to be reliable and reproducible [12, 20]. Despite these shortcomings, we believe the results are important because in the future they can improve diagnostic yield in patients with LBP.

In conclusion, endplate sclerosis exists in all types of Modic changes, especially in mixed Modic types, and not only in type III changes, as previously assumed. Endplate sclerosis was not detected in MRI, which may depend on the amount of mineralization of the bone marrow.

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