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FULL PAPER

Diffusion-weighted magnetic resonance imaging in differentiating acute infectious spondylitis from degenerative Modic type 1 change; the role of *b*-value, apparent diffusion coefficient, claw sign and amorphous increased signal

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Objective: To examine the effect of using different *b*-values on the utility of diffusion-weighted (DW) MRI in differentiating acute infectious spondylitis from Modic type 1 and the discriminative accuracy of related apparent diffusion coefficient (ADC), claw-sign and amorphous increased signal.

Methods: 43 patients with equivocal diagnosis of acute infectious spondylitis/Modic type 1 by using MR images were prospectively studied. The discriminative accuracy of DW MRI using three *b*-values of 50, 400, 800 s mm⁻², ADC, claw sign and amorphous increased signal was examined.

Results: DW MRI differentiated infectious spondylitis from Modic type 1 change most accurately when a *b*-value of 800 s mm⁻² was chosen [sensitivity, 91.7%; specificity, 96.8%; positive-predictive value (PPV), 91.7%; negative-

predictive value (NPV), 96.8%; and accuracy, 95.3%]. The optimal cut-off ADC value was $1.52 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ (sensitivity, 91.7%; specificity, 100%; PPV, 100%; NPV, 96.9%; and accuracy, 97.7%). Best visualized at a *b*-value of 50 s mm⁻², claw sign (for degeneration) and amorphous increased signal (for infection) were 100% accurate.

Conclusion: Should DW MRI be used in differentiating acute infectious spondylitis from degeneration, large *b*-values are required. With low *b*-values, however, claw sign and amorphous increased signal are very accurate in this regard.

Advances in knowledge: DW MRI using large *b*-values could be used in differentiating acute infectious spondylitis from Modic type I.

INTRODUCTION

The documentation of decreased signal intensity on *T*₁ weighted (T1W) MRI coupled with increased signal intensity on *T*₂ weighted (T2W) sequences in the marrow adjacent to the end plates indicates the replacement of the bone marrow elements with fibrovascular tissue, a condition known as degenerative Modic type 1 change.¹⁻³ In addition to degeneration, such signal changes may exist in infection, rendering conventional MRI non-specific for diagnostic purposes,⁴ particularly when clinical clues are also inconclusive.⁵ This diagnostic dilemma could increase cost and lead to mismanagement of patients.⁶

At the moment, spinal infections are encountered more often than before, possibly due to increased

elderly and immunocompromised populations, conducting more spinal surgeries and improved imaging techniques.⁷

Initially aimed to investigate brain abnormalities, diffusion-weighted (DW) MRI and related diffusion values such as the apparent diffusion coefficient (ADC) are now being used frequently in evaluating a wide range of spinal pathologies such as benign and malignant compression fractures,⁸⁻¹⁰ osteoporosis¹¹ and infection.⁸⁻¹⁰ DW MRI works on the basis of signal attenuation in biological tissues caused by the Brownian water motion of the spins,¹² and the ADC combines the effects of diffusion and perfusion in the extracellular extravascular space.¹³

An important parameter that has consequential influences on the quality of DW imaging (DWI) is the chosen b -value.¹⁴ It has been shown that T_2 effect can interfere with a correct interpretation of DW images, a phenomenon that is known as “ T_2 -shine-through” effect. To overcome this flaw, choosing diffusion gradients with high b -values (*i.e.* $>150 \text{ s mm}^{-2}$) has been suggested.¹⁵ Despite this widely accepted notion that DWI with high b -values enhances the sensitivity,¹³ to the best of the authors’ knowledge, the role of b -values has not been investigated in relation to the discriminative accuracy of DW MRI in patients with equivocal changes of the end plates on conventional MR images. A factual answer to this ambiguity is clinically important, because modern MR devices often provide instructions that include several suggested b -values for imaging of a particular region in the body that may cause uncertainty in making optimal decisions by physicians and imaging technologists.

Apart from signal intensity and ADC values, it has been recently proposed that some specific findings on DW sequences namely “claw sign” and “amorphous increased signal” could be used with high precision in distinguishing between infection and degeneration in the lumbar vertebral end plates.^{16–20} The relevant works, however, are scarce, and the results need to be confirmed in further studies.²⁰

Thus, the present study is designed to examine the utility of DW MRI in differentiating acute infectious spondylitis from Modic type 1 in patients with low back pain and equivocal findings by conventional MRI and, at the same time, to assess the discriminative accuracy of related ADC values, claw sign and amorphous increased signal in this regard.

METHODS AND MATERIALS

Study design and patients

From April 2010 through to June 2014, 48 consecutive patients with end plate changes on T1W and T2W MR images of the lumbar spine suggesting both acute spondylodiscitis and Modic type I change were prospectively enrolled in this study. The patients were identified from a total of 1806 lumbar MR images in subjects with low back pain acquired during this time at our imaging centre.

The initial inclusion criterion was the presence of acute lumbar symptoms accompanied with bone marrow changes adjacent to the end plates, detectable as hypointensity on T1W images and hyperintensity on T2W images. A senior radiologist specialized in MRI of the spine decided on the inclusion of patients into this study after reviewing the initial lumbar MR images. This person had no other role in conducting the present study.

An institutional ethics committee approved this work and informed written consents were obtained from the participants. This study has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

The exclusion criteria were a history of a previous spinal surgery, intervertebral disc herniation or vertebral fracture ($n = 3$);

documentation of a recent antibiotic/anti-inflammatory therapy ($n = 1$); the presence of advanced infectious spondylitis with abscess formation detectable on MR images or disseminated bone marrow disease such as a metastatic condition ($n = 1$); and pregnancy. On this basis, 5 patients were excluded, leaving 43 patients for the final analysis.

Standard of reference

The diagnosis of infectious spondylitis (n , 12) was established with CT-guided bone biopsy in 7 patients and on the basis of clinical and laboratory findings and imaging follow-ups²¹ in 5 patients. The supporting laboratory findings were an elevated erythrocyte sedimentation rate, elevated levels of C-reactive protein, leukocytosis and positive blood cultures.²¹ The final diagnosis was brucellosis in 10 patients and tuberculosis in 2 patients. The remaining 31 patients with no clinical or laboratory findings suggesting infection were assigned to the Modic type-1 degeneration group.²² All patients were followed up clinically and by MRI for at least 2 years,^{18,22} and the initial diagnosis was established in all cases. On the follow up in degenerative group, Modic type 1 in 7 patients partially converted Modic type 2, and 17 patients fully converted Modic type 2. No change was documented in seven patients.

Imaging techniques

A standard lumbar MRI protocol was used in this study. Sagittal and axial T1W and T2W non-contrast MR images were obtained from the lumbosacral spine using a 1.5-T scanner (MAGNETOM Avanto 1.5-T MRI system; Siemens, Erlangen, Germany) with gradient echo-planar capabilities and a standard phased-array surface receiver coil for imaging the spine.

Axial and sagittal T1W turbo spin-echo sequences [repetition time (TR)/echo time (TE), 580/11; turbo factor, 22; turbo acquisition time, 2 min 29 s], axial and sagittal T2W turbo spin-echo sequences [TR/TE, 4000/120; turbo factor, 4; turbo acquisition time, 2 min 5 s (axial views); turbo acquisition time, 2 min 9 s (sagittal views)] and sagittal DW sequences (three-scan trace) were acquired. The resulting DW images were non-isotropic.

An echo-planar two-dimensional diffusion sequence (TR/TE, 5900/84 ms; field of view $300 \times 70 \text{ mm}$; matrix 156×192) was used for sagittal spinal DWI using three b -values of 50, 400 and 800 s mm^{-2} in the same plane and orientation as used in routine sequences. These three b -values were suggested by the manufacturer of the imaging machine, and the present study aimed to compare them to find the strongest diffusion effects. Of note, some previous studies have suggested that using a high diffusion gradient (b -value) may enhance the sensitivity of DWI compared with lower b -values.^{13,23} The acquisition time for echo-planar two-dimensional diffusion was about 2 min.

Image analysis

The signal intensity of the intervertebral disc and body of the abnormal vertebra was obtained adjacent to the end plates and reported as hypointense, isointense or hyperintense (Figures 1 and

2) relative to the presumed normal marrow¹ in both T1W and T2W sequences by the senior radiologist who selected patients for inclusion in the study, and in DW MR images by two other radiologists who were unaware of clinical and laboratory findings.

An excellent interrater agreement²⁴ was present in reporting signal intensities in DW MR images (Cohen's kappa = 91%). In case of any discrepancy, a third radiologist was arbitrated.

ADC mapping was performed after DWI data were transferred to a workstation (Leonardo Console v. 2.0; Siemens AG Medical Solutions, Forchheim, Germany). We used all the three b -values (i.e. 50, 400 and 800 s mm^{-2}) for ADC calculation. Briefly, on sagittal ADC maps, three circular regions of interest (ROIs) in sizes proportionate to the vertebral lesion were placed on three different locations in the region with abnormal signals (Figure 3) by a medical imaging technologist accompanied with a radiologist. The ROIs that included regions with normal signals or vertebral margins were excluded. The related mean ADC value was generated automatically by the dedicated software provided by the manufacturer of the imaging machine syngo MR B15 (Siemens Healthcare, Erlangen, Germany). For each lesion, the three ADC values were averaged and reported.

To prevent image distortion by susceptibility artefacts, distortion correction filters available on the imaging system were used.

Finally, the same two radiologists who reported signal intensities on DW images were asked to report the presence or absence of "claw sign" (Figure 4)¹⁷⁻¹⁹ and/or "amorphous increased signal" (Figure 5)¹⁶ on DW MR images acquired using all the three mentioned b -values. Complete (100%) interrater agreements were present in this regard.

Statistical analysis

The SPSS® software v. 19.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) was used for statistical analysis.

The distribution of quantitative data was tested using the Kolmogorov–Smirnov analysis. Fisher's exact test, independent samples t -test and independent samples Mann–Whitney U test were used, where appropriate. The receiver operator characteristics curve was used in reporting the optimal cut-off value. Sensitivity, specificity, PPV, NPV and accuracy were also calculated.²⁵ The paired inter- and intraobserver comparisons were analyzed using Cohen's kappa coefficient. A significance level of p -value ≤ 0.05 was used.

RESULTS

The infectious spondylitis group comprised seven males (58.3%) and five females (41.7%), with the mean age of 52.33 ± 16.00 years (range: 32–79 years). In the group with Modic type 1 change, there were 9 males (29%) and 22 females (71%), with the mean age of 44.32 ± 11.30 years (range: 23–74 years). The two groups were comparable in terms of sex (Fisher's exact test $p = 0.09$) and age (independent samples t -test $p = 0.08$).

All the lesions in both groups were reported as hypointense on T1W images and as hyperintense on T2W images (Figures 1(a,b) and 2(a,b)).

Findings on DW MR images using the three different b -values are summarized in Table 1. By using a b -value of 50 s mm^{-2} , all the lesions were reported as hyperintense (Figures 1c and 2c). By using a b -value of 400 s mm^{-2} , all the lesions in the infectious spondylitis group were reported as hyperintense, whereas in the Modic type 1 change group, there were 27 images (87.1%) reported as hyperintense and 4 images (12.9%) reported as isointense (Fisher's exact test $p = 0.56$) (Figures 1d and 2d). When a b -value of 800 s mm^{-2} was selected, reported hyperintense lesions were significantly more frequent in the infectious spondylitis group than in the Modic type 1 change group (91.7% vs 3.2%; Fisher's exact test $p < 0.001$) (Figures 1e and 2e).

Figure 1. A 42-year-old female with Modic type 1 degenerative change in the lumbar region. (a) Sagittal T_1 weighted MR image showing hypointensity at the involved bone marrow and intervertebral level. (b) Sagittal T_2 weighted MR image showing hyperintensity at the involved bone marrow and intervertebral level. (c) Sagittal diffusion-weighted MR image with a b -value of 50 s mm^{-2} showing hyperintensity at the involved bone marrow and intervertebral level. (d) Sagittal diffusion-weighted MR image with a b -value of 400 s mm^{-2} showing hyperintensity at the involved bone marrow and intervertebral level. (e) Sagittal diffusion-weighted MR image with a b -value of 800 s mm^{-2} showing isointensity at the involved bone marrow and intervertebral level.

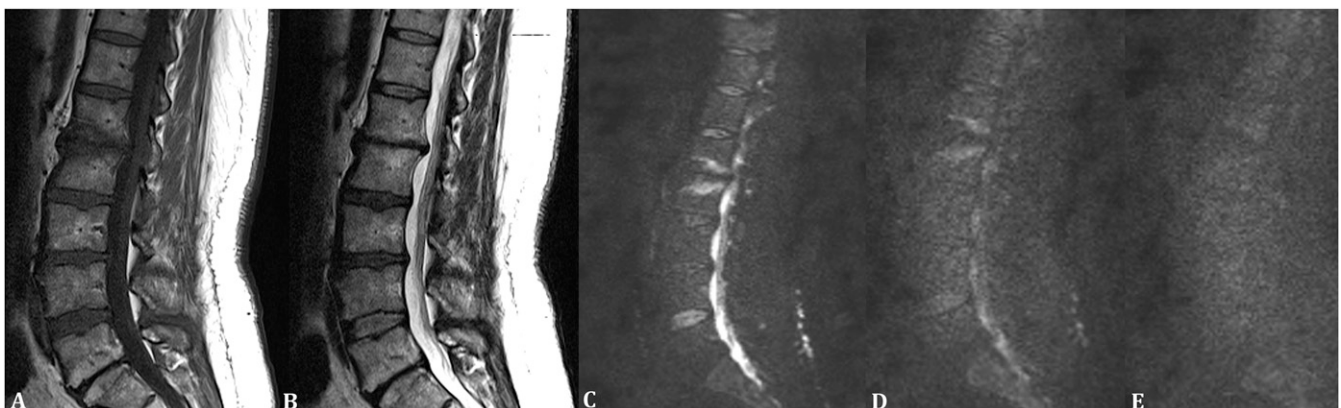
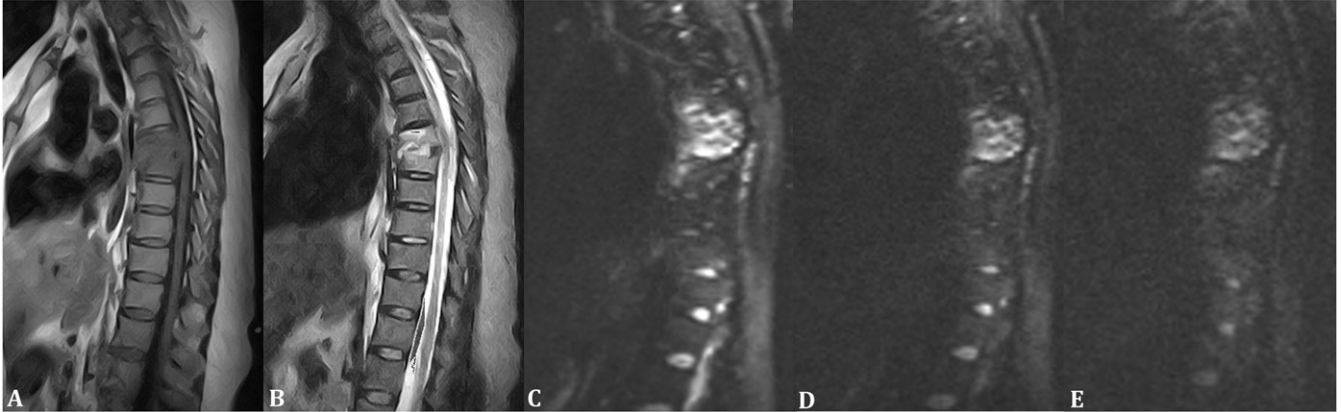


Figure 2. A 51-year-old female with infectious spondylitis in the lumbar region. (a) Sagittal T_1 weighted MR image showing hypointensity at the involved bone marrow and intervertebral level. (b) Sagittal T_2 weighted MR image showing hyperintensity at the involved bone marrow and intervertebral level. (c) Sagittal diffusion-weighted MR image with a b -value of 50 s mm^{-2} showing hyperintensity at the involved bone marrow and intervertebral level. (d) Sagittal diffusion-weighted MR image with a b -value of 400 s mm^{-2} showing hyperintensity at the involved bone marrow and intervertebral level. (e) Sagittal diffusion-weighted MR image with a b -value of 800 s mm^{-2} showing hyperintensity at the involved bone marrow and intervertebral level.

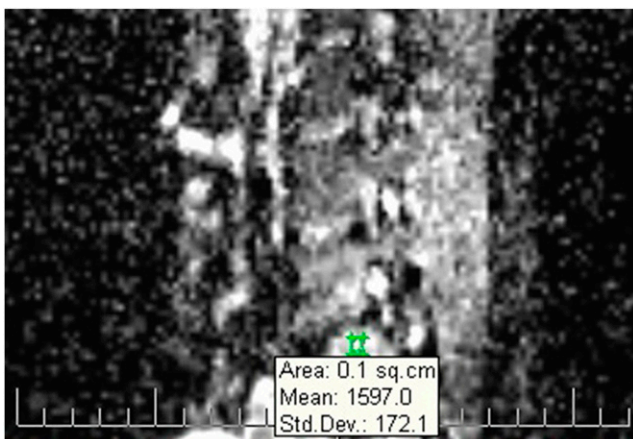


The mean ADC value in patients with infectious spondylitis was significantly lower than that in patients with Modic type 1 change ($1.31 \pm 0.12 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$; median, 1.30; range, 1.16–1.61 vs $1.80 \pm 0.12 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$; median, 1.76; range, 1.61–1.97; independent samples Mann–Whitney U test $p < 0.001$).

Using the receiver operator characteristics curve analysis, the optimal cut-off ADC value in differentiating infectious spondylitis from Modic type 1 change was set at $1.52 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ with an area under the curve of 0.99 (95% confidence interval: 0.98–1.00; $p < 0.001$), a sensitivity of 91.7% and a specificity of 100%.

Claw sign (Figure 4) was present on all DW MR images of the patients with Modic type 1 change, whereas no case with

Figure 3. A sample image illustrating the use of a circular region of interest in a patient with Modic type I change. The related mean apparent diffusion coefficient value was generated automatically (1597.0 in this case). Std. Dev., standard deviation; sq.cm, square centimeter.



infectious spondylitis showed this sign (Fisher's exact test $p < 0.001$). Amorphous increased signal (Figure 5), by contrast, was found only on DW MR images of the patients with infectious spondylitis (100% vs 0%; Fisher's exact test $p < 0.001$).

Indicators of the diagnostic performance of the studied variables in differentiating infectious spondylitis from Modic type 1 change are set out in Table 2.

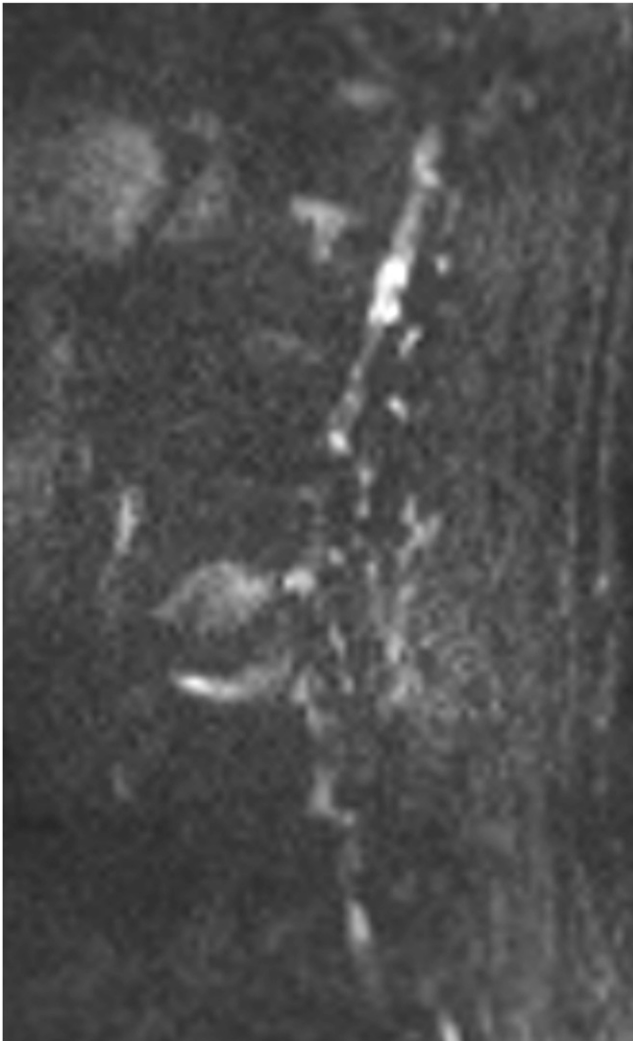
DISCUSSION

End plate changes frequently spotted on spinal images are usually associated with degeneration. Sometimes, however, it is difficult to distinguish between degenerative changes and infection relying only on conventional imaging findings, clinical presentations and laboratory derangements.²⁶ This is a clinically important issue, because infectious spondylitis is far more serious than degeneration in terms of morbidity.²²

Although various imaging techniques such as plain radiography, CT and radionuclide studies have been tried to diagnose spinal infections, they are generally inaccurate in acute cases.^{21,27} MRI has been found the most sensitive (94%) and specific (93–97%) imaging modality for early detection of spinal infection.²⁷ When a conventional sequence is used, however, a repeat study in the following 2 weeks is usually necessary in highly suspicious cases with equivocal initial findings.²¹

In line with previous reports,^{1,19,28} signals of abnormal vertebrae with degeneration or infection were similar in the present work, namely hypointense on T1W images and hyperintense on T2W images. In healthy adults, the bone marrow contains 20–70% fatty tissue with nearly 7% increase per decade of life. In the case of infection, replacement and depletion of fatty bone marrow occurs, leading to hypointense signal on T1W images and hyperintense signal on T2W images.²⁶ Because of this similarity between degeneration and infection in routine MR sequences, differential diagnosis

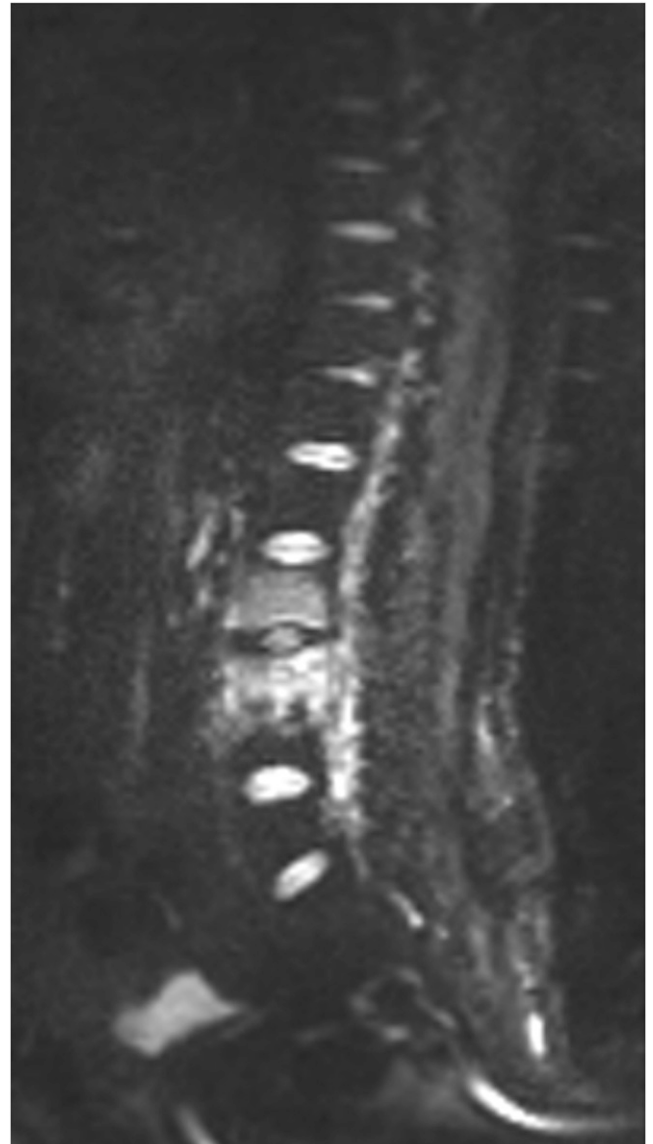
Figure 4. Sagittal diffusion-weighted MR image with a b -value of 50 s mm^{-2} in a 68-year-old male with Modic type 1 change and typical claw-sign.



mandates employment of more sensitive surrogate imaging methods.¹⁹

In contrast to conventional MRI, DW sequences provide microscopic and dynamic information.²⁹ The latter could be used for biological tissue characterization through exploiting random motion of water protons in that tissue.³⁰ Few studies, hitherto, have examined usefulness of DW MRI in differentiating Modic type 1 change from infectious spondylitis. Buyn²⁸ examined 10 patients with pyogenic spondylitis and 50 patients with erosive osteochondritis. Using a b -value of 165 s mm^{-2} , all patients with infection had hyperintense signals on DW images. Park et al¹⁹ analyzed spin-echo and DW MR images of 8 patients with Modic type 1 change and 14 cases with infectious spondylitis. On DW images with a b -value of 165 s mm^{-2} , 11 infectious cases were hyperintense and the 3 others were hypointense. All cases with degenerative changes, however, were hypointense. Balliu et al⁸ examined 14 patients with acute spondylodiscitis using DWI with a b -value of 500 s mm^{-2} . Again, hyperintensity was reported in all patients. In a

Figure 5. Sagittal diffusion-weighted MR image with a b -value of 50 s mm^{-2} in a 39-year-old male with infectious spondylitis and amorphous increased signal.



retrospective investigation, Oztekin et al¹ reviewed radiology records of 27 patients with Modic type 1 change and 18 patients with spondylodiscitis. On DW MR images with a chosen b -value of 150 s mm^{-2} , all patients with spondylodiscitis were hyperintense, and the remaining cases with Modic type 1 change were hypointense. Eguchi et al²¹ studied 16 patients with end plate abnormalities apparent on MR images of the lumbar spine, including 5 patients with infectious spondylitis and 4 patients with Modic type 1 change. Using a b -value of 1000 s mm^{-2} , DWI revealed hyperintensity in the group with infectious spondylitis and isointensity/hypointensity in cases with degeneration.

DW images are generated by using bipolar, large gradient, magnetic fields. A b -value denotes the amount of diffusion weighting and using larger b -values leads to higher sensitivity in differentiating between regions of high and low diffusion.^{31,32}

Table 1. Signal intensity of the end plates with infectious spondylitis or Modic type 1 changes compared with normal bone marrow on diffusion-weighted MR sequences using three different b -values

b -value ($s\text{ mm}^{-2}$)	Group	Signal intensity			p -value
		Hyperintense	Isointense	Hypointense	
50	Infectious spondylitis	12 (100)	0 (0)	0 (0)	–
	Modic type 1	31 (100)	0 (0)	0 (0)	
400	Infectious spondylitis	12 (100)	0 (0)	0 (0)	0.56
	Modic type 1	27 (87.1)	4 (12.9)	0 (0)	
800	Infectious spondylitis	11 (91.7)	1 (8.3)	0 (0)	<0.001 ^a
	Modic type 1	1 (3.2)	26 (83.9)	4 (12.9)	

Values in parentheses indicate percentage.

^a $p \leq 0.05$ is statistically significant.

Choosing a correct b -value is pivotal for obtaining a proper DW MR image because it determines assessment of perfusion and cellular density in a selected region of a biological tissue.^{33,34} All the mentioned studies examined the usefulness of DWI in differentiating between infectious and degenerative end plate changes employing different b -values. It is not clear whether using different b -values could influence the accuracy of DWI for this purpose. Using lower b -values (50 and 400 s mm^{-2}) in the present study proved not to be sufficiently discriminative (Figures 1(c,d) and 2(c,d)). On DW MR images with a larger b -value (400 s mm^{-2}), however, all cases with acute infectious spondylitis showed hyperintensity, whereas in the group with Modic type 1 change only isointense/hypointense signals were observed (Figures 1e and 2e).

Accuracy of DW sequence could be compromised by T_2 -shine-through effect.³⁵ The fact that majority of our cases showed hyperintensity on both T2W and DW images with low b -values reflects the presence of this effect. Suppose a pair of DW images is obtained at $b_0 = 0$ and $b_1 > 0$. The ADC value can be calculated as

$$S_1 = S_0 \cdot \exp(b_1 \cdot \text{ADC})$$

where S_0 and S_1 are signal intensities of the images obtained at b_0 and b_1 , respectively.³⁶ Signal attenuation on DW images at a given b -value is influenced by both diffusion and perfusion.

Since the signal attenuation of the perfusion component on DW images takes place mostly with low b -values, when a larger gradient factor (b -value) is chosen, signals from the perfusion component could be eliminated, leaving a DW image that largely reflects the diffusion component. Therefore, using higher b -values attenuates interference from T_2 at the expense of reducing signal-to-noise ratio.^{33,34} Such reduction, however, did not negatively affect the principal objective of the present work (Table 2). Nevertheless, a possible solution to wrinkle out T_2 -shine-through effect without changing signal-to-noise ratio is using quantitative analysis of DWI, such as calculating ADC.^{15,33}

The mean/median ADC value in infectious spondylitis ranged between 0.79 and $1.16 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$ in previous reports.^{9,37,38} It was $1.80 \pm 0.12 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$ in our patients with degeneration, significantly higher than that in the other group with infection ($1.31 \pm 0.12 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$; $p < 0.001$). In a similar study performed by Dallaudière et al,³⁸ ADC values were compared between patients with spondylarthritides axial active inflammatory lesions (n , 27) and those with Modic type 1 changes (n , 22). They found significantly higher ADC values for axial active inflammatory lesions than for Modic type 1 changes (median: $0.79 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$ vs $0.59 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$). In conformity with our results, they concluded that DWI is a sensitive and fast sequence that could help to discriminate

Table 2. Sensitivity, specificity, positive-predictive value (PPV), negative-predictive value (NPV) and accuracy of different study variables on diffusion-weighted MR sequences in differentiating infectious spondylitis from Modic type 1 change

Parameter	Sensitivity	Specificity	PPV	NPV	Accuracy
Signal intensity					
b -value: 50 s mm^{-2}	100	0	27.9	0	27.9
b -value: 400 s mm^{-2}	100	12.9	30.8	100	37.2
b -value: 800 s mm^{-2}	91.7	96.8	91.7	96.8	95.3
ADC ($>1.52 \times 10^{-3}\text{ mm}^2\text{ s}^{-1}$)	91.7	100	100	96.9	97.7
Claw-sign	100	100	100	100	100
Amorphous increased signal	100	100	100	100	100

ADC, apparent diffusion coefficient.

Figures indicate percentage.

between the two conditions. By contrast, Eguchi et al²¹ reported a lower mean ADC value in cases with degeneration (Modic type 1, type 2 and type 3) than in patients with infection ($0.62 \pm 0.32 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ vs $1.07 \pm 0.12 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$).

It should be borne in mind that larger ADC values indicate an increased diffusion of water in a sampled region on the ADC map (or the ROI) by the examiner. Conversely, lower ADC values correspond to ROIs with lower diffusion.³⁹ In Modic type 1 change, the water content of a depleted bone marrow increases. This condition, in turn, leads to an increase in the extracellular volume fraction, a raised ADC value, and development of low signal intensity on DW MR images. Conversely, in acute infectious spondylitis densely infiltrated inflammatory cells reduces the extracellular volume and results in low ADC values and documentation of high signal intensity on DW MR sequences.^{1,9,28} Therefore, the discrepancy in the study of Eguchi et al²¹ was that despite documentation of a significantly higher rate of hyperintensity on DW images of patients with infectious spondylitis than those with degenerative changes, the mean ADC value, at the same time, was significantly higher in the same group of patients.

It has been shown that when spinal infection is not acute or when antimicrobial therapy was already started before DW study, ADC values are expected to be less than that in cases with acute, untreated infection; possibly due to the regression of the inflammatory activity and resolution of local oedema by the time of treatment.³¹ To the best of our knowledge, the present study is the first one that took this critical factor into consideration.

Our optimal cut-off value of ADC for distinguishing lumbar spine degeneration from infection was 1.52 (sensitivity, 100%; specificity, 91.7%). This figure is similar to that ($1.3 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$) calculated by Pui et al.⁹ Using this cut-off point, the sensitivity, specificity, PPV, NPV and accuracy of ADC for characterizing between Modic type 1 changes and infectious spondylitis were 91.7%, 100%, 100%, 96.9% and 97.7%, respectively. Comparing these figures with those resulted from DWI with a *b*-value of 800 s mm^{-2} (91.7%, 96.8%, 91.7%, 96.8% and 95.3%, respectively) indicates superiority of ADC value over DWI in differentiating between degeneration and infection in the end plates.

On DW images, a restricted diffusion at the boundary of Modic type 1 changes and the normal marrow has been reported and called as claw sign.¹⁶ The presence of this well-defined, high signal claw and diffusion restriction at the advancing border of the proliferative process has been reported to be consistent with degenerative disease rather than infection in the end plates with a very high PPV and NPV.^{17–20} By contrast, the presence of amorphous increased signal on DW images has been suggested as a good indicator of osteomyelitis and infection.¹⁶ In conformity with these reports, the claw sign was present on all our DW images obtained with lower *b*-values (more conspicuous with 50 s mm^{-2}) in patients with Modic type 1 changes, whereas no case with infectious spondylitis demonstrated this sign on related DW images. Amorphous increased signal, by contrast, was only evident on DW images obtained with lower *b*-values in patients who suffered from

infectious spondylitis. Interestingly, the sensitivity, specificity, PPV, NPV and accuracy of both signs for characterizing between Modic type 1 changes and infectious spondylitis were all 100%. This is the first study in the literature that compares the utility of DWI (using different *b*-values), ADC value, the claw sign and amorphous increased signal simultaneously in differentiating lumbar spine acute infection from degeneration.

This work bears some limitations that need to be acknowledged here. Bone biopsy is known as the gold standard in differentiating infectious spondylitis from degenerative changes in the end plates.^{1,21} For obvious reasons, it was not possible to obtain biopsy samples in patients with degeneration in the present study. However, it has been reported that clinical and radiological follow-up can be relied on in such cases with equivocal imaging findings at presentation.^{1,21} Long follow-ups of patients in the present study (at least 2 years) is an important point of strength that almost fully compensates the mentioned limitation.

Although not routinely used in clinical setting,³⁸ dynamic contrast-enhanced MRI has been suggested as an optimal imaging technique in quantifying spondyloarthritic inflammatory changes, especially during the posttherapy period.⁴⁰ Comparing the results of dynamic contrast-enhanced MRI to DWI/ADC findings in patients with equivocal diagnosis of lumbar vertebral infection/degeneration might be interesting in future studies.

A rather small sample size of patients with infectious spondylitis due to its rarity is another potential limitation of the present prospective study. Although this shortcoming could potentially decrease the power of the ADC cut-off value in differentiating infection from degeneration, the relevant results in the present work were striking, indicating that the effect of this limitation was, if any, minimal.

Last but not least, it should be noted that infectious spondylitis and Modic type 1 changes might share some physiopathological features that may interfere with discriminative capability of DWI. For example, the inflammatory nature of Modic type 1 changes has been suggested previously.⁵ In addition, a concomitant presence of pyogenic spondylitis has been reported in 4% of patients with Modic type 1 changes with no external manifestation of infection.⁴¹ In some recent studies, even the possibility of an infectious aetiology has been raised in patients with Modic type 1 changes.^{2,42} These possibilities need to be elucidated in future studies.

CONCLUSIONS

This study showed that DWI is an accurate method in distinguishing Modic type 1 changes from acute infectious spondylitis only if large *b*-values ($800 \times 10^{-3} \text{ mm}^2 \text{ s}^{-1}$ in the present work) are used. When lower *b*-values are chosen, the claw sign and amorphous increased signal are very helpful in this regard. The discriminative accuracy of quantitative analysis (ADC value) lies between those of DWI with large *b*-values and in using claw sign/amorphous increased signal.

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