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FULL PAPER

The application of T2W SPIR-FLAIR in the diagnosis of hip synovitis in patients with spondyloarthritis

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Objective: To investigate the feasibility and accuracy of T₂ weighted spectral pre-saturation inversion recovery combined with fluid-attenuated inversion recovery (T2W SPIR-FLAIR) in the diagnosis of hip synovitis in patients with spondyloarthritis (SpA).

Methods: 10 volunteers underwent a T2W SPIR and 4 T2W SPIR-FLAIR sequence scans with different inversion times (TIs) to determine the optimum TI that could effectively suppress the intra-articular fluid signals. Hip MRI including T2W SPIR-FLAIR and enhanced T₁ weighted (T1W) SPIR sequences was performed in 45 patients with SpA and totally 90 hips were evaluated. McNemar's test and Kappa test were used to compare the diagnostic results of synovitis between T2W SPIR-FLAIR and enhanced T1W SPIR.

Results: A TI of 2100 ms was selected as the optimum TI. 32 hips from 17 patients exhibited high signal intensity within the articular cavity on both T2W SPIR-FLAIR and

enhanced T1W SPIR sequences, while only 3 hips showed high signals within the articular cavity on T2W SPIR-FLAIR. The remaining 55 hips did not show high signals within the articular cavity on both sequences. The T2W SPIR-FLAIR and enhanced T1W SPIR sequences had similar values in the diagnosis of hip synovitis ($p = 0.25$) and a high degree of diagnostic consistency (Kappa = 0.929).

Conclusion: T2W SPIR-FLAIR can effectively suppress the intra-articular fluid signals, while retaining the signals of thickened synovial membranes and can be used for the diagnosis of hip synovitis in patients with SpA.

Advances in knowledge: The enhanced T1W SPIR is a classic sequence for synovitis diagnosis, but it requires the injection of contrast agents. The T2W SPIR-FLAIR and enhanced T1W SPIR sequences had similar values in the diagnosis of hip synovitis ($p = 0.25$) and a high degree of diagnostic consistency (Kappa = 0.929).

INTRODUCTION

Spondyloarthritis (SpA) encompasses a group of chronic, progressive and disabling diseases, with an incidence rate of 1–2%.^{1,2} Early diagnosis and treatment is the key to improving the prognosis in patients with SpA.³ MRI is the most sensitive imaging diagnostic method for SpA.^{4–6}

SpA may involve the sacroiliac joints, spine and peripheral joints. Hip involvement in patients with SpA is a common, disabling problem and is believed to be predictive of worse outcomes.^{7,8} Previous studies indicate that synovitis is the most common MRI finding of hip involvement in patients with SpA. Synovitis is often the only sign observed at the early stages of hip involvement.⁸ Therefore, hip synovitis is very important in the early diagnosis of hip involvement in patients with SpA.

Although synovium exists within the articular cavity, the normal synovium is not visible on MR images. Synovitis involves synovial lining cell amplification, lymphocytes and plasma cells infiltration, and increased blood supply.^{9–11} Synovial thickening and effusion often coexist in synovitis. The signals of the thickened synovial membranes and the intra-articular fluids are similar and cannot be distinguished from each other using the conventional non-enhanced MRI sequences.^{12–14} The diagnosis of synovitis relies on the presence of intra-articular effusion on non-enhanced MR sequence images.^{12,13} However, normal articular cavity contains a small amount of synovia. It is difficult to distinguish the normal amount of synovia from the small amount of intra-articular effusion.

The enhanced T1W SPIR (T₁ weighted spectral pre-saturation inversion recovery) is a classic sequence for

synovitis diagnosis. The thickened synovial membranes during the acute phases of synovitis show a significant abnormal enhancement on the enhanced T1W SPIR images, while the intra-articular fluids do not show enhancement.^{13,14} Although the enhanced T1W SPIR sequence can distinguish thickened synovial membranes from intra-articular fluids (the normal synovia and effusion), it requires the injection of contrast agents, which increases the health care costs of patients and introduces the risk of contrast agent allergy and nephrogenic systemic fibrosis in patients with kidney dysfunction.^{15,16}

T_2 weighted (T2W) SPIR sequence is commonly used in the observation of acute inflammation. Both intra-articular fluids and thickened synovial membranes show significantly higher signals on T2W SPIR images. Fluid-attenuated inversion recovery (FLAIR) sequence has the ability of suppressing intra-articular fluid signals with appropriate inversion time (TI).¹⁷ We propose the following hypothesis: compared with T2W SPIR, T2W SPIR-FLAIR sequence can effectively suppress the intra-articular fluid signals and retain the thickened synovial membrane signals. The unsuppressed high-signal areas within the articular cavity can be considered as the thickened synovial membranes. So, T2W SPIR-FLAIR sequence can be used to diagnose synovitis and assess its severity.

This study investigated the feasibility and accuracy of the T2W SPIR-FLAIR sequence in diagnosing hip synovitis, using the significant abnormal enhancement of the synovial membranes on the enhanced T1W SPIR sequence images as the gold standard in the diagnosis of synovitis. To our knowledge, no previous work has employed the T2W SPIR-FLAIR sequence in the diagnosis of synovitis.

METHODS AND MATERIALS

Recruitment of volunteers and patients

10 volunteers were recruited from the medical staff of our hospital (8 males and 2 females). The inclusion criteria include (1) good health; (2) age of 20–45 years; (3) no hip symptoms; (4) no history of hip injury or infection; and (5) no contraindications to MRI examination.

Patient inclusion criteria include (1) meeting the 2009 Assessment of Spondyloarthritis International Society criteria for the classification of SpA;¹ and (2) no contraindications to MRI examination. Patient exclusion criteria include: (1) history of cancer; (2) hip infection; (3) biologic treatment; (4) history of hip surgery; and (5) avascular necrosis of the femoral heads. The study was approved by the hospital ethics committee, and all healthy volunteers and patients signed a written informed consent form.

From October 2014 to June 2015, 45 consecutive patients (36 males and 9 females) at our hospital were recruited according to the inclusion and exclusion criteria: age of 25.2 ± 5.5 years (range: from 15 to 43 years). The interval between the first symptoms related to SpA and the time of MRI examination was 25.5 ± 17.6 months (range: from 3 to 121 months).

Table 1. Scan sequences and parameters

Sequence	TR/ TE (ms)	Slice thickness/ gap (cm)	Layers	Acquisition matrix	Reconstruction matrix	ETL	NSA	SEF	Scan time
T1W	543/10	3/0.3	22	308 × 514	1056 × 1056	7	1	2	1'36"
T2W SPIR	Shortest/60	3/0.3	22	324 × 497	896 × 896	15	1	1.6	2'31"
T2W SPIR-FLAIR	7000/120	3/0.3	22	260 × 426	768 × 768	36	1	2	3'16"
Enhanced T1W SPIR	543/10	3/0.3	22	308 × 514	1056 × 1056	7	1	2	1'36"

ETL, echo train length; FLAIR, fluid-attenuated inversion recovery; NSA, number of averages; SEF, sensitivity-encoding factor; SPIR, spectral pre-saturation inversion recovery; T1W, T₁ weighted; T2W, T₂ weighted; TE, echo time; TR, repetition time.

Determination of inversion time value

To get the optimal TI, which can effectively suppress the intra-articular fluid signal and exert minimal impact on other tissue signals on the T2W SPIR-FLAIR sequence images, the 10 volunteers underwent bilateral hip turbo spin-echo (TSE) coronal scan. This was achieved by using a 16-channel phased-array sensitivity-encoding (SENSE) body coil on a Philips-Ingenia 3.0-T MRI machine (Philips Medical Systems, Best, Netherlands). A T2W SPIR sequence and four T2W SPIR-FLAIR sequences, with TIs of 2300, 2200, 2100 and 2000 ms, respectively, were scanned in each volunteer. Scan parameters are listed in Table 1. The T2W SPIR and four T2W SPIR-FLAIR images were transferred to a workstation. The slice which contained the most intra-articular fluid was selected on the T2W SPIR images. Regions of interest (ROIs) were manually placed over the fluid area of the articular cavity so as to only include fluid intensity. ROIs were copied onto the four T2W SPIR-FLAIR images and the signal intensity (SI) of the ROIs were measured and recorded. Based on comparison with the T2W SPIR images, the effectiveness of the T2W SPIR-FLAIR with different TIs in the suppression of the intra-articular fluid signals was evaluated. On T2W SPIR-FLAIR sequences, the TI which could effectively suppress the intra-articular fluid high signal and had minimum SI of ROIs was selected as the optimum TI.

MRI

Patients underwent TSE coronal and axial hip scans using the same coils and scanner mentioned above. Scan sequences include T1W, T2W SPIR, T2W SPIR-FLAIR and enhanced T1W SPIR. The TI value of the T2W SPIR-FLAIR sequence was determined by the scan results of the healthy volunteers. Other scan parameters are shown in Table 1. The patients were asked to empty their bladder 30 min before scanning to reduce the motion artefacts of urine. Saturation bands were positioned above, below and in front of the scan areas on T2W SPIR-FLAIR to reduce the vascular pulsation artefacts. The enhanced T1W SPIR scan was performed half minute after an i.v. injection of 0.1 mmol kg^{-1} of Gd-DTPA2 (Magnevist®; Bayer Schering Pharma, Berlin, Germany).¹⁸

Image analysis

The significant abnormal enhancement of the synovial membranes on the enhanced T1W SPIR images was diagnosed as synovitis, while the retained high signals within the articular cavity on the T2W SPIR-FLAIR images was diagnosed as synovitis. Two radiologists with 15 and 5 years' experience in musculoskeletal radiology, who were blinded to patient data (clinical parameters, medical history, findings of other imaging modalities), independently evaluated whether synovitis could be diagnosed based on T2W SPIR-FLAIR and post-contrast-enhanced T1W SPIR images. To avoid mutual interference between T2W SPIR-FLAIR and enhanced T1W SPIR, the analyses of the images of these two sequences were not conducted on the same day. The disagreement in the evaluation was reviewed and judged by a third radiologist with >20 years' experience in musculoskeletal radiology.

To evaluate the image quality, the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the T2W SPIR-FLAIR and enhanced T1W SPIR sequences were compared. The SNR was measured in all 90 hips of the 45 patients. The CNR was measured only in the hips diagnosed with synovitis by both T2W SPIR-FLAIR and enhanced T1W SPIR sequences. The SNR and CNR were calculated from the original images according to the following equations:

$$\text{SNR} = \text{SI}_{\text{femoral head}} / \text{SD}_{\text{air}}$$

$$\text{CNR} = (\text{SI}_{\text{synovium}} - \text{SI}_{\text{intra-articular fluid}}) / \text{SD}_{\text{air}}$$

where $\text{SI}_{\text{femoral head}}$ is the mean value of the SI of the three ROIs placed in the femoral heads in the mid-coronal slice; SD is the standard deviation of the SI; SD_{air} is the mean value of the SD of the three ROIs measured in the air outside the pelvis; $\text{SI}_{\text{synovium}}$ is the mean value of the SI of the ROIs painted in the thickened synovial membrane area; $\text{SI}_{\text{intra-articular fluid}}$ is the mean value of the SI of the three ROIs painted over the intra-articular fluid. The ROIs for the measurement of $\text{SI}_{\text{femoral head}}$ and SD_{air} were round and 0.25 cm^2 in size. The ROIs for the measurement of

Figure 1. A 23-year-old healthy male volunteer with same level hip joint coronal T_2 weighted spectral pre-saturation inversion recovery (T2W SPIR) image (a), T2W SPIR-fluid-attenuated inversion recovery (FLAIR) image with an inversion time (TI) of 2200 ms (b) and T2W SPIR-FLAIR image with TI of 2100 ms (c): T2W SPIR is showing high signals of a small amount of synovia at bilateral hips (arrows). On T2W SPIR-FLAIR with TI of 2200 ms, although the high signals of urine in the bladder are completely suppressed, the high signals of synovia remain visible (arrows). The high signals of synovia are completely suppressed on T2W SPIR-FLAIR with TI of 2100 ms.

Table 2. The comparison between T_2 weighted spectral pre-saturation inversion recovery combined with fluid-attenuated inversion recovery (T2W SPIR-FLAIR) and enhanced T_1 weighted (T1W) SPIR in the diagnosis of hip synovitis in 45 patients (90 hips)

T2W SPIR-FLAIR	Enhanced T1W SPIR		Total
	+	–	
+	32	3	35
–	0	55	55
Total	32	58	90

+, with synovitis; –, without synovitis.

SI_{synovium} were manually painted along the thickened synovium. Using the T2W SPIR images for visual guidance, the ROIs for the measurement of $SI_{\text{intra-articular fluid}}$ were manually painted over the fluid area of the articular cavity. To ensure that the ROIs were in the same area in the T2W SPIR-FLAIR and enhanced T1W SPIR sequences, the ROIs were drawn in enhanced T1W SPIR images and copied onto the same slice of T2W SPIR-FLAIR.

Statistical analysis

Data were analyzed using SPSS® v. 17.0 statistical software package (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). The differences in SNR and CNR between T2W SPIR-FLAIR and enhanced T1W SPIR were compared using paired *t*-test. McNemar's test and Kappa test were used to compare the values of T2W SPIR-FLAIR and enhanced T1W SPIR in the diagnosis of hip synovitis. The enhanced T1W SPIR sequence was used as the gold standard in the diagnosis of synovitis. The sensitivity, specificity, diagnostic accuracy and positive and negative-predictive values of T2W SPIR-FLAIR in diagnosing hip synovitis were evaluated.

RESULTS

Inversion time value determination

The hip MRI of the 10 volunteers indicated that high intra-articular fluid signals were visible in all 20 hips on the T2W SPIR sequence images. Compared with T2W SPIR, the number of hip joints with completely suppressed high intra-articular fluid

signals on the T2W SPIR-FLAIR sequence images with TIs of 2300, 2200, 2100 and 2000 ms were 0, 5, 20 and 20, respectively (Figure 1). The mean SI of the intra-articular fluid measured on the T2W SPIR-FLAIR sequence images with TIs of 2300, 2200, 2100 and 2000 ms were 28.34 ± 3.49 , 11.8 ± 3.52 , 4.8 ± 1.61 and 5.15 ± 1.69 , respectively ($F = 316.39$; $p < 0.05$). Therefore, a TI of 2100 ms was chosen as the optimum TI.

Comparison between T2W SPIR-FLAIR and enhanced T1W SPIR in the diagnosis of hip synovitis
There were visible high intra-articular fluid signals on the T2W SPIR images of all patients (90 hips). The enhanced T1W SPIR showed significant enhancement of synovial membranes in 17 patients (32 hips) (Table 2). All the enhanced areas of the synovial membranes on the enhanced T1W SPIR images also showed high signals on the T2W SPIR-FLAIR images (Figures 2 and 3). Three hips showed high signals within the articular cavity on the T2W SPIR-FLAIR images, but did not show enhancement of synovial membranes on the enhanced T1W SPIR images. The rest of the hips (55 hips) did not show high signals within the articular cavities on the T2W SPIR-FLAIR and the enhanced T1W SPIR images (Figure 4).

McNemar's test and Kappa test were used to compare the values of T2W SPIR-FLAIR and enhanced T1W SPIR in the diagnosis of hip synovitis. The results showed that these two sequences had similar values in the diagnosis of hip synovitis ($p = 0.25$) and a high degree of diagnostic consistency (Kappa = 0.929). By setting the enhanced T1W SPIR results as the gold standard in the diagnosis of synovitis, the diagnostic sensitivity, specificity, accuracy and positive and negative-predictive values of T2W SPIR-FLAIR in the diagnosis of hip synovitis were 100, 94.8, 96.7, 91.4 and 100%, respectively.

Comparison of image quality between T_2 weighted spectral pre-saturation inversion recovery combined with fluid-attenuated inversion recovery and enhanced T_1 weighted spectral pre-saturation inversion recovery

The SNR of the enhanced T1W SPIR (34.24 ± 5.85) was significantly higher ($t = -8.57$, $p < 0.001$) than that of the T2W

Figure 2. A 32-year-old male patient with SpA with same level hip joint coronal T_2 weighted spectral pre-saturation inversion recovery (T2W SPIR) image (a), T2W SPIR-fluid-attenuated inversion recovery (FLAIR) image (b) and enhanced T_1 weighted (T1W) SPIR image (c): T2W SPIR is showing significantly high intra-articular signals at bilateral hips (arrows). The high signals of the articular cavity remain visible (arrows) on T2W SPIR-FLAIR. The high signal areas shown on T2W SPIR-FLAIR are displaying significant enhancements on the enhanced T1W SPIR (arrows).

Figure 3. A 22-year-old male patient with SpA with same level hip joint coronal T_2 weighted spectral pre-saturation inversion recovery (T2W SPIR) image (a), T2W SPIR-fluid-attenuated inversion recovery (FLAIR) image (b) and enhanced T_1 weighted (T1W) SPIR image (c): the high signals of the right articular cavity on T2W SPIR are not suppressed on T2W SPIR-FLAIR (arrows). The high intra-articular signal areas on T2W SPIR-FLAIR are showing significant enhancements on the enhanced T_1 weighted (T1W) SPIR (arrows). The high signals of the left articular cavity on T2W SPIR (arrowheads) are completely suppressed on T2W SPIR-FLAIR. There is no visible synovial membrane enhancement of the left articular cavity on the enhanced T1W SPIR.

SPIR-FLAIR (23.81 ± 6.39). There was no significant difference ($t = -1.034$, $p = 0.308$) in CNR between T2W SPIR-FLAIR (55.20 ± 10.52) and enhanced T1W SPIR (52.28 ± 16.16).

The inter observer agreement in the diagnosis of hip synovitis

The evaluations of the two observers regarding the high intra-articular signals on the T2W SPIR-FLAIR images and the abnormal synovial enhancements on the enhanced T1W SPIR images were highly consistent, with Kappa values of 0.885 and 0.904, respectively (Table 3).

DISCUSSION

Inversion recovery (IR) sequence with different TIs can selectively suppress different tissue signals. FLAIR sequence is one of the IR sequences with a long TI. When the TI is approximately 69% of fluid T_1 value, the longitudinal magnetization of the fluid is close to zero, and the fluid signal can be effectively suppressed. Based on the above information, we propose the following hypothesis: the composition and the T_1 relaxation time of the thickened synovial membranes and the intra-articular fluids are different in synovitis. Therefore, selecting an appropriate TI value can effectively suppress intra-articular

fluid signals (normal synovia and effusion) while retaining the signals of the thickened synovial membranes. Since no previous T_1 values of the intra-articular fluid have been reported, the optimization of TI was implemented within TI values ranging from 2000 to 2300 ms, based on experience. 10 healthy volunteers underwent a hip T2W SPIR and four T2W SPIR-FLAIR sequence scans with TIs of 2300, 2200, 2100 and 2000 ms, respectively. The results revealed that T2W SPIR-FLAIR sequences with TIs of 2100 and 2000 ms could effectively suppress intra-articular fluid signals, while T2W SPIR-FLAIR sequences with TIs of 2300 and 2200 ms could not. Moreover, T2W SPIR-FLAIR sequences with TI of 2100 ms had the minimum SI of intra-articular fluid among the four TIs (2300, 2200, 2100 and 2000 ms). So, a TI of 2100 ms was chosen for the T2W SPIR-FLAIR sequence in patients with SpA. Our results showed that T2W SPIR-FLAIR with TI of 2100 ms can effectively differentiate thickened synovial membranes from effusion and can be used in the diagnosis of hip synovitis in patients with SpA. By using the enhanced T1W SPIR results as the gold standard in the diagnosis of synovitis, the diagnostic sensitivity, specificity, accuracy and positive and negative-predictive values of T2W SPIR-FLAIR were 100, 94.8, 96.7, 91.4 and 100%, respectively.

Figure 4. A 24-year-old male patient with SpA with same level hip joint coronal T_2 weighted spectral pre-saturation inversion recovery (T2W SPIR) image (a), T2W SPIR-fluid-attenuated inversion recovery (FLAIR) image (b) and enhanced T_1 weighted (T1W) SPIR image (c): the intra-articular high-signal areas on T2W SPIR are completely suppressed on T2W SPIR-FLAIR (arrows). There is no visible synovial membrane enhancement on the enhanced T1W SPIR.

Table 3. The interobserver agreement in the diagnosis of hip synovitis

Sequences	Agreement	
	Consistency (%)	Kappa
T ₂ W SPIR-FLAIR	94.4	0.885
Enhanced T ₁ W SPIR	95.6	0.904

FLAIR, fluid-attenuated inversion recovery; SPIR, spectral pre-saturation inversion recovery; T₁W, T₁ weighted; T₂W, T₂ weighted.

The application of T₂W SPIR-FLAIR in the diagnosis of synovitis is promising; however, it has several limitations. Firstly, T₂W SPIR-FLAIR requires a long repetition time, resulting in a long duration of scan time, which limits its usage as a routine clinical application.¹⁹ Secondly, the T₂W SPIR-FLAIR images are prone to artefacts. Thirdly, the T₂W SPIR-FLAIR images suppress fat and liquid signals, resulting in a lower SNR.¹⁷ To overcome these limitations, we used TSE sequence and a long echo train length combined with the application of SENSE coil (SENSE factor of 2) in our study, which decreased the scan time to 3 min and 16 s. Moreover, the patients were required to empty their bladder before the examination to reduce the artefact of urine. We also added the saturated bands above, below and in front of the scan areas, which effectively reduced the vascular pulsation artefacts. Although the SNR of T₂W SPIR-FLAIR was lower than that of enhanced T₁W SPIR in this study, there was no significant difference between the CNR of T₂W SPIR-FLAIR and enhanced T₁W SPIR.

Previous clinical applications of T₂W SPIR-FLAIR mainly focused on optic neuropathy.^{17,19,20} This is the first study to apply this sequence in the diagnosis of hip synovitis. Jahng et al²¹ applied double IR sequence in the detection of knee synovitis. They demonstrated that double IR sequence could effectively differentiate thickened synovial membranes from effusion. Both Jahng et al's study and ours focused on enhancing the thickened synovial membrane signals through the suppression of fat and

fluid signals; however, the scan sequences and scan locations were different. Compared with Jahng et al's research, the patients recruited in this study were not limited to those who had visible joint effusion.

This study has several limitations. Firstly, owing to the limited total scan time, the optimization of the TI was not performed in the patient scan. The TI of 2100 ms, which was the optimal TI in healthy volunteers, was employed in the scanning of patients with SpA. It is possible that the T₁ relaxation times of the joint fluid in healthy volunteers are different from those in patients with SpA. Takahashi et al²² reported that the protein level in the painful temporomandibular joint lavage fluid was higher than that of pain-free joints. Imoto et al,²³ in their research on temporomandibular joint effusion, stated that there is a possibility that the T₁ of the joint effusion in the inflamed synovial tissue was shortened by the protein content. Moreover, the T₁ of the intra-articular fluids may also vary among patients. Secondly, we used the existence of significant abnormal enhancement of the synovial membranes on the enhanced T₁W SPIR images as the gold standard in the diagnosis of synovitis. However, compared with the acute phase, the blood supply of the thickened synovial membranes decreases during the non-acute phases of synovitis, which results in the non-significant signal enhancement and leads to a false-negative diagnosis of synovitis. In this study, three joints showed abnormally high signals on the T₂W SPIR-FLAIR images, but there was no visible synovial membrane enhancement on the enhanced T₁W SPIR images. It is difficult to determine whether it was a false-positive diagnosis of T₂W SPIR-FLAIR or a false-negative diagnosis of enhanced T₁W SPIR.

In conclusion, this study shows that T₂W SPIR-FLAIR can effectively suppress the fluid signals while retaining the thickened synovial membrane signals. The application of this sequence shows high sensitivity and specificity in the diagnosis of hip synovitis, which does not require the injection of contrast agents.

REFERENCES

1. Sieper J, Rudwaleit M, Baraliakos X, Brandt J, Braun J, Burgos-Vargas R, et al. The Assessment of SpondyloArthritis international Society (ASAS) handbook: a guide to assess spondyloarthritis. *Ann Rheum Dis* 2009; **68**(Suppl. 2): 1–44. doi: <https://doi.org/10.1136/ard.2008.104018>
2. Sieper J, Braun J, Rudwaleit M, Boonen A, Zink A. Ankylosing spondylitis: an overview. *Ann Rheum Dis* 2002; **61** (Suppl. 3): 8–18.
3. Barkham N, Keen HI, Coates LC, O'Connor P, Hensor E, Fraser AD, et al. Clinical and imaging efficacy of infliximab in HLA-B27-Positive patients with magnetic resonance imaging-determined early sacroiliitis. *Arthritis Rheum* 2009; **60**: 946–54. doi: <https://doi.org/10.1002/art.24408>
4. Oostveen J, Prevo R, den Boer J, van de Laar M. Early detection of sacroiliitis on magnetic resonance imaging and subsequent development of sacroiliitis on plain radiography. A prospective, longitudinal study. *J Rheumatol* 1999; **26**: 1953–8.
5. Maksymowych WP. MRI in ankylosing spondylitis. *Curr Opin Rheumatol* 2009; **21**: 313–17. doi: <https://doi.org/10.1097/BOR.0b013e32832af481>
6. Zochling J, Baraliakos X, Hermann KG. Magnetic resonance imaging in ankylosing spondylitis. *Curr Opin Rheumatol* 2007; **19**: 346–52. doi: <https://doi.org/10.1097/BOR.0b013e32816a938c>
7. Vander Cruyssen B, Munoz-Gomariz E, Font P, Mulero J, de Vlam K, Boonen A, et al. Hip involvement in ankylosing spondylitis: epidemiology and risk factors associated with hip replacement surgery. *Rheumatology (Oxford)* 2010; **49**: 73–81. doi: <https://doi.org/10.1093/rheumatology/kep174>
8. Huang ZG, Zhang XZ, Hong W. The application of MR imaging in the detection of hip involvement in patients with ankylosing spondylitis. *Eur J Radiol* 2013; **82**: 1487–93. doi: <https://doi.org/10.1016/j.ejrad.2013.03.020>

9. Appel H, Kuhne M, Spiekermann S, Köhler D, Zacher J, Stein H, et al. Immunohistochemical analysis of hip arthritis in ankylosing spondylitis: evaluation of the bone-cartilage interface and subchondral bone marrow. *Arthritis Rheum* 2006; **54**: 1805–13. doi: <https://doi.org/10.1002/art.21907>
10. Chen WS, Chen CH, Lin KC, Tsai CY, Liao HT, Wang HB, et al. Immunohistological features of hip synovitis in ankylosing spondylitis with advanced hip involvement. *Scand J Rheumatol* 2009; **38**: 154–5. doi: <https://doi.org/10.1080/03009740802409504>
11. Revell PA, Mayston V. Histopathology of the synovial membrane of peripheral joints in ankylosing spondylitis. *Ann Rheum Dis* 1982; **41**: 579–86. doi: <https://doi.org/10.1136/ard.41.6.579>
12. Tamai M, Kawakami A, Uetani M, Fukushima A, Arima K, Fujikawa K, et al. Magnetic resonance imaging (MRI) detection of synovitis and bone lesions of the wrists and finger joints in early-stage rheumatoid arthritis: comparison of the accuracy of plain MRI-based findings and gadolinium-diethylenetriamine pentaacetic acid-enhanced MRI-based findings. *Mod Rheumatol* 2012; **22**: 654–8. doi: <https://doi.org/10.3109/s10165-011-0575-8>
13. Hayashi A, Roemer FW, Katur A, Felson DT, Yang SO, Alomran F, et al. Imaging of synovitis in osteoarthritis: current status and outlook. *Semin Arthritis Rheum* 2011; **41**: 116–30. doi: <https://doi.org/10.1016/j.semarthrit.2010.12.003>
14. Loeuille D, Sauliere N, Champigneulle J, Rat AC, Blum A, Chary-Valckenaere I. Comparing non-enhanced and enhanced sequences in the assessment of effusion and synovitis in knee OA: associations with clinical, macroscopic and microscopic features. *Osteoarthritis Cartilage* 2011; **19**: 1433–9. doi: <https://doi.org/10.1016/j.joca.2011.08.010>
15. Grobner T. Gadolinium—a specific trigger for the development of nephrogenic fibrosing dermopathy and nephrogenic systemic fibrosis? *Nephrol Dial Transplant* 2006; **21**: 1104–8. doi: <https://doi.org/10.1093/ndt/gfk062>
16. Ersoy H, Rybicki FJ. Biochemical safety profiles of gadolinium-based extracellular contrast agents and nephrogenic systemic fibrosis. *J Magn Reson Imaging* 2007; **26**: 1190–7. doi: <https://doi.org/10.1002/jmri.21135>
17. Jackson A, Sheppard S, Laitt RD, Kassner A, Moriarty D. Optic neuritis: MR imaging with combined fat-and water-suppression techniques. *Radiology* 1998; **206**: 57–63. doi: <https://doi.org/10.1148/radiology.206.1.9423652>
18. Ostergaard M, Stoltenberg M, Løvgreen-Nielsen P, Volck B, Sonne-Holm S, Lorenzen I. Quantification of synovitis by MRI: correlation between dynamic and static gadolinium-enhanced magnetic resonance imaging and microscopic and macroscopic signs of synovial inflammation. *Magn Reson Imaging* 1998; **16**: 743–54.
19. Jackson A, Sheppard S, Johnson AC, Annesley D, Laitt RD, Kassner A, et al. Combined fat-and water-suppressed MR imaging of orbital tumors. *AJNR Am J Neuroradiol* 1999; **20**: 1963–9.
20. Hickman SJ. Optic nerve imaging in multiple sclerosis. *J Neuroimaging* 2007; **17**(Suppl. 1): S42–5. doi: <https://doi.org/10.1111/j.1552-6569.2007.00136.x>
21. Jahng GH, Jin W, Yang DM, Ryu KN. Optimization of a double inversion recovery sequence for noninvasive synovium imaging of joint effusion in the knee. *Med Phys* 2011; **38**: 2579–85. doi: <https://doi.org/10.1118/1.3581060>
22. Takahashi T, Nagai H, Seki H, Fukuda M. Relationship between joint effusion, joint pain, and protein levels in joint lavage fluid of patients with internal derangement and osteoarthritis of the temporomandibular joint. *J Oral Maxillofac Surg* 1999; **57**: 1187–93. doi: [https://doi.org/10.1016/S0278-2391\(99\)90483-4](https://doi.org/10.1016/S0278-2391(99)90483-4)
23. Imoto K, Otonari-Yamamoto M, Nishikawa K, Sano T, Yamamoto A. Potential of fluid-attenuated inversion recovery (FLAIR) in identification of temporomandibular joint effusion compared with T2-weighted images. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011; **112**: 243–8. doi: <https://doi.org/10.1016/j.tripleo.2011.03.004>