Diagnostic performance for erosion detection in sacroiliac joints on MR T1-weighted images: comparison between different slice thicknesses

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Diagnostic performance for erosion detection in sacroiliac joints on MR T1-weighted images: comparison between different slice thicknesses

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Highlights

- Diagnostic accuracy of T1-weighted MRI for erosion depends on the slice thickness.
- More erosions can be detected with a slice thickness of 2 or 3 mm than 4 or 5 mm.
- Slice thickness of 2 or 3 mm achieves better diagnostic accuracy vs. CT for erosion.

Abstract

Purpose: To assess the effect of slice thickness on the diagnostic accuracy of erosion detection at MR T1-weighted images (T1WI) of the sacroiliac joints (SIJ) in adult patients suspected of sacroiliitis.

Method: Patients aged 18-60 years with clinical suspicion of sacroiliitis were enrolled. All patients underwent CT and 3 Tesla MRI of the SIJs on the same day. CT at 1 mm slice thickness, semi-coronal spin echo T1WI sequences with four different slice thicknesses (2, 3, 4 and 5 mm) were obtained. For scoring erosions, each SIJ was divided into four quadrants. Presence or absence of erosions was scored on T1WI sequences by two independent readers blinded to other data. Inter-reader agreement was assessed using κ statistics. Diagnostic accuracy of MRI for erosions at each slice thickness was evaluated vs. consensus CT as reference standard, using area under the receiver operating characteristic curve (AUC).

Results: Fifty-three patients (23 men, 30 women, mean age, 39.0 years ± 10.2) were included. Inter-reader agreement for erosion score on all T1WI sequences was moderate (κ value 0.54 to 0.60). With increasing slice thickness, both the recorded total number of erosions and sensitivity for erosion vs. CT decreased. The AUC were significantly higher for 2 mm and 3 mm T1WI than for 4 mm and 5 mm T1WI.

Conclusions: The diagnostic accuracy of T1WI for erosion detection vs. a CT reference standard is affected by slice thickness. Thinner slices (2 or 3 mm) had significantly higher diagnostic accuracy than thicker slices (4 or 5 mm).

Abbreviations

ASAS, Assessment of SpondyloArthritis international Society; AUC, Area under the ROC curve; axSpA, axial spondyloarthritis; CNR, contrast-to-noise ratio; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic; SIJ, sacroiliac joint; SNR, signal-to-noise ratio; T1WI, T1-weighted images

Key words: slice thickness; magnetic resonance imaging; spondyloarthritis; erosion

1. Introduction

Axial spondyloarthritis (axSpA) is a chronic inflammatory disease that mainly affects the axial skeleton [1]. As sacroiliitis is a distinctive feature of axSpA [1, 2], imaging of the sacroiliac joints (SIJs) plays a critical role in the diagnosis of axSpA. Although not included in the Assessment of SpondyloArthritis international Society (ASAS) 'positive MRI' criteria [3], structural changes of the SIJs, especially erosions, have played a role in the diagnosis and follow-up of patients with axSpA [4-7]. It has been reported that the inclusion of erosions can improve the sensitivity of disease diagnosis [5]. The presence of erosions of SIJ is highly specific for SpA and may enhance confidence in the classification of axSpA [4, 8-10] and help differentiate SpA from other diseases [11].

Conventional radiography has been used for assessment of structural lesions of the SIJs for many years [2]. Nevertheless, its low sensitivity and inter-reader reliability [2, 12, 13] make its use limited in detecting the disease in an early stage. CT serves as a reference standard for detection of erosions in sacroiliitis [14-17]. However, the radiation exposure from CT scans of the sacroiliac joints may increase cancer risk especially in young patients with suspected SpA [18, 19]. Moreover, as CT cannot detect active lesions in SpA, performing a CT scan usually will not change the treatment of the patient [20]. Thus CT is not recommended for general use in SpA.

MRI can detect both active inflammation and structural lesions in SpA without use of ionizing radiation. In comparison to radiograph and CT, active inflammatory lesions including bone marrow edema, capsulitis, enthesitis and joint space fluid can be seen on MRI. For structural lesion detection, although there are explorations of gradient echo sequences for erosion detection [21], a T1-weighted spin echo sequence is still the most commonly used sequence [22] in clinical practice and clinical studies. Previous studies focused on the reliability of T1-weighted images (T1WI) for detecting erosions [5, 8, 12, 13], using a slice thickness of 3 or 4 mm. However, the optimal slice thickness of T1WI for detecting erosions has not been discussed in literature. Erosions are sometimes small lesions, which may not be as clearly seen on thick slices as on thin slices. Whether different slice thickness affects the detection of erosions on T1WI remains unknown.

This study aims to determine the inter-reader agreement and diagnostic accuracy for erosion detection on MR spin echo T1WI with different slice thicknesses (2 mm, 3 mm, 4 mm, and 5 mm) in patients suspected of sacroiliitis, vs. CT as a reference standard.

2. Material and methods

2.1. Study group

The study was approved by the local ethics committee and written informed consent was obtained from all patients.

Patients aged 18-60 years, suspected of sacroiliitis clinically by a rheumatologist in a tertiary hospital were consecutively and prospectively invited for the study between January and October 2019. Pregnant patients, those with metal implants in the pelvis or any contraindications to MRI were excluded. All patients underwent CT and MRI scans of the SIJs on the same day.

2.2 Imaging protocol

MRI was performed on a 3.0 Tesla MRI unit (Prisma, Siemens Healthineers, Erlangen, Germany) with a body flexed array coil (Siemens Healthineers, Erlangen, Germany). Four semi-coronal spin echo T1WI sequences with different slice thicknesses (2 mm, 3 mm, 4 mm, 5 mm) were scanned in the same orientation, which was along the long axis of the S2 vertebral body. All sequences were performed with a distance factor of 10% (slice gap, 0.2mm, 0.3 mm, 0.4 mm and 0.5 mm, respectively). Scanning parameters are summarized in **Table 1**.

CT examinations were performed on a dual-source spiral CT scanner (Somatom Definition Flash, Siemens Healthineers, Erlangen, Germany). 120-kV CT images were aquired. For scoring erosions, semi-coronal images (with the same orientation as the semi-coronal T1WI) were reconstructed with a slice thickness of 1mm and an increment of 1mm using a bone kernel (I50h).

2.3. Image reading

The MRI and and CT datasets were anonymized and exported using Syngo.via software (version VB20, Siemens Healthineers, Erlangen, Germany). Images were displayed in random order within each exercise. Only semi-coronal images were evaluated both on CT and MRI. Firstly, the anonymized T1WI sequences of all patients were mixed and two readers (Reader 1, a junior musculoskeletal radiologist with 4 years' experience, and Reader 2, a senior musculoskeletal radiologist with 15 years' experience) independently scored the T1WI images, blinded to CT and other MR images. Four weeks after all scoring on T1WI was completed, the same two readers scored the CT images in consensus to generate a reference standard. Both readers were blinded to the clinical information during scoring.

Score for lesions The definition for erosions was modified from the ASAS MRI working group [22]. In line with this definition, only T1WI was evaluated. Erosion was defined as a defect in subchondral bone associated with full-thickness loss of dark appearance (on MRI)/ high density delineation (on CT) of the subchondral cortex.

Each SIJ was divided into four quadrants for scoring [23]. The presence (score = 1) or absence (score = 0) of erosions for each SIJ quadrant was scored on CT and all T1WI. For all datasets, in order to score for the same part of the joint, scoring started from the transitional slice defined as the first slice in the cartilaginous portion that has a visible portion of the ligamentous joint when viewed from anterior to posterior [23]. The whole anterior cartilaginous portion of the SIJ was scored.

Score for diagnostic confidence For all T1WI datasets, the diagnostic confidence of every score for erosions was simultaneously assessed using a four-point scale: 1= poor confidence, 2= low confidence, 3= moderate confidence, 4= high confidence, a scoring system similar to that used in previous studies [24, 25].

2.4. Statistical analysis

Results from the two readers were analyzed separately. Erosion scores were analyzed on the quadrant level, using CT results as a reference standard. All quadrants with a score of 1 were considered as positive quadrants. Inter-reader agreement on T1WI with different slice thicknesses was analyzed using percentage agreement and Cohen's kappa [26]. A percentage agreement over 80% was considered acceptable [26]. κ values below 0.20 were considered to represent 'slight', 0.21-0.40 'fair', 0.41-0.60 'moderate', 0.61-0.80 'substantial' and 0.81-1.00 'almost perfect' agreement [27]. Positive rates between two readers on each T1WI sequence were compared using McNemar's test.

For each MRI slice thickness, diagnostic performance parameters for erosion vs. CT, including sensitivity, specificity, positive and negative predictive values (PPV, NPV) for erosion detection were calculated with 95% confidence intervals (CI). Receiver operating characteristic (ROC) curves were derived based on the combination of the lesion score and diagnostic confidence score. Area under ROC curves (AUCs) was calculated and compared among different MRI slice thicknesses. Diagnostic confidence scores were compared using Friedman's test, with pairwise comparison performed by Wilcoxon signed-rank test. Correction for multiple comparison was not performed as we took the present study as an exploratory study [28].

A p value < 0.05 was considered to indicate a statistically significant difference. All p values were calculated using a two-tailed significance level. Statistical analysis was performed using SPSS (Version 26.0, IBM, USA).

3. Results

The data flow is summarized in **Fig. 1**. Fifty-three patients (23 men, 30 women, mean age, 39.0 years ± 10.2, range, 18-56 years) were included for analysis. Two patients underwent CT scan 6 days after MR scan without any treatment in the interval. All the other patients underwent CT and MRI scans on the same day and the mean time interval was 1.7 hours ± 0.4 (range, 0.4–2.7 hours).

We studied 106 SIJs (424 quadrants) All quadrants were assessable on CT and T1WI. On CT, erosions were present on 18% (77 of 424) of quadrants in 33% patients (18 of 53, 10 men, 8 women, mean age 35.4 years ± 11.3).

3.1. Inter-reader agreement on T1WI with different slice thicknesses

Inter-reader κ values are displayed in **Table 2**. For presence or absence of erosions, the inter-reader agreement was moderate on all T1WI datasets. Percentage agreement was acceptable on all T1WI datasets (83%, 86%, 89% and 89% on 2, 3, 4 and 5 mm T1WI, respectively).

3.2. Diagnostic performance

Frequencies of erosions scored by two readers on T1WI are shown in **Fig. 2**. For both readers, the frequency of erosion detected at MRI decreased with increasing MRI slice thickness. Reader 1 scored significantly more erosions than Reader 2 on all T1WI datasets ($p = 0.001$ for 3 mm T1WI, $p < 0.001$ for the other T1WI datasets).

The diagnostic performance for erosion detection on T1WI with different slice thicknesses is summarized in **Table 3**. For both readers, the sensitivity for erosion detection decreased with the increase of slice thickness, with a range of 66-88% (Reader 1) and 44-77% (Reader 2). Notably for Reader 2, the sensitivities on 4 mm and 5 mm T1WI were poor (55% and 44%, respectively) . For Reader 1, the specificity increased when the slice thickness increased, which ranged from 82% to 91%. For Reader 2, specificities were high on all slice thicknesses, ranging from 92% to 95%. Examples of erosions on CT and T1WI datasets are displayed in **Fig. 3** and **Fig. 4**.

Overall diagnostic accuracy for erosion detection was further evaluated using ROC analysis, as shown in in **Fig. 5** and **Table 4**. For both readers, the AUC for erosion detection on 2 mm and 3 mm T1WI were higher compared to those on 4 mm and 5 mm T1WI. For Reader 2, the differences in AUCs between 2 mm/3 mm T1WI *vs* 4 mm/5 mm T1WI were all significant, while for Reader 1 the difference between 2 mm T1WI and 5 mm T1WI was not significant, with a p value close to 0.05. There was no significant difference between AUC of 2 mm T1WI and 3 mm T1WI for both readers.

Diagnostic confidence scores are summarized in **Fig. 6**. For reader 1, no difference was found among the confidence scores on 2 mm, 3 mm, 4 mm and 5 mm T1WI ($p=0.193$ using Friedman's test). For reader 2, difference was only found between 3 mm T1WI and 2 mm T1WI ($p=.029$ using Wilcoxon's signed rank test).

4. Discussion

According to our study, the diagnostic performance for erosion detection on T1-weighted MRI vs. a CT reference standard depends on the slice thickness, in a group of patients suspected of sacroiliitis. With increasing MRI slice thickness, two readers both showed increasing specificity, decreasing sensitivity and decreasing total lesion detection. Diagnostic accuracy measured by AUC was significantly higher on 2 mm and 3 mm T1WI than on 4 mm and 5 mm T1WI.

To our knowledge, the effect of slice thickness on inter-reader agreement of erosion detection on T1WI has not been discussed in literature. Our study shows that the inter-reader agreement for the binary erosion scores were moderate and similar across all T1WI datasets. The κ values in the present study are comparable to the results in literature, which varied from 0.46 to 0.76 for erosion detection on T1WI with a slice thickness of 3 mm or 4 mm [8, 12, 21, 29]. However, direct comparison of the inter-reader κ value with other studies may not be appropriate as it can be affected by the prevalence rate of the lesion in the study group [30], as well as the differences in study design and scoring methods [31]. Although a clear description of erosion definition was made before scoring, it is not surprising that the scoring results were different between readers with different of experience levels. The junior reader scored significantly more erosions than the senior reader. The senior reader was more conservative for scoring erosions, which might be because experienced readers tend to apply more strict criteria for decision making [32].

Several studies have been published on the diagnostic accuracy of erosion detection on T1WI using CT as a reference standard. Baraliakos et al. [16] found a quadrant-level sensitivity of 62% and a specificity of 88% on T1WI with a slice thickness of 3 mm for erosion detection in 109 patients with axSpA. Results from Hu et al. [33] were similar, with a sensitivity of 61 % and a specificity of 95% in 43 patients with SpA. Diekhoff et al. [13] evaluated the diagnostic accuracy for erosion detection on 3 mm T1WI in 110 patients suspected for SpA, and they found a sensitivity of 79% and a specificity of 93% on the patient level. In general, our results on 3 mm T1WI (Reader 1: sensitivity 82%, specificity 89%, Reader 2: sensitivity 65%, specificity 92%) confirm the diagnostic accuracy of erosion detection on T1WI in previous studies. The minor differences can be related to the difference in study population and the definition of erosion between the present study and previous studies.

To our knowledge, no data are available regarding the effect of slice thickness of acquired images on erosion detection using T1WI. It is known that the size of erosions in axSpA is variable. Usually erosions measure a few millimeters, but erosions can be single and small. Even 'definite erosions' may be smaller than 3 mm [13]. In our study, the total amount of erosions detected and the AUCs of 2 or 3 mm T1WI were significantly higher than those of 4 or 5 mm T1WI. These findings were consistent between the two readers with different levels of experience, indicating that erosions can be missed and diagnostic accuracy can be decreased with a slice thickness of 4 or 5 mm. This is likely due to increasing partial volume effect that comes with a thicker slice thickness. The larger slice gap with the increasing slice thickness may also lead to decreased detection of small erosions which may lie within the gap. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) decrease with a thinner slice thickness and smaller interslice gap. This might be a reason for more false positive findings and loss of specificity on thinner slices. However, increasing slice thickness affected sensitivity more than specificity. Loss of sensitivity was approximately 10% for both readers when slice thickness increased from 3 mm to 4 mm, while the increase of specificity was only 2% for Reader 1 and 3% for Reader 2. Thus using a slice thickness of no more than 3 mm may be beneficial for erosion detection, in comparison to a slice thickness of 4 mm, which has been commonly used in clinical studies [8, 20, 34]. For diagnosis and monitoring of axSpA, whether clinical benefits can be acquired using T1WI with thinner slice thicknesses still need further study.

This study has several limitations. Firstly, although the T1WI datasets were fully anonymized and randomly displayed, readers cannot be totally blinded to the slice thickness of the T1WI during scoring due to the different overall appearance of these slices. This is an unavoidable source of possible bias. Secondly, the results were not correlated with clinical diagnosis. This is for two reasons: the final clinical diagnosis of some patients is still unknown; the sample size (n=53) is still small for a patient-level analysis. Third, CT was used as a reference standard for imaging of erosions. Studies showed that high resolution three dimensional MR sequence may detect more erosions than CT with higher interpretation confidence [17], indicating that CT may not be perfect as reference standard. We read CT by consensus, but recognize that there is some inter-observer variability in any imaging gold standard. Finally, the prevalence of erosions in the study population was low, leading to a wide confidence interval for the acquired sensitivities.

5. Conclusions

In conclusion, we demonstrated that detection of erosions on MR T1WI of the SIJ depends on the slice thickness. Erosions can be missed with a slice thickness of 4 or 5 mm. A slice thickness of 2 or 3 mm improves the diagnostic accuracy of erosion detection.

Credit author statement

Min Chen: Conceptualization, Data curation; Formal analysis, Methodology, Software, Validation; Visualization; Writing – original draft; Writing – review & editing **Nele Herregods**: Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing **Jacob L. Jaremko**: Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing **Philippe Carron**: Validation; Visualization; Writing – original draft; Writing – review & editing **Dirk Elewaut**: Validation; Visualization; Writing – original draft; Writing – review & editing **Filip Van den Bosch**: Validation; Visualization; Writing – original draft; Writing – review & editing **Lennart Jans:** Conceptualization; Data curation; Formal analysis; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing

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Declarations of interest

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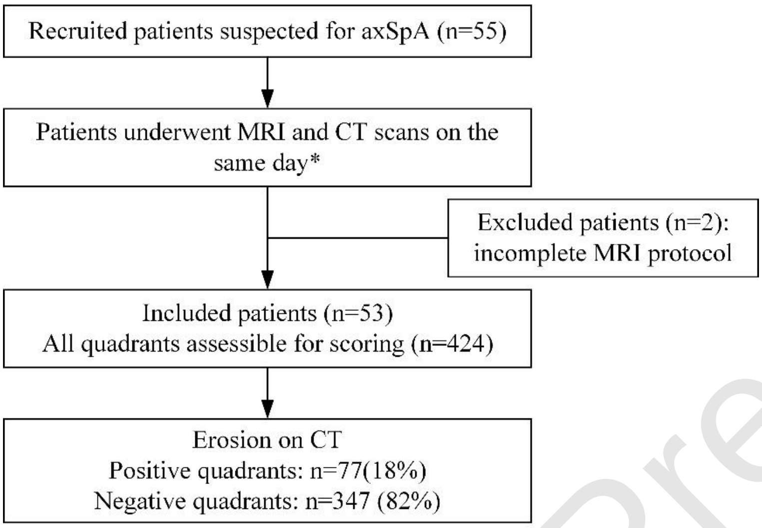

Fig. 1. Inclusion of patients and CT results. AxSpA, axial spondyloarthritis. *: Two patients underwent CT scans 6 days after MRI without any treatment in the interval. They were not excluded from the study population. AxSpA, axial spondyloarthritis.

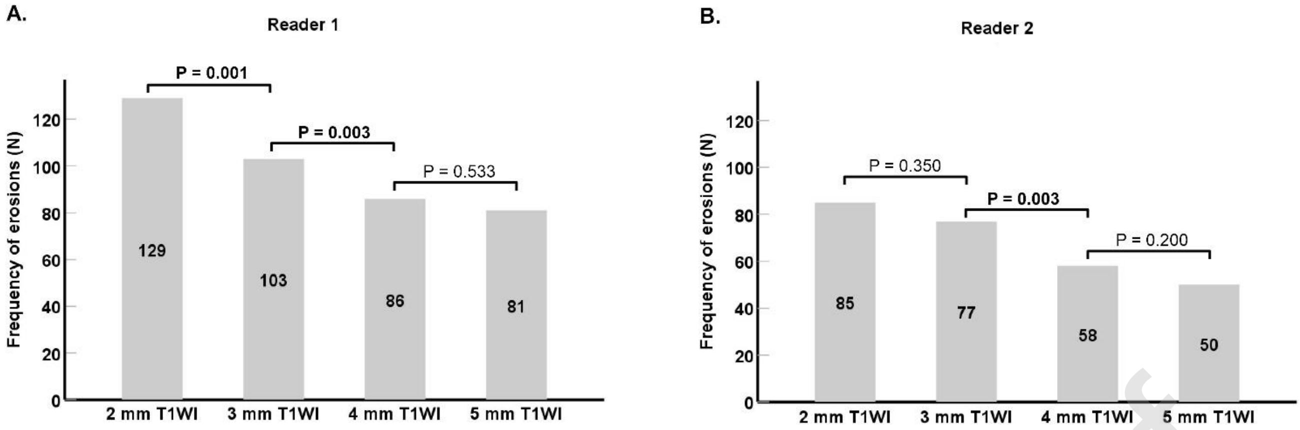

Fig. 2. Number (N) of erosions scored on MR T1-weighted images (T1WI) with different slice thicknesses by Reader 1 (A) and Reader 2 (B). Numbers within the column are the total numbers of positive quadrants. Comparison between slice thicknesses was made using McNemar's test. *p* values <0.05 are highlighted in **bold** font.

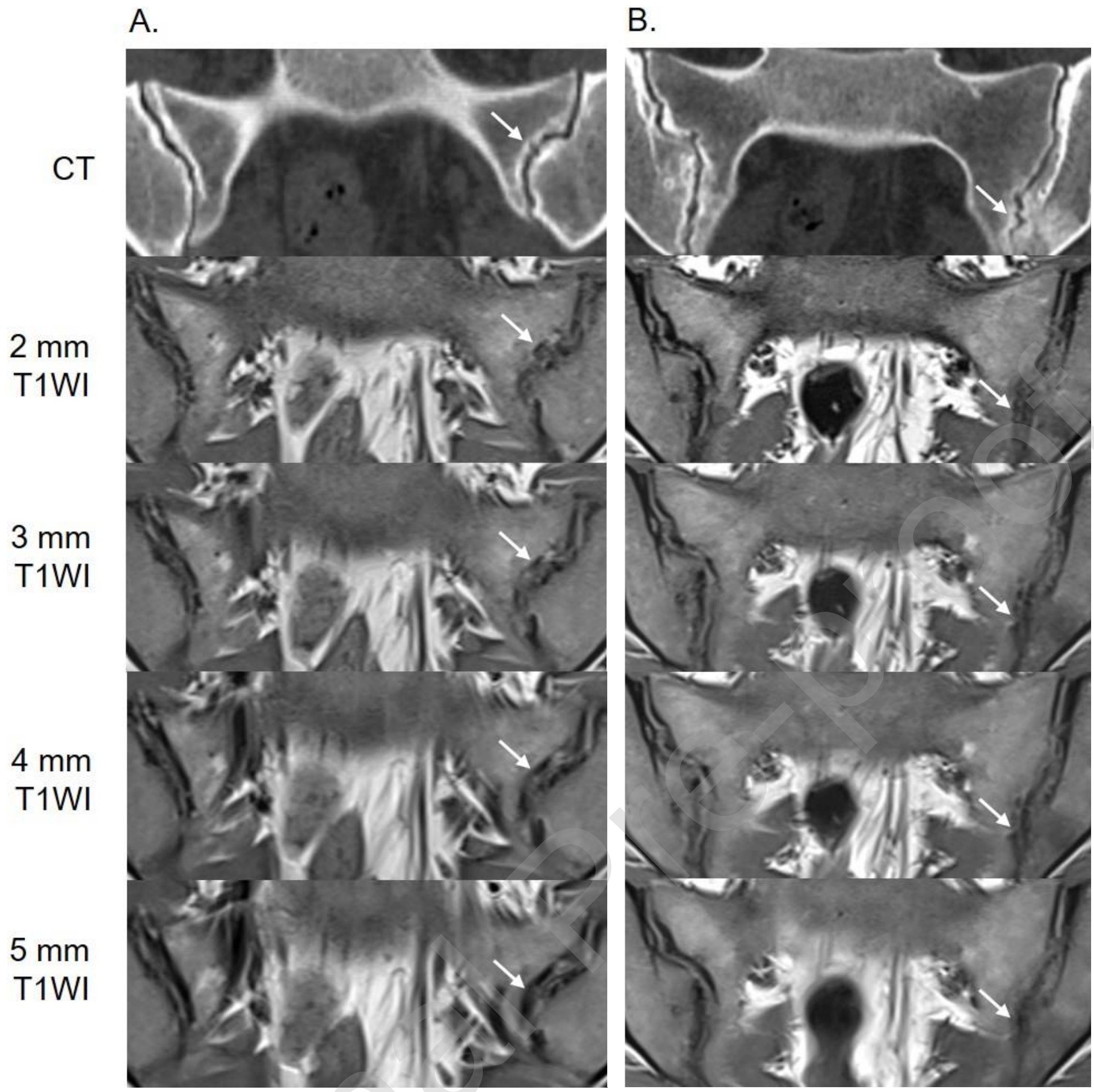

Fig. 3. Examples of erosion detection on MR T1-weighetd images (T1WI) with different slice thicknesses in comparison to CT. (A) Images of a 27-year-old woman suspected of sacroiliitis: erosions are seen on the left sacrum on CT (arrows). Erosions were depicted only on 2 mm and 3 mm T1WI for this quadrant. (B) Images of a 40-year-old woman suspected of having sacroiliitis. Erosions of the left joint (arrows) are more clearly depicted on thinner slices, especially on 2 mm T1WI.

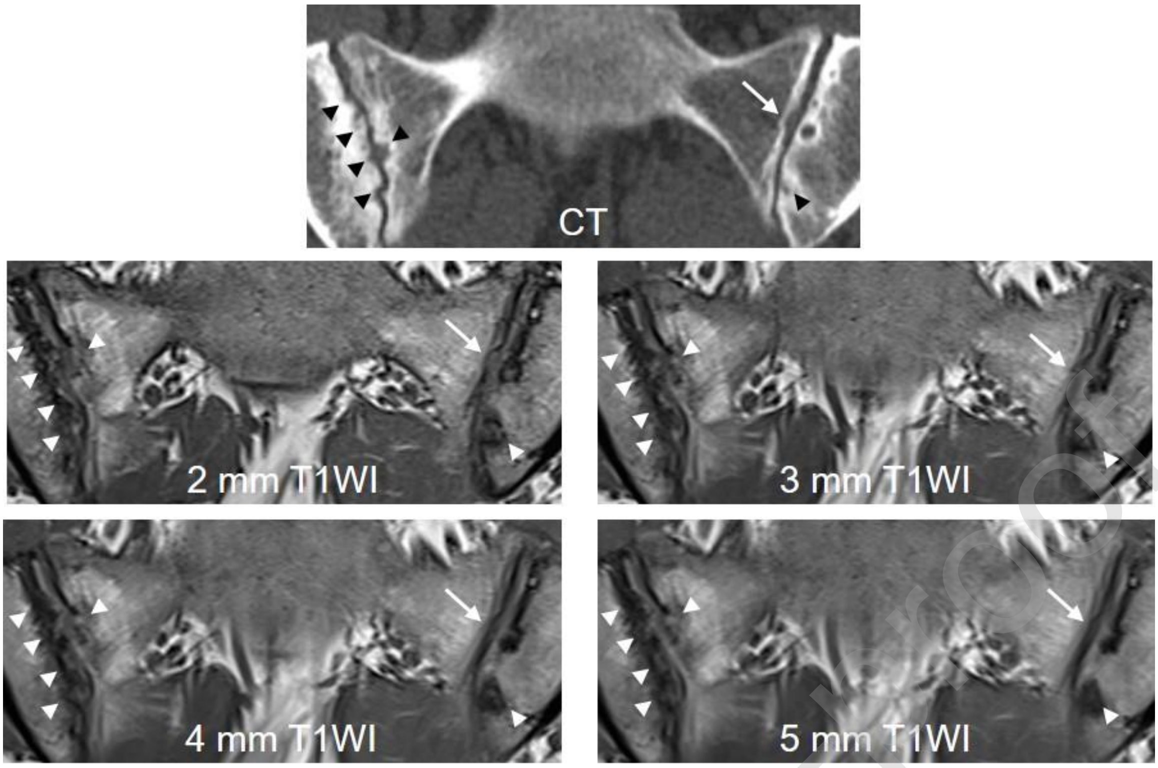

Fig. 4. Images of a 29-year-old man with extensive erosions detected on CT and MR T1-weighted images (T1WI). Erosions were seen on both joints (black arrowheads on CT image and white arrowheads on T1WI images). Note the small cortical defect on the left sacral articular surface (white arrows), which is well depicted on 2 mm T1WI, less-well depicted on 3 mm T1WI and not revealed on 4 mm and 5 mm T1WI.

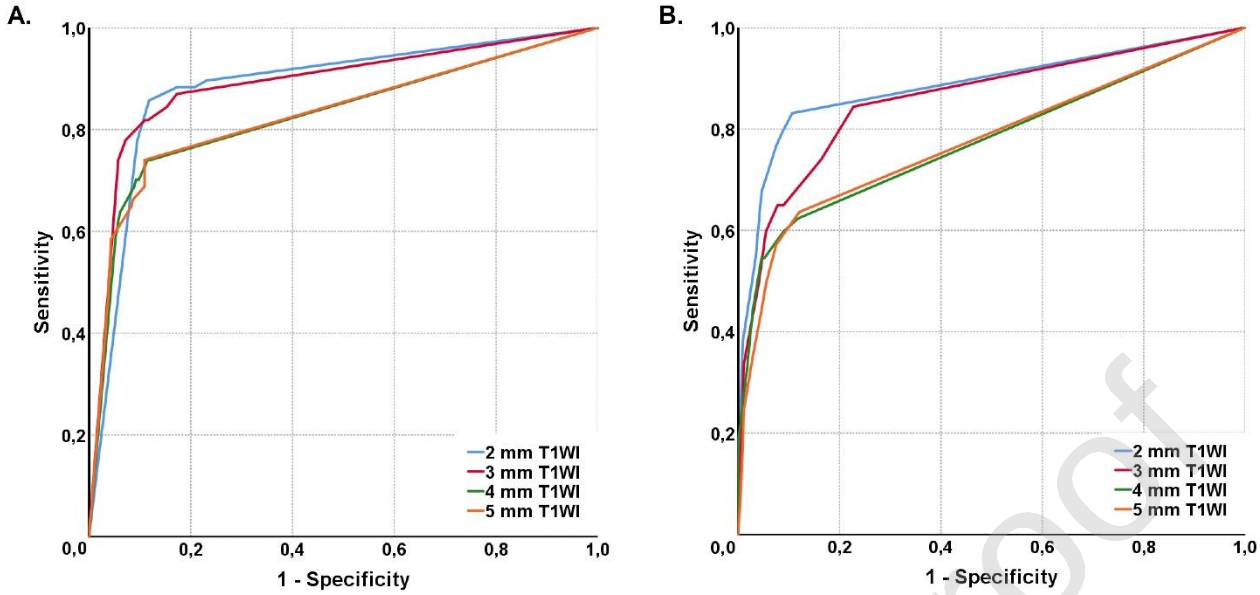

Fig. 5. Receiver operated characteristic (ROC) curves derived from a combination of erosion score and diagnostic confidence score on MR T1-weighted images (T1WI). Illustration of the line colors: blue lines: ROCs of 2 mm T1WI, red lines: 3 mm T1WI, green lines: 4 mm T1WI, orange lines: 5 mm T1WI. (A) Results from Reader 1, (B) Results from Reader 2.

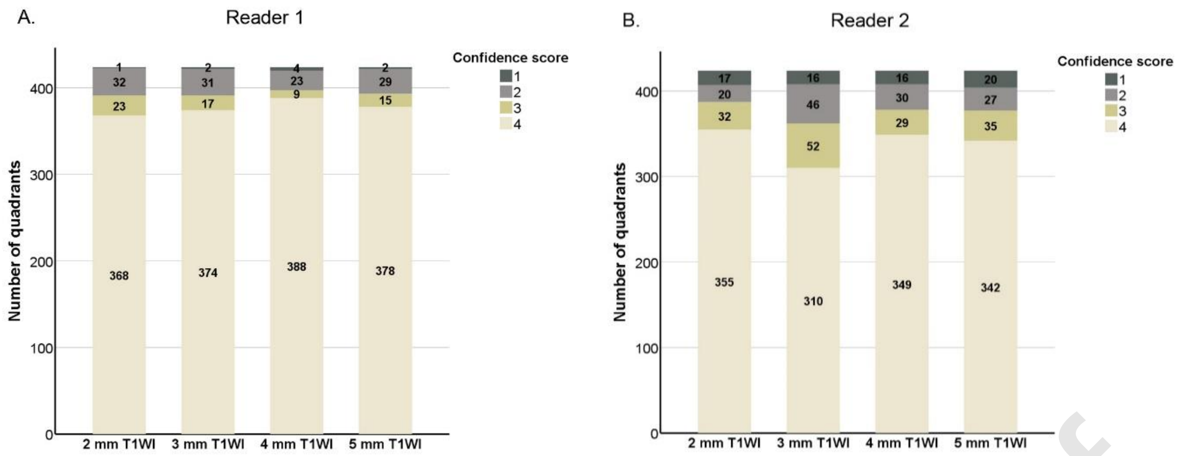

Fig. 6. Diagnostic confidence scores on T1-weighted images (T1WI) with different slice thicknesses by reader 1 (A) and reader 2 (B). Numbers within the column are the number of quadrants with different diagnostic confidence levels.

Table 1 Scan parameters for MR spin echo T1-weighted images (T1WI) with different slice thicknesses.

	T1WI			
Slice thickness (mm)	2	3	4	5
Gap (mm)	0.2	0.3	0.4	0.5
Repetition time (ms)	540-926	473-867	432-715	559-715
Echo time (ms)	10	9.9	9.9	9.9
Flip angle (°)	137	150	149	145
Bandwidth (±Hz)	230	230	230	230
Matrix	269×384	269×384	269×384	269×384
Field of view (cm)	22×22	22×22	22×22	22×22
Number of signals aquired	2	2	2	2

Table 2 Inter-reader agreement for erosion evaluation on MR T1-weighted images (T1WI) with different slice thicknesses.

Erosion score on T1WI with different slice thicknesses	
Total number of quadrants	424
κ value (95% confidence interval)	
2 mm	0.54 (0.46-0.63)
3 mm	0.58 (0.49-0.67)
4 mm	0.60 (0.50-0.70)
5 mm	0.58 (0.52-0.64)

Table 3 Diagnostic performance of MR T1-weighted images (T1WI) with different slice thicknesses compared to CT.

Reader	Slice thickness (mm)	Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)
Reader 1					
	2	88 (68/77) [79-94]	82 (286/347) [(78-86]	97 (286/295) [94-98]	53 (68/129) [44-61]
	3	82 (63/77) [72-89]	89 (307/347) [85-91]	96 (307/321) [93-97]	61 (63/103) [52-70]
	4	70 (54/77) [59-79]	91 (315/347) [87-93]	93 (315/338) [90-95]	63 (54/86) [52-72]
	5	66 (51/77) [55-76]	91 (317/347) [88-94]	92 (317/343) [89-95]	63 (51/81) [52-73]
Reader 2					
	2	77 (59/77) [66-85]	93 (321/347) [89-95]	95 (321/339) (92-97)	69 (59/85) [59-78]
	3	65 (50/77) [54-75]	92 (320/347) [89-95]	92 (320/347) [89-95]	65 (50/77) [54-75]
	4	55 (42/77) [44-65]	95 (331/347) [93-97]	90 (331/366) [87-93]	72 (42/58) [60-82]
	5	44 (34/77) [34-55]	95 (331/347) [93-97]	89 (331/374) [85-91]	68 (34/50) [54-79]

Data in parentheses are nominator and denominator. Data in brackets are the 95% confidence intervals. NPV, negative predictive value PPV, positive predictive value.

Table 4 Receiver operating characteristic (ROC) analysis and *p* values for pairwise comparison of area under the curves (AUCs)

		Slice thickness	2 mm	3 mm	4 mm	5 mm
Reader 1	AUC		0.884 (0.842-0.926)	0.889 (0.845-0.933)	0.827 (0.773-0.881)	0.829 (0.776-0.882)
	p value	2 mm	NA			
		3 mm	0.840	NA		
		4 mm	**0.046**	**0.020**	NA	
		5 mm	0.066	**0.027**	0.941	NA
Reader 2	AUC		0.885 (0.839-0.931)	0.858 (0.808-0.908)	0.775 (0.716-0.835)	0.775 (0.716-0.834)
	p value	2 mm	NA			
		3 mm	0.365	NA		
		4 mm	**0.001**	**0.003**	NA	
		5 mm	**0.001**	**0.007**	0.994	NA

Statistically significant *p* values are in bold font. AUCs are displayed with 95% confidence interval in parentheses. NA, not applicable.