

Detection of Erosions in Sacroiliac Joints of Patients with Axial Spondyloarthritis Using the Magnetic Resonance Imaging Volumetric Interpolated Breath-hold Examination

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ABSTRACT. Objective. The volumetric interpolated breath-hold examination (VIBE) magnetic resonance imaging (MRI) technique can visualize erosive cartilage defects in peripheral joints. We evaluated the ability of VIBE to detect erosions in sacroiliac joints (SIJ) of patients with axial spondyloarthritis (axSpA) compared to the established T1-weighted MRI sequence and computed tomography (CT).

Methods. MRI (T1-weighted and VIBE) and CT scans of SIJ of 109 patients with axSpA were evaluated by 2 blinded readers based on SIJ quadrants (SQ). Erosions were defined according to Assessment of Spondyloarthritis international Society (ASAS) definitions. Scores were recorded if readers were in agreement.

Results. Erosions were less frequently detected by CT (153 SQ) than by T1-weighted MRI (182 SQ; $p = 0.008$) and VIBE-MRI (199 SQ; $p < 0.001$ vs CT and $p = 0.031$ vs T1-weighted MRI). Taking CT as the gold standard, the sensitivity of VIBE-MRI (71.2%) was higher than that for T1-weighted MRI (63.4%), with similar specificity (87.3% vs 88%, respectively). In linear regression analysis, younger age was significantly associated with occurrence of erosions independently in VIBE-MRI ($\beta = 0.384$, $p < 0.001$) and T1-weighted MRI ($\beta = 0.369$, $p < 0.001$) compared to CT.

Conclusion. The VIBE-MRI sequence was more sensitive than T1-weighted MRI in identifying erosive damage in the SIJ, especially in younger patients. This might be due to the ability of VIBE-MRI to identify structural changes in the cartilage that have not yet extended to the underlying bone, where CT seems to be superior. (J Rheumatol First Release June 1 2019; doi:10.3899/jrheum.181304)

Key Indexing Terms:

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Imaging of the sacroiliac joints (SIJ) is important for diagnosis and classification of axial spondyloarthritis (axSpA)^{1,2,3}. Inflammatory changes of the SIJ are pathognomonic for both early and later stages of axSpA, while in later stages structural changes such as erosions and ankylosis represent the consequences of chronic inflammation. Although magnetic resonance imaging (MRI) is the only imaging technique that can identify both inflammatory and structural changes⁴, other imaging techniques such as

computed tomography (CT) and conventional radiography are still used to detect chronic changes in both the SIJ and the spine of patients with axSpA⁵. While conventional radiography has limited value because it provides only a 2-dimensional view, CT is still considered the gold standard for imaging the complex anatomical structure of the SIJ^{5,6,7,8}.

The volumetric interpolated breath-hold examination (VIBE) MRI technique, called 3D-FLASH sequence with fat saturation, is capable specifically of detecting abnormalities at the cartilage level in a high-resolution image⁹, and also has been found to be useful for early detection of active sacroiliitis when used as a contrast-enhanced MRI with subtraction technique^{10,11}. VIBE-MR imaging has been introduced in musculoskeletal and other diagnostic imaging procedures as a promising substitute for T1-weighted sequences¹².

Considering the need for better visualization of structural changes, particularly erosions¹³, we analyzed the capability of the novel VIBE-MRI and the established T1-weighted MRI sequence for detecting erosions in the SIJ of patients with axSpA in comparison to CT.

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MATERIALS AND METHODS

Patient selection. Patients with clinical diagnosis of axSpA and complete sets of MRI (in T1-weighted sequence, Figure 1a and 2a; and VIBE sequence, Figure 1b and 2b) and CT scans (Figure 1c and 2c) of the SIJ were identified in the clinical database of our tertiary rheumatology institution, independent of disease activity or treatment. Because this was a retrospective analysis of images that were performed in daily routine practice and due to a clinical indication, ethical committee approval was not needed.

Inclusion criteria were a diagnosis of axSpA according to the treating rheumatologist and availability of the complete set of images within a maximum of 7 days from each other.

Imaging protocols and processing of images. All patients were examined with the same imaging equipment and the same protocols of the respective imaging technique, as follows.

CT examinations. Axial and semicoronal views of SIJ for all patients. All CT examinations were performed in the same 16-row scanner (Somatom Sensation, Siemens) with body weight-adapted scan measures (kV, mA): tube voltage 120 kV, tube current 140 kV, automatic tube volate with CARE Cose 4D, collimation 16×0.6 mm, slice thickness 1 mm, spiral pitch 0.65 mm, and picture matrix 512×512 pixels. Images were reconstructed using Syngo Software.

MRI examinations. Semicoronal view of SIJ was taken for all patients. All MRI examinations were performed in the same scanner (Aera 1.5 Tesla, Siemens) with phased-array coils, using the following sequences: T1-weighted turbo spin-echo sequence [repetition time (TR) 510 ms, time to echo (TE) 11 ms, slice thickness 3 mm] and VIBE 3D spoiled turbo gradient echo sequence (TR 25 ms, TE 7 ms, slice thickness 0.89-1 mm) with fat saturation and without addition of contrast agent.

All images were blind-labeled by an independent person and assigned a unique study number. Two readers experienced in evaluating MRI and CT scans of SIJ in musculoskeletal imaging evaluated the images independently from each other after a calibration exercise with randomly selected images (15 of each technique) that were not part of our study. Evaluation of images was performed by evaluation of all CT (both orientations) first and all MRI (semicoronal orientation) thereafter, in a separate session and without having access to the corresponding MRI or CT images.

Structural damage was evaluated using the definitions of erosions provided in the Assessment of Spondyloarthritis international Society (ASAS) handbook, being defined as bone defects at the joint margin, occurring throughout the cartilaginous compartment of the joint, and appearing as single lesions or confluent erosions/pseudodilation¹⁴. Recording of erosions was based on SIJ quadrants (SQ) and only when the reader was convinced that a lesion was present. Any doubtful lesions (for any reason) were not counted as positive.

Statistical analysis. Intraclass correlation coefficient (ICC) was calculated for the readings between readers for CT and MRI separately. Comparisons between imaging techniques were performed by the Wilcoxon test. Linear regression analysis for evaluation of the influence of age on the occurrence of different structural lesions was performed by modeling the differences in the number of lesions in different imaging techniques as dependent variables. Analyses were performed with SPSS v.21 software.

RESULTS

A total of 109 patients with axSpA were included in the analyses, resulting in 872 SQ for each of the imaging

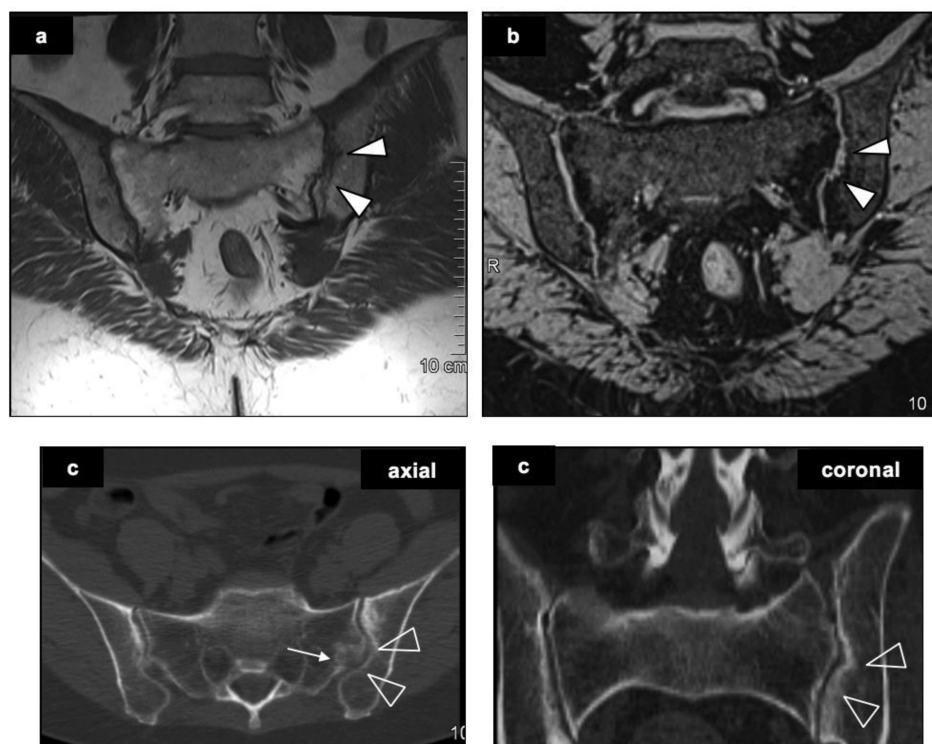


Figure 1. Differences between MRI and CT. SIJ-MRI of a 32-year-old patient with axial spondyloarthritis. A. T1-weighted MRI sequence. B. VIBE sequence. C. CT in axial and semicoronal views. Full arrowheads indicate erosions, seen on both MRI sequences. Empty arrowheads indicate the same areas, but erosions are not visible on CT scan. Arrow indicates area of insertion of ligaments in the sacral bone. VIBE: volumetric interpolated breath-hold examination; MRI: magnetic resonance imaging; CT: computed tomography; SIJ: sacroiliac joints.

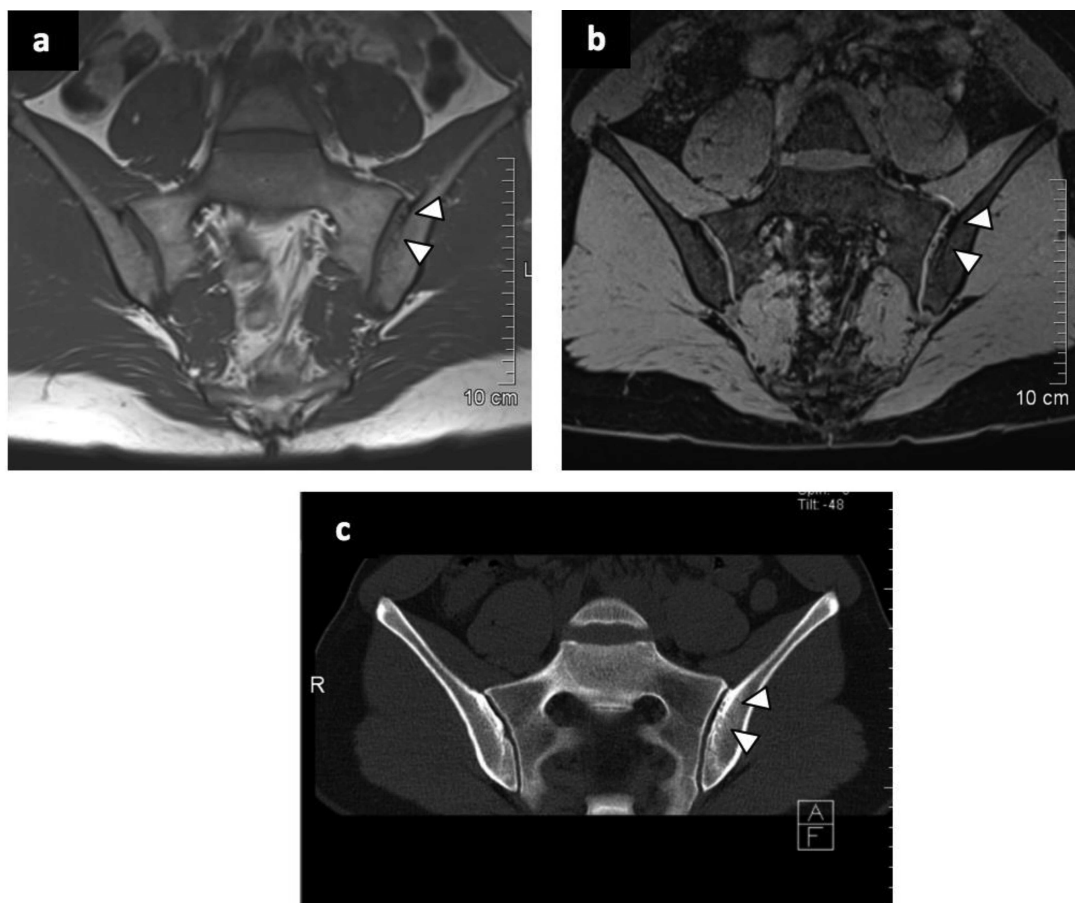


Figure 2. Similarities between MRI and CT. SIJ-MRI of a 45-year-old patient with axial spondyloarthritis. A. T1-weighted MRI sequence. B. VIBE sequence. C. CT in the semicoronal view. Arrowheads indicate erosions, seen on both MRI sequences and the CT scan. VIBE: volumetric interpolated breath-hold examination; MRI: magnetic resonance imaging; CT: computed tomography; SIJ: sacroiliac joints.

methods or sequence. The mean (\pm SD) age was 45.3 ± 13.9 years, 67.9% were male, 82.3% were HLA-B27-positive, the mean time since diagnosis was 4.8 ± 5.8 years (range 1–14 yrs), the mean Bath Ankylosing Spondylitis Disease Activity Index score (BASDAI, scale 0–10) was 4.9 ± 1.8 units, and the mean C-reactive protein concentration was 1.9 ± 2.3 mg/dl. Overall, $n = 872$ SQ were available to be analyzed. Demographic and disease characteristics of patients with complete sets of MRI and CT scans are given in Table 1.

Agreement for positive and negative findings was high ($> 80\%$ of SQ in all subgroups) and agreement between readers for both CT and MRI analyses was excellent (ICC = 0.997 and 0.979, respectively).

Quantitative analysis of detection of erosions in MRI and CT examinations. Overall, significantly more SQ with erosions were detected by VIBE-MRI ($n = 199$) compared to T1-weighted MRI ($n = 182$; $p = 0.031$) and CT ($n = 153$; $p < 0.001$ compared to VIBE-MRI and $p = 0.008$ compared to T1-weighted MRI). The number of SQ with erosions identified by all 3 imaging techniques was 90, while 19 other SQ (21.1% additional SQ) with erosions were identified by

VIBE-MRI and CT, but not with T1-weighted MRI; and another 7 SQ (7.7% additional SQ) with erosions were identified by T1-weighted MRI and CT, but not with VIBE-MRI. The number of SQ with erosions identified by VIBE-MRI but not with CT was 91, while the number of SQ with erosions identified by T1-weighted MRI but not with CT was 85 (Table 2). Overall, the sensitivity of VIBE-MRI and T1-weighted MRI in comparison to CT as the gold standard was 71.2% and 63.4%, respectively, while the specificity was 87.3% and 88.2%.

Linear regression analysis showed that occurrence of more erosions on MRI as compared to CT was significantly associated with a younger patient age ($\beta = 0.384$ for VIBE-MRI and $\beta = 0.369$ for T1-weighted MRI; both $p < 0.001$), while this was not the case in the direct comparison between VIBE-MRI and T1-weighted MRI ($\beta = 0.127$, $p = 0.224$).

DISCUSSION

The established gold standard for detection of erosions in the SIJ is CT scanning. More than 30 years ago, Vogler, *et al*¹⁵ reported on the low prevalence of erosions in SIJ in the

Table 1. Demographic and disease characteristics of the patients with complete sets of magnetic resonance imaging and computed tomography scans for this study.

Characteristic	Value
Mean age, yrs	45.3 ± 13.9
Age < 45 yrs, %	50.5
Male, %	67.9
HLA-B27-positive, %	82.3
Mean time since diagnosis, yrs	4.8 ± 5.8 (range 1-14)
Disease duration < 3 yrs, %	53.2
Mean BASDAI score (0-10)	4.9 ± 1.8
Mean C-reactive protein, mg/dl	1.9 ± 2.3
Total no. sacroiliac joint quadrants	872

BASDAI: Bath Ankylosing Spondylitis Disease Activity Index.

general population. In the last decade there have been many reports on erosive changes in these joints also by use of MRI techniques, especially T1-weighted sequences⁴. In comparison to CT, MRI has the advantage of providing information on inflammatory and chronic changes without using radiation, which makes it generally preferable for identification¹³ and diagnosis of chronic inflammatory diseases such as axSpA — a disease that starts in early adulthood¹⁴.

We took advantage of a relatively novel MRI technique using VIBE sequences, which produce thinner image slices, leading to a high in-plane resolution and detection of tissue abnormalities especially in the cartilaginous area¹². We describe the results of a systematic comparison of VIBE to T1-weighted MRI and CT for detection of structural damage in SIJ of patients with axSpA.

In comparison to CT scanning, we show that the VIBE technique is more sensitive than T1-weighted MRI for detection of structural damage in axSpA. Although erosions

were visualized by CT scans that were not detected by MRI techniques, VIBE detected the highest number of SQ with structural damage and erosions when all techniques were compared directly. This is of special interest in the context of the most recent update of the ASAS MRI working group, which notes that erosions are the structural lesions that are genuinely related to SpA in the context of interpretation of a “positive” MRI¹³ in case of doubtful cases of bone marrow edema. In addition, this might also be of relevance for improvement of the reported fair to moderate agreement when reading MRI scans for erosive changes¹⁶. Interestingly, this possible advantage of MRI and especially of the VIBE-MRI sequence was prominent for younger patients, as shown by linear regression analysis. Consequently, and in contrast to current recommendations that propose conventional radiographs as the first imaging method to diagnose sacroiliitis as part of diagnostic investigation for suspicion of axSpA⁵ and recent reports that T1-weighted MRI may be as sensitive as CT in detecting erosions in axSpA¹⁷, application of VIBE may even be superior for identification of structural damage of axSpA in the early disease stages, with initial involvement restricted to the articular cartilage and before erosions extend to the subchondral bone layers, when it would become detectable as erosion of bone visible by CT.

This is not the first report on the use of VIBE-MRI in detection of erosions in SIJ; recently, a study was published by Diekhoff, *et al*¹⁸ on the same topic. However, that study included patients with low back pain and suspicion of axSpA, in contrast to our patients, who were already diagnosed with somewhat long disease duration. This difference may also explain the differences between the sensitivity and specificity for VIBE and MRI as compared to CT as the gold standard. Nevertheless, knowing that the limits of MRI in recognition

Table 2A. Sensitivity and specificity for volumetric interpolated breath-hold examination (VIBE)-MRI in the detection of erosions, compared to computed tomography (CT).

		Positive	VIBE Negative	Total	
CT	Positive	109	44	153	Sensitivity for VIBE, 71.2% Specificity for VIBE, 87.3%
	Negative	91	628	719	
	Total	200	672		

Table 2B. Sensitivity and specificity for T1-weighted MRI (T1w) in the detection of erosions, compared to computed tomography (CT).

		Positive	T1 Negative	Total	
CT	Positive	97	56	153	Sensitivity for T1w, 63.4% Specificity for T1w, 88.2%
	Negative	85	634	719	
	Total	182	690		

MRI: magnetic resonance imaging.

of axSpA-related cases are related more to its specificity and not its sensitivity, we emphasize that based on the current data, the gain in sensitivity using VIBE-MRI is not at the expense of specificity. Clearly, the diagnostic and prognostic relevance of erosions detected by CT compared to VIBE-MRI and T1-weighted MRI deserves more study, especially to determine the benefits and limitations of a novel technique such as VIBE-MRI. This technique, as a gradient-echo imaging method, may be subject to more artifacts than spin-echo imaging modes such as T1-weighted MRI. These effects include intravoxel dephasing and susceptibility to paramagnetic effects, which may be reasons for the so-called “MRI overcall” in the detection of structural findings that might be (mis)interpreted as destructive changes on the cartilage level. Our data may also point in such a direction, because the marginally higher sensitivity of VIBE compared to T1 scan was at the cost of marginally lower specificity. Our findings may be due to a higher rate of false-positive lesions detected by VIBE, based on the gold standard of CT, and thus be the result of hypersensitivity of this MRI technique. Alternatively, they may represent a better performance of VIBE as compared to CT, and this requires confirmation by future studies that include a control group of subjects without axSpA. Further, correct interpretation of such findings would require a high standard of experience in reading MRI scans, especially for a complex anatomical area like the SIJ. However, for the experienced radiologist, the VIBE-MRI appears to be suitable for use in patients referred for evaluation of axSpA.

Also, from a practical point of view, with its performance time of just 3-5 min in addition to the recommended protocol for performing MRI in patients with suspicion of axSpA¹⁹, which includes the T1-weighted MRI and the short-tau inversion recovery sequence for detection of structural changes and bone marrow edema, respectively, VIBE is a feasible technique for daily routine practice.

MRI examinations with the established T1-weighted sequence and the VIBE sequence were found to be sensitive for identification of articular destructive damage in the MRI of SIJ in patients with axSpA. Overall, VIBE performed better than T1-weighted MRI. Further research is required to evaluate and directly compare all available imaging methods for the SIJ in patients with axSpA and controls.

REFERENCES

1. Rudwaleit M, van der Heijde D, Landewe R, Listing J, Akkoc N, Brandt J, et al. The development of Assessment of Spondyloarthritis International Society classification criteria for axial spondyloarthritis (Part II): Validation and final selection. *Ann Rheum Dis* 2009;68:777-83.
2. van der Linden S, Valkenburg HA, Cats A. Evaluation of diagnostic criteria for ankylosing spondylitis. A proposal for modification of the New York Criteria. *Arthritis Rheum* 1984;27:361-8.
3. van den Berg R, de Hooze M, Rudwaleit M, Sieper J, van Gaalen F, Reijnen M, et al. ASAS modification of the Berlin algorithm for diagnosing axial spondyloarthritis: Results from the Spondyloarthritis Caught Early (SPACE)-cohort and from the Assessment of Spondyloarthritis International Society (ASAS)-cohort. *Ann Rheum Dis* 2013;72:1646-53.
4. Weber U, Pedersen SJ, Ostergaard M, Rufibach K, Lambert R, Maksymowicz W. Can erosions on MRI of the sacroiliac joints be reliably detected in patients with ankylosing spondylitis? — A cross-sectional study. *Arthritis Res Ther* 2012;14:R124.
5. Mandl P, Navarro-Compan V, Terslev L, Aegerter P, van der Heijde D, D'Agostino MA, et al. EULAR recommendations for the use of imaging in the diagnosis and management of spondyloarthritis in clinical practice. *Ann Rheum Dis* 2015;74:1327-39.
6. Lawson TL, Foley WD, Carrera GF, Berland LL. The sacroiliac joints: Anatomic, plain roentgenographic, and computed tomographic analysis. *J Comput Assist Tomogr* 1982;6:307-14.
7. Ryan LM, Carrera GF, Lightfoot RW Jr, Hoffman RG, Kozin F. The radiographic diagnosis of sacroiliitis. A comparison of different views with computed tomograms of the sacroiliac joint. *Arthritis Rheum* 1983;26:760-3.
8. Fam AG, Rubenstein JD, Chin-Sang H, Leung FY. Computed tomography in the diagnosis of early ankylosing spondylitis. *Arthritis Rheum* 1985;28:930-7.
9. Algin O, Gokalp G, Ocakoglu G. Evaluation of bone cortex and cartilage of spondyloarthropathic sacroiliac joint: efficiency of different fat-saturated MRI sequences (T1-weighted, 3D-FLASH, and 3D-DESS). *Acad Radiol* 2010;17:1292-8.
10. Rademacher J, Poddubnyy D. Emerging drugs for the treatment of axial spondyloarthritis. *Expert Opin Emerg Drugs* 2018;23:83-96.
11. Algin O, Gokalp G, Baran B, Ocakoglu G, Yacizi Z. Evaluation of sacroiliitis: Contrast-enhanced MRI with subtraction technique. *Skeletal Radiol* 2009;38:983-8.
12. Zheng ZZ, Shan H, Li X. Fat-suppressed 3D T1-weighted gradient-echo imaging of the cartilage with a volumetric interpolated breath-hold examination. *AJR Am J Roentgenol* 2010;194:W414-9.
13. Lambert RG, Bakker PA, van der Heijde D, Weber U, Rudwaleit M, Hermann KG, et al. Defining active sacroiliitis on MRI for classification of axial spondyloarthritis: Update by the ASAS MRI Working Group. *Ann Rheum Dis* 2016;75:1958-63.
14. 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:ii1-44.
15. Vogler JB 3rd, Brown WH, Helms CA, Genant HK. The normal sacroiliac joint: A CT study of asymptomatic patients. *Radiology* 1984;151:433-7.
16. Jacquemin C, Rubio Vargas R, van den Berg R, Thevenin F, Lenczner G, Reijnen M, et al. What is the reliability of non-trained investigators in recognising structural MRI lesions of sacroiliac joints in patients with recent inflammatory back pain? Results of the DESIR cohort. *RMD Open* 2016;2:e000303.
17. Diekhoff T, Hermann KA, Greese J, Schwenke C, Poddubnyy D, Hamm B, et al. Comparison of MRI with radiography for detecting structural lesions of the sacroiliac joint using CT as standard of reference: Results from the SIMACT study. *Ann Rheum Dis* 2017;76:1502-8.
18. Diekhoff T, Greese J, Sieper J, Poddubnyy D, Hamm B, Hermann KG. Improved detection of erosions in the sacroiliac joints on MRI with volumetric interpolated breath-hold examination (VIBE): Results from the SIMACT study. *Ann Rheum Dis* 2018;77:1585-9.
19. Rudwaleit M, Jurik AG, Hermann KG, Landewe R, van der Heijde D, Baraliakos X, et al. Defining active sacroiliitis on magnetic resonance imaging (MRI) for classification of axial spondyloarthritis: A consensual approach by the ASAS/OMERACT MRI Group. *Ann Rheum Dis* 2009;68:1520-7.