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Vertebral end-plate (Modic) changes on lumbar spine MRI: correlation with pain reproduction at lumbar discography

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Abstract The vertebral end-plate has been identified as a possible source of discogenic low back pain. MRI demonstrates end-plate (Modic) changes in 20–50% of patients with low back pain. The aim of this study was to investigate the association between Modic changes on MRI and discogenic back pain on lumbar discography. The MRI studies and discograms of 58 patients with a clinical diagnosis of discogenic back pain were reviewed and the presence of a Modic change was correlated with pain reproduction at 152 disc levels. Twenty-three discs with adjacent Modic changes were injected, 21 of which were associated with pain reproduction. However, pain was also reproduced at 69 levels where no Modic change was seen. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for a Modic change as a marker of a painful disc were 23.3%, 96.8%, 91.3% and 46.5% respectively. Modic changes, therefore, appear to be a relatively specific but insensitive sign of a painful lumbar disc in patients with discogenic low back pain.

Key words Low back pain · MRI · Discography · Vertebral end-plate

Introduction

Vertebral end-plate (Modic) changes were first described independently by de Roos et al. [9] and Modic et al. [15] as being a feature associated with degenerative intervertebral disc disease. Type I changes consist of reduced signal intensity (SI) in the vertebral end-plates on T1- and increased SI on T2-weighted sequences (Fig. 1). They are associated with fissuring of the cartilaginous end-plate and increased vascularity within the subchondral bone marrow on histological examination. Type II changes consist of increased SI on T1- and either increased SI or isointensity on T2-weighted sequences (Fig. 2). In such cases, biopsy reveals fatty replacement of the marrow [15], which is thought to be the result of marrow ischaemia [9]. Type III changes consist of reduced SI on both T1- and T2-weighted sequences due to subchondral sclerosis (Fig. 3). Type I changes commonly progress to Type II changes and rarely revert back to normal, whereas Type II changes appear not to change with time [15]. Modic changes are identified in 20–50% of patients, with the incidence increasing with age [9, 15]. However, it is not known why some degenerative discs are associated with Modic changes while others are not.

Crock [6, 7] proposed the concept of "internal disc disruption", suggesting that repeated trauma to the intervertebral disc could result in the production of inflammatory substances within the nucleus pulposus. Diffusion of such toxic chemicals through the vertebral end-plate could then result in a local inflammatory reaction resulting in back pain.

Inflammation in the subchondral bone adjacent to the end-plate would result in reduced SI on T1-weighted MRI sequences and increased SI on T2-weighted MRI sequences, equivalent to a Type 1 Modic change. The possi-

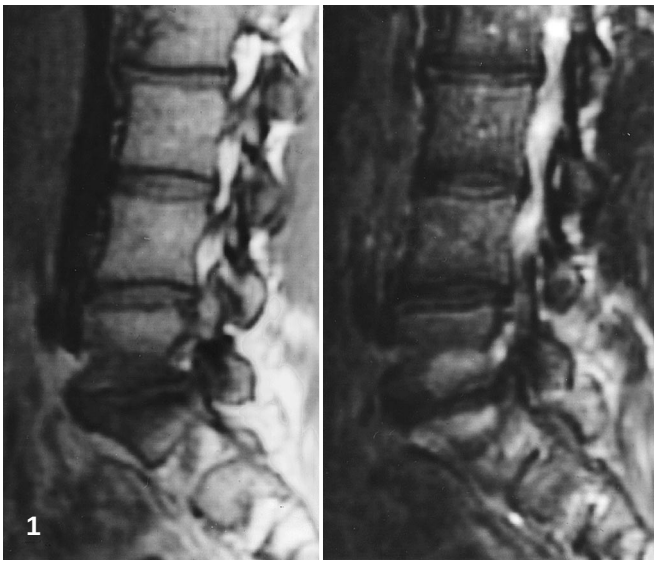

Fig. 1 Sagittal T1- *(left)* and T2- *(right)* weighted MR images showing a Type I end-plate change at the L5/S1 level consisting of low signal intensity (SI) on T1 images and high SI on T2 images

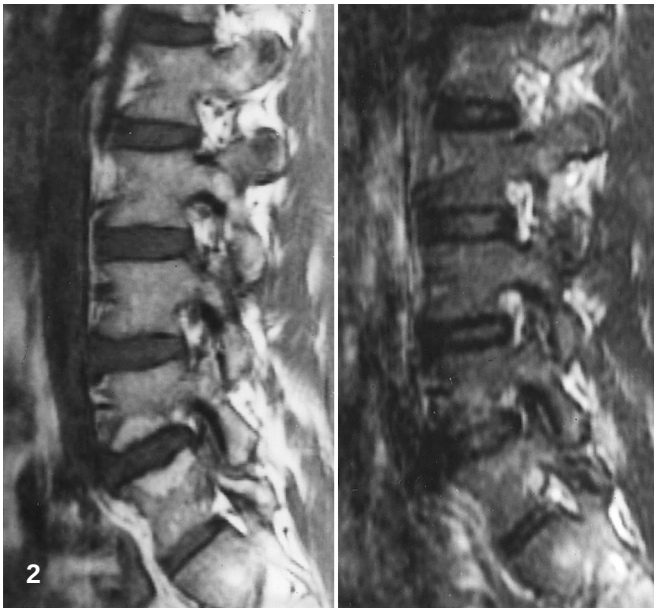

Fig. 2 Sagittal T1- *(left)* and T2- *(right)* weighted MR images showing a Type II end-plate change at the L4/L5 level consisting of high SI on T1 images and moderately increased SI on T2 images

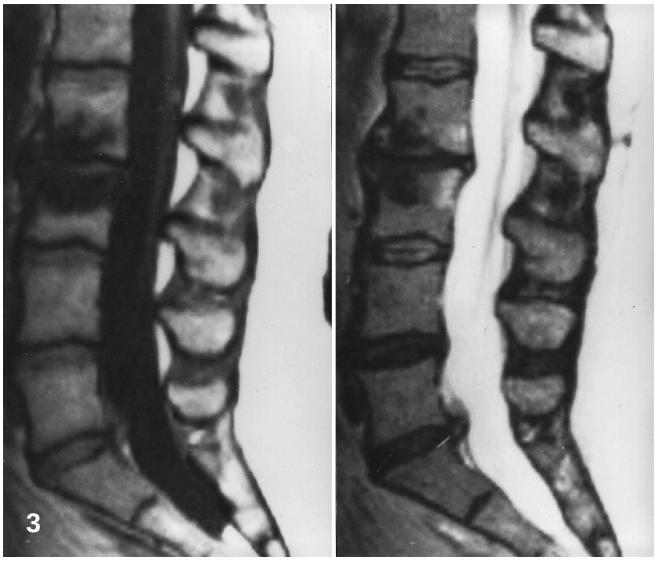

Fig. 3 Sagittal T1- *(left)* and T2- *(right)* weighted MR images showing a combined Type I and III end-plate change at the L2/L3 level consisting of low SI on T1 images and a mixture of low and high SI on T2 images

bility therefore arises that Modic changes are in some cases the result of chemical inflammation from degenerative discs and may be a secondary sign on MRI of "internal disc disruption" and discogenic low back pain. Previous studies have tried to correlate disc degeneration and the high-intensity zone (HIZ) on MRI with pain reproduction at lumbar discography, with variable results [1, 5, 11, 16, 17, 19–22]. The aim of the present study was to correlate the presence of Modic changes with pain reproduction at lumbar discography, in a group of patients with a clinical diagnosis of discogenic low back pain. The relationship between Modic changes, disc degeneration and the HIZ was also investigated.

Materials and methods

This was a retrospective review of 58 consecutive patients for whom the lumbar spine MRI studies and discograms were available. All patients had been referred over a period of 30 months by a single spinal surgeon for investigation of 'discogenic' low back pain, with or without associated leg pain, as a precursor to spinal fusion. The study group included 31 men and 27 women with a mean age of 42 years (range 21–63 years).

Lumbar spine MR examinations had been performed at between 0.5-T and 1.5-T field strength using a dedicated lumbar spine surface coil and standard T1- and T2-weighted spin echo MR sequences. All MR studies were retrospectively re-reviewed for the purposes of the study by a consultant musculoskeletal radiologist and a spinal surgeon, who were blinded to the discogram findings. Sagittal T2-weighted images were assessed for the presence and site of degenerative discs, based on a reduction of signal intensity with or without loss of disc height. Modic changes, as previously defined [9, 15], were assessed using a combination of T1- and T2-weighted images. Marrow changes associated with Schmorl's nodes were not recorded. The presence and location of high-intensity zones (HIZ; focal areas of increased SI on sagittal T2-weighted sequences in the posterior annulus of a degenerative disc, as defined by Aprill and Bogduk [1]) were also recorded.

Discography had been performed by a single radiologist, using a standard posterolateral injection technique. Normal discs had been injected in the majority of cases to act as an internal control for assessment of pain response. Non-ionic contrast medium was injected until there was either a firm end-point to the injection, until pain was provoked, or to a maximum of 5–6 ml, when no pain was provoked. Factors recorded included disc morphology, volume of contrast medium injected, presence and location of annular tears and patient response (no pain, atypical pain or pain reproduction). For the purposes of this study, pain reproduction (defined as pain that was either very similar to or totally reproduced the patient's symptoms) was the only criterion for a positive discogram. Although the discographer had access to the MRI studies prior to discography, all patients had been referred for discography based

on clinical features. Discograms had been performed for the identification of painful levels prior to spinal fusion, and not with any future study in mind. We do not believe, therefore, that the identification of Modic changes on MRI prior to discography could have biased the discographer.

For statistical purposes, the following definitions were used. A true-positive study was defined as one where a Modic change was present and associated with pain reproduction. A true-negative study was one where no Modic change was seen and there was no pain reproduction at discography. A false-positive study was one in which a Modic change was present but there was no pain reproduction at discography and a false-negative study was when a Modic change was not present but pain reproduction occurred at discography. The association between presence of disc degeneration, Modic changes and HIZs on MRI and pain reproduction on discography was assessed using Fisher's exact test.

Results

MRI studies revealed disc degeneration at 128 of 290 levels (44.1%). Modic changes were identified at 31 levels in 28 patients (48.3% of patients; 24.2% of degenerative disc levels). Thirty-one HIZs were demonstrated. The MRI features are summarized in Table 1.

Discography was performed at 152 levels. Ninety-six were considered degenerative based on loss of normal nuclear morphology, while a further 12 discs were considered abnormal due to the presence of a radial annular tear, although the nuclear morphology was considered to be essentially normal. Several discs that appeared degenerative on MRI had not been injected, either because there was no clinical indication or because the disc space was severely narrowed and injection proved impossible (typically at the L5/S1 level).

Forty-four discs were considered normal, based on normal nuclear morphology and the absence of pain. The relationship between disc degeneration, annular tears and patient response is summarized in Table 2.

The relationship between disc degeneration as assessed by MRI and pain reproduction at discography is summarized in Table 3.

Of the 31 disc levels associated with Modic changes on MRI, 23 were injected at discography. Eight discs with adjacent Modic changes were not injected. One patient had a lytic L3/4 spondylolisthesis with Modic changes at both L3/4 and L5/S1. In this case, discography was only required at the levels adjacent to the slip. In six other cases, Modic changes were present adjacent to a severely

Table 1 Distribution of degenerative discs, Modic changes and high-intensity zones (HIZs) on MRI

Disc level	Degen. discs	Modic changes	Modic change (type)				HIZ
			I	II	III	Mixed	
L1/2	9	0	0	0	0	0	0
L2/3	11	1	0	0	0	1(II/III)	2
L3/4	26	4	3	0	0	1(I/III)	4
L4/5	41	10	0	9	0	1(II/III)	14
L5/S1	41	16	3	12	0	1(I/III)	11
Total	128	31	6	21	0	4	31

Table 2 Distribution of degenerative discs, annular tears and the response to injection at discography

Disc level	No. of discs injected	Degen. discs	Annular tears[a]	Pain reproduction
L1/2	1	1	1	1
L2/3	18	10	10	8
L3/4	46	28	24	22
L4/5	58	44	34	37
L5/S1	29	25	17	22
Total	152	108	86	90

[a] Annular tear defined as a radial tear extending to the periphery of the annulus with (complete) or without (partial) associated leak of contrast medium from the disc

Table 3 The relationship between disc degeneration at MRI (*DD*) and pain reproduction at discography (*P*)

	No P	P
No DD	49	12[a]
DD	13	78

[a] Essentially normal nucleus, but annular tear present at discography. See Results
Fisher's exact $P < 0.0001$
Sensitivity = 0.867
Specificity = 0.79
Negative predictive value (NPV) = 80.3
Positive predictive value (PPV) = 85.7

Table 4 The relationship between Modic changes at MRI (*MC*) and pain reproduction at discography (*P*)

	No P	P	Total
No MC	60	69	129
Type I	0	5	5
Type II	2	16	18
Type III[a]	0	3	3

[a] All Type III changes were combined with either Type I or II changes

Table 5 The relationship between combined Modic changes at MRI (*MC*) and pain reproduction at discography (*P*)

	No P	P
No MC	60	69
MC	2	21

Fisher's exact $P < 0.00004$
Sensitivity = 0.233
Specificity = 0.968
NPV = 46.5
PPV = 91.3

Table 6 The relationship between Modic changes (*MC*) and the HIZ

	No MC	MC
No HIZ	109	16
HIZ	20	7

Fisher's exact $P = 0.13$

Table 7 The relationship between combined Modic changes at MRI (*MC*) and pain reproduction at discography (*P*)

	No P	P
No MC	57	52
MC	2	14

Fisher's exact $P = 0.003$

narrowed degenerative L5/S1 disc, which could not be successfully injected. The relationship between Modic changes and pain reproduction is summarised in Tables 4 and 5. The relationship between Modic changes and HIZs is summarised in Table 6. Table 7 shows the relationship between Modic changes and pain reproduction after discs with a HIZ were excluded.

Discussion

Since the initial description of Modic changes on lumbar spine MRI [9, 15], there have been few studies that have attempted to identify the cause of such changes. Vertebral end-plate signal changes consistent with marrow oedema may be seen in infective discitis [8], following intraosseous disc herniation (Schmorl's nodes) [23] and within 3 months of chemonucleolysis [13]. However, in the absence of such predisposing causes, Modic changes have only been identified adjacent to degenerative discs, a feature that is again confirmed in the present study. Both patient groups that were imaged in the initial studies [9, 15] were symptomatic, and it is therefore not known whether such changes are identified in patients who have never experienced low back pain. Studies that have compared the MRI findings in both symptomatic and asymptomatic populations have not assessed Modic changes [2, 4, 12, 25].

Toyone et al. [24] studied patients with low back pain and vertebral end-plate changes classified as either Type A (low SI on T1-weighted sequences) or Type B (high SI on T1-weighted sequences), finding that Type A changes correlated with a greater degree of back pain and segmental hypermobility, while Type B changes were more common in patients with stable degenerative disc disease. Their suggestion, that Modic changes may be a marker of segmental instability, is supported in a study by Lang et al. [14], who demonstrated conversion of Type I end-plate changes to Type II end-plate changes following successful spinal fusion for low back pain.

Several studies have attempted to correlate the MRI features of disc degeneration (reduced SI on T2-weighted sequences and disc bulge) with pain reproduction at discography [11, 17, 22]. Although MRI was found to be sensitive for the identification of degenerative discs, it was unreliable at identifying which disc was the source of pain. Furthermore, discs that appeared normal on MRI were occasionally found to be the site of pain reproduction at discography. These findings are not surprising, since it would appear that radial tears of the periphery of the annulus are the major source of pain reproduction at discography [16]. In the present study, a strong correlation was demonstrated between the presence of radial annular tears and pain reproduction (Table 2), confirming the clinical diagnosis of 'discogenic' back pain in our patient population. The general consensus at the present time is that MRI cannot replace discography for identifying which disc is the source of back pain.

The MRI demonstration of annular tears, as manifest by the high intensity zone (HIZ) [1, 21] increased the specificity of MRI for the identification of painful discs, but the value of this sign is limited by a very low sensitivity [20]. Also, Ricketson et al. [19] were unable to identify a relationship between the presence of a HIZ and a concordant pain response at discography. The identification of other MRI features that can help identify painful discs would therefore be advantageous.

Collins et al. [5] attempted to correlate Modic changes with symptomatic discs at discography, identifying such changes in 6 of 13 patients with positive discograms. Modic changes were also present adjacent to asymptomatic discs. However, their discography technique could be criticised, since only 1–2 ml of contrast medium was injected at each disc space. It is likely that this volume of injection would miss many symptomatic discs since, in our experience, degenerative discs, or discs with full-thickness annular tears, can easily accept 2–4 ml of contrast medium before pain is produced.

In the present study, the incidence and distribution of Modic changes was similar to that seen in previous studies [9, 15]. We also identified several mixed Modic changes, which is consistent with the suggestion that Modic changes progress from one type to another and that they all represent different stages of the same pathological process. A significant association between the presence of disc degeneration on MRI and pain reproduction at discography was demonstrated ($P < 0.0001$) (Table 3). However, as in previous studies, discs that were considered normal at MRI could be associated with abnormal discography, and not all degenerative discs at MRI were associated with pain reproduction (Table 3). The presence of Modic changes also showed a highly significant association with pain reproduction at discography ($P < 0.00004$). The addition of this sign to that of disc degeneration in-

creased the specificity for identification of a painful disc from 79% to 97%. Since the number of Modic changes (particularly Types I and III) was small, it was not possible to separate them into individual types for the purpose of valid statistical evaluation. However, it was noted that all Type I changes, or combined changes including Type I, were associated with pain reproduction. As with other studies [9, 15], Type II Modic changes predominated. The majority of Type II changes were also associated with pain reproduction, which is inconsistent with the findings of Toyone et al. [24]. However, Modic et al. [15] did note that Type II changes could mask the inflammatory end-plate changes associated with infective discitis, so it is possible that in the present study relating to discogenic back pain, end-plate inflammation is being masked by Type II changes. Modic changes were found to have a very low sensitivity (23%) for concordant back pain. Also, the absence of Modic changes was not a good predictor of the absence of pain (i.e. the sign has a low negative predictive value).

The relationship between Modic changes and the HIZ (Table 6) was investigated to ensure that the pain reproduction at disc levels with Modic changes could not be attributed to the HIZ. No significant association was identified between these two signs, indicating that a Modic change on MRI may be used as an independent sign of a painful disc at discography. Furthermore, the relationship between Modic changes and pain reproduction when those discs with a HIZ were excluded still showed a very significant association (Table 7).

Possible sources of discogenic low back pain include the peripheral annular tear [16] and the vertebral end-plate [3]. Our clinical experience is that patients with isolated Type I end-plate changes and clinically severe pain respond well to anterior discectomy and fusion, but that the outcome is less predictable in the absence of such end-plate changes. We are unaware of any studies that have assessed the sensitivity of MRI in the identification of Type I changes in the vertebral end-plate. However, Brown et al. [3] demonstrated increased vascularity and type C nerve endings histologically in the end-plates of 18 discs in 15 patients who had undergone anterior discectomy and fusion for chronic low back pain. Unfortunately, they did not report the MRI findings in these patients, so it is not known whether Modic changes were seen at these end-plates. It may be that conventional spin echo MRI is relatively insensitive at identifying these changes. The use of fat-suppression techniques (either T2-weighted or T1-weighted with intravenous enhancement) can significantly increase the identification of vertebral metastases compared to conventional spin echo MRI techniques [10]. It is possible that the use of such sequences can increase the identification of Modic changes, and it would be valuable to repeat this study using such MRI sequences.

No pain was reproduced at 2 of the 23 disc levels with Modic changes (both Type II changes). This could be explained by the findings of Rhyne et al. [18], who showed that the natural history of discogenic low back pain is one of gradual spontaneous resolution. It is possible that these discs were at one stage the source of back pain.

Conclusion

We investigated the significance of Modic changes on MRI in a group of patients with a clinical diagnosis of ‘discogenic’ back pain confirmed by discography. If the high specificity of Modic changes can be confirmed in different centres performing discography, then it is reasonable to suggest that levels at which a Modic change is present need not be injected. In certain circumstances, this may eliminate the need for discography; for instance, if multilevel changes are present and surgical policy is to perform only single-level fusion.

Although Modic changes appear to be a highly specific indicator of a painful intervertebral disc, as assessed by discography, the lack of sensitivity of conventional MRI techniques limits the value of this sign at present. Further studies, using alternative MRI sequences to improve sensitivity, are indicated.

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