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The value of chemical shift imaging and T1-Dixon MRI in evaluation of structural changes in sacroiliac joint in ankylosing spondylitis

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Abstract

Background: The aim of this study was to assess the diagnostic value of dual gradient-echo T1-weighted sequence (in phase and out of phase) and the related Dixon images in evaluation of structural changes observed in sacroiliac joint in patients diagnosed with ankylosing spondylitis. Forty patients with low back pain were included in the study; they underwent T1-Dixon and routine MRI study on the sacroiliac joint in addition to pelvic CT.

Results: This study was carried out on forty patients, 27 (67.5%) males and 13 (32.5%) females, their mean age was 34.93 ± 11.21 years, and mean duration of symptoms was 8.1 ± 7.4 years. The mean Ankylosing Spondylitis Disease Activity Score ASDAS value was 4.03 ± 0.85 years. The most common structural change was subchondral fat deposition. Dixon MRI was significantly superior to T1WI in simple quantification of the amount of fat with $P=0.036$ and excellent inter-rater reliability (96%), $P=0.0001$. The number of erosions/backfills detected on Dixon was higher than that detected in T1WI with higher accuracy (97.5%) and excellent inter-rater reliability (95%), $P=0.0001$. ASDAS showed significant positive correlation with erosion/backfill ($r=69$, $P=0.0001$) and with maximal fat deposition detected on Dixon ($r=32$, $P=0.044$). There were significant difference between the patients having high ASDAS and others having very high ASDAS scores regarding the sub-articular sclerosis ($P=0.013$).

Conclusion: 3D T1-based Dixon is a helpful imaging technique in proper assessment of different structural changes in sacroiliitis, its integration into routine MR protocol is recommend as it could yield a better depiction of erosive/backfill and fat deposition.

Keywords: Chemical shift imaging, MRI, T1 Dixon, Sacroiliitis, Ankylosing spondylitis, ASDAS

Background

Sacroiliitis (SI) is the classic hallmark for diagnosis of ankylosing spondylitis (AS) and other axial spondyloarthropathy. Magnetic resonance imaging (MRI) is by far the best diagnostic imaging tool for diagnosis of sacroiliitis, its advantage is not only in providing early detection of the articular structural changes, but also in

assessment of disease activity as well. The most widely performed MR protocol should contain fast spin-echo T1-weighted images to assess for structural joint changes as erosions and backfills. However, compared to the CT (which is the standard imaging for demonstrating erosions and backfills), T1WI is proven to have a lower sensitivity. Therefore; adding another pulse sequence as T2* or fat suppressed T1 sequence might be needed to enhance the image contrast at the cartilage/bone interface and increase such sensitivity. Furthermore, adding

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a physiologic aspect to MRI protocol could enhance its ability in detection of early disease, for example, T2 mapping which is an emerging physiologic technique in joint imaging could be helpful in early detection of sacroiliac pathologic joint changes; it has been validated as a potentially helpful tool in identification of patients with spondyloarthritis in early disease stages [1–7].

Aim of the work

The aim of this study was to demonstrate the diagnostic value of dual gradient-echo T1-chemical shift imaging (in phase and out of phase) and related Dixon images in evaluation of structural changes observed in sacroiliac joint in patients diagnosed with ankylosing spondylitis.

Methods

This observational analytic prospective study was conducted from June 2021 through December 2021 after being ethically approved by the institution committee.

Study participants

Forty patients suffered from non-traumatic low back pain were referred from Rheumatology clinic to the MRI unit to be recruited in the study; informed written consent was obtained from each patient prior to participating in the study. All recruited patients were submitted to thorough medical history taking and assessment using Ankylosing Spondylitis Disease Activity Score (ASDAS), values < 1.3 denote inactive disease, ≥ 1.3 and < 2.1 denote moderate activity, ≥ 2.1 and < 3.5 denote high activity, and > 3.5 denote very high disease activity.

Inclusion criteria

The inclusion criteria were low back pain and clinical/laboratory criteria of ankylosing spondylitis.

Exclusion criteria

Recent pelvic trauma, previous sacroiliac operation, claustrophobic patients, and patients who could not undergo MRI are excluded from the study.

CSI and MRI techniques

All MRI studies were performed on a 1.5-T Ingenia; Philips closed MRI using body coil. The following sequences were performed in all patients:

- 1- Coronal FSE T1WI (TR/TE 1366/10), (matrix 280×250), (bandwidth 238.7), (slice thickness/gap 3/2 mm), (acquisition time 1.59 s), (FOV = 250).
- 2- 3D T1-Dixon sequence with four set images in coronal plane (TR/TEs, 6.1/4.2 and 2.1) (matrix 352×308), (bandwidth 634.1). (slice thickness 2 mm), (acquisition time 2.22 s) (FOV = 350).

- 3- Coronal FSE T2-SPAIR (TR/TE 3596/80), (matrix 216×194), (bandwidth 438.4), (slice thickness/gap 4/3 mm), (acquisition time 2.17 s), (FOV = 282), frequency selective fat saturation.

CT technique

All patients were examined by MDCT using GE 16-detector row CT machine, patients were in supine position with head first. Reformatted axial oblique and coronal oblique images were obtained in post-processing image analysis at 3 mm slice thickness by using standard bone window.

Image analysis

Two observers with 14 and 8 years of experience interpreted the images independently. The entire MR sequences and CT series were carefully scrutinized assessing the following variables: Bone marrow edema, erosions and backfill, subchondral sclerosis, subchondral fat deposition, and ankylosis. For bone marrow edema, only subchondral T2 hyperintense areas, at either iliac or sacral sides, were considered for diagnosis of activity according to Assessment of SpondyloArthritis International Society (ASAS) as follow: (when more than one lesion observed in a single slice, or when a lesion is observed in two consecutive cuts with depth of at least 1 mm).

For bony erosions and backfill, erosions were detected as focal bone defects or full thickness loss of on the hypointense articular margin that are expressed on T1WI or T1-Dixon images as hypointense lesions which may coalesce together giving joint space pseudo-dilatation, when erosive lesions attain central hyperintensity on T1-weighted or in phase Dixon images and have low signal sclerotic border, they are considered as backfills. The number of erosions/backfills was assessed on T1 and Dixon images. The subchondral bone sclerosis was observed as low signal band at the subchondral region on all sequences and should be more than 5 mm thickness. The subchondral region was examined for the presences of fat deposition which appears as area of increased signals on T1WI and all Dixon images (notably the fat only images) except the fluid only images which show signal nulling, the maximal depth of involvement was measured on T1WI and all Dixon images. Bone ankylosis was diagnosed when bone marrow signals/bony bridges are observed across the joint on T1WI and all Dixon images with subsequent complete loss of the hypointensity of the iliac and sacral cortices. CT images were analyzed for

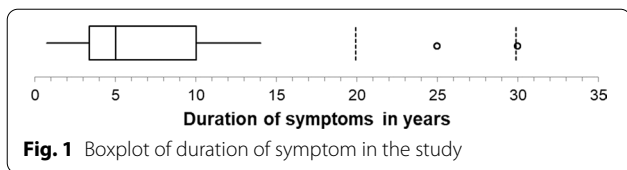


Fig. 1 Boxplot of duration of symptom in the study

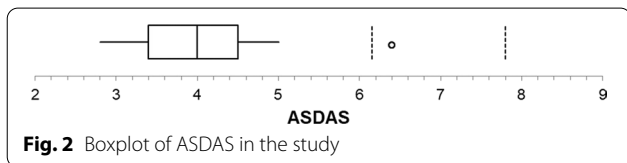


Fig. 2 Boxplot of ASDAS in the study

the presence and number of erosions at both sides of the joint.

Statistical analysis

Results of MRI and CT were recorded, tabulated and statistically analyzed using SPSS 16; data were represented as number and percent or mean ± SD. Comparison between MRI & CT findings was done using CT study as a reference standard imaging in erosions. Correlation between structural changes and ASDAS was done and Spearman correlation coefficient (r) was assessed. Inter-rater agreement was assessed for erosion/backfill and fat deposition on Dixon images.

Results

This study was carried out on forty patients, 27 (67.5%) males and 13 (32.5%) females. The mean age of all patients was 34.93 ± 11.21 years. All patients had chronic symptoms and most of them were diagnosed with ankylosing spondylitis years ago, mean duration of symptoms was 8.1 ± 7.4 years. The ASDAS scoring system in all cases was either high (6 cases) or very high (34 cases), the mean ASDAS value was 4.03 ± 0.85 years (Figs. 1 and 2).

There was a variety of imaging features including both active and structural changes observed in almost all cases in the study, the most commonly observed structural changes was the fat deposition. Features of active disease were not observed on 3D Dixon sequence as it is T1-based. All structural changes observed on conventional T1WI and T2WI were also seen on chemical shift images (IP/OP) and related Dixon images, and Dixon images did not result in the diagnosis of additional cases (Table 1).

Regarding sub-articular fat deposition, Dixon MRI was significantly superior when compared with T1WI in simple quantification of the amount of fat expressed as maximal depth in millimeter. On the same manner Dixon

Table 1 Active and structural imaging features in sacroiliitis

	Number of cases	Percentage	Number of total cases	Percentage
Active changes in MRI				
Edema	19	47.5	21	52.5
Effusion	2	5		
Structural changes in MRI				
Erosions/backfill	16	40		
Fat deposition	34	85	38	95
Subchondral sclerosis	19	47.5		
Bone ankylosis	13	32.5		

Table 2 Comparison between MRI T1 and Dixon in maximum fat depth

Maximal fat depth (mm): mean ± SD	T1 N = 40	Dixon N = 40	P value
	8.18 ± 4.04	10.35 ± 5.02	0.036

Table 3 Sensitivity and specificity for detecting Erosions/Backfills in T1WI & Dixon

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Number in T1	87.5	100	100	92	92.5
Number in Dixon	93.75	100	100	96	97.5

detected erosions/backfill more than that was detected in T1WI with higher overall accuracy = 97.5% (Tables 2 and 3; Figs. 3 and 4).

The structural changes showed variable differences between the patients having high ASDAS scores and those with very high ASDAS scores. The significant difference was noted in the sub-articular sclerosis (Table 4).

Among structural changes detected in the study, ASDAS showed significant reasonable positive correlation with erosion/backfill and with maximal fat deposition detected on Dixon (Table 5).

Inter-rater reliability

The percent agreement was excellent between readers of Dixon images; the inter-reader reliability was

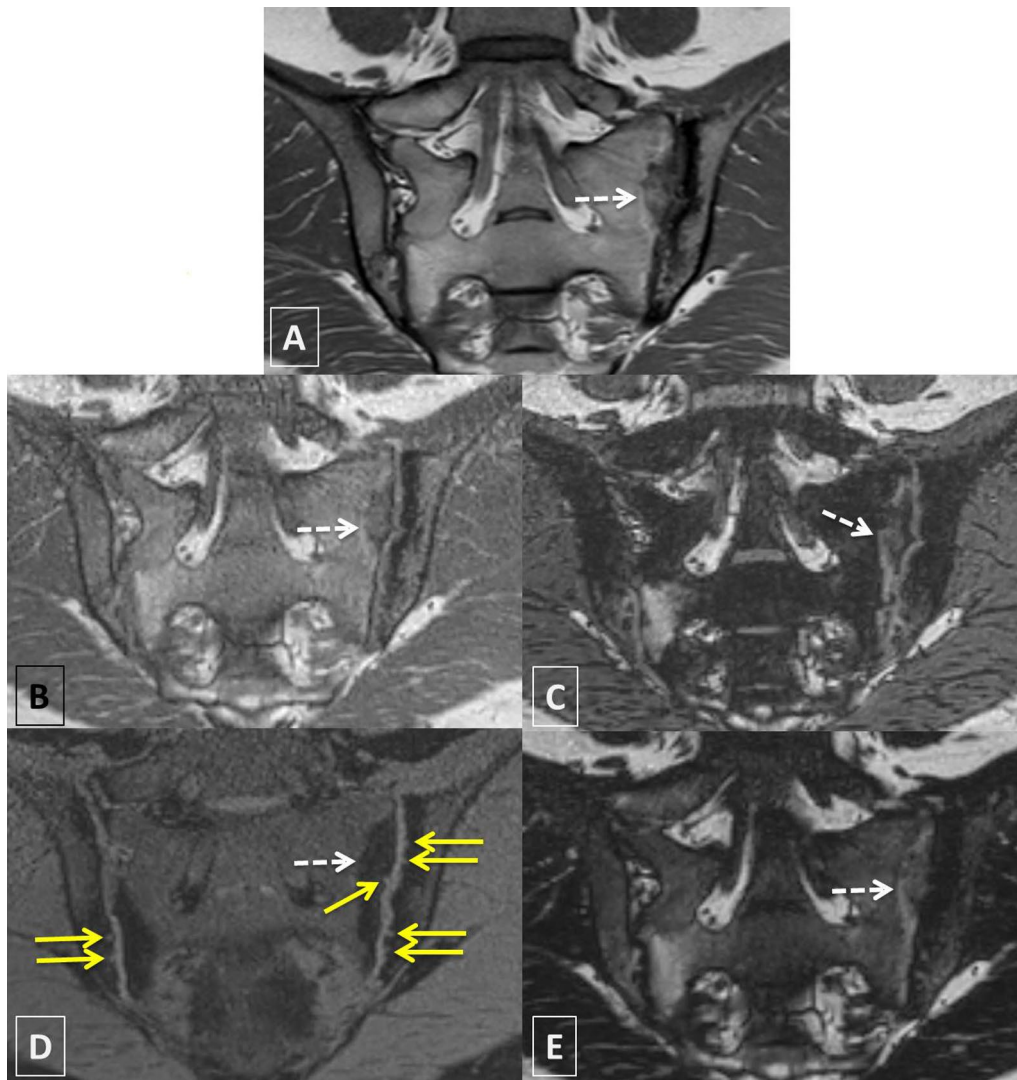


Fig. 3 Twenty eight years male patient with two years history of AS, low back pain and very high ASDAS=6. T1WI, IP & OP images (A–C) show subchondral hypointense sclerosis along with marginal medial hyperintensity (dashed arrow) consistent with superadded fat deposition, the extent of deposited fat is well depicted on fluid only and fat only images (D, E) (dashed arrow). Moreover, the fluid only (D) detect more and more erosive/backfill changes than do other images (yellow arrows)

calculated at 96% and 95% for measurement of maximal depth of fat deposition and for counting the erosions/backfills on Dixon images, respectively (Table 6).

Discussion

Sacroiliitis is the classic hallmark for diagnosis of ankylosing spondylitis, furthermore; sacroiliitis has been found to be frequently linked to other inflammatory arthritis in our community [8].

The imaging tool of choice for diagnosis of sacroiliitis is MRI; the most widely utilized MR protocols should include 2D T1-weighted images (with or without fat

suppression) in order to detect articular surface erosions. Although T1-weighted images have adequately high anatomic details, it could have low sensitivity in demonstrating erosions/backfills when compared with multi-detector CT, this gap could be related to inherited high resolution of CT images, furthermore; the complex anatomy and tiny articular cartilage add more challenges on 2D MR images when delineating the articular surface along its undulating contour. This study tried to close such a gap; it adapted the MRI protocol by adding a sequence that could improve and turn around

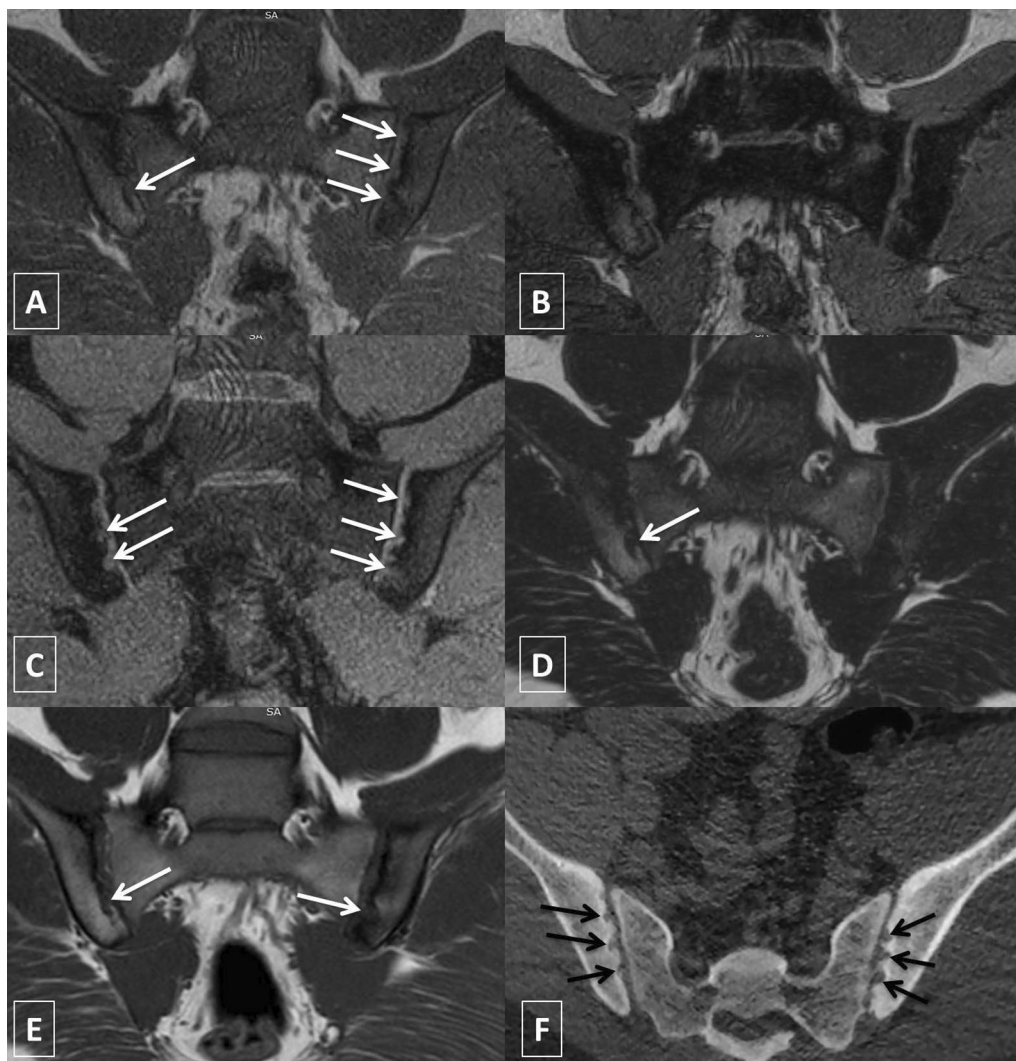


Fig. 4 Eighteen years male patient with four years history of AS and low back pain, ASDAS was very high = 5.8. IP, OP, fluid only & fat only Dixon images (A–D) show multiple bilateral iliac erosions with sclerotic margins (white arrows), some have T1 hyperintensity consistent with backfills, note how T1WI (E) shows fewer lesions when compared with Dixon images and CT (F) (black arrows)

the situation, it is T1-based Dixon sequence and its 3D acquisition [9, 10].

The current study figured out a variety of structural changes which were found in almost all cases, among them the fat deposition was the most common structural changes that are generally observed in chronic stages. All erosions in the study had sclerotic borders and/or T1 hyperintensity within the erosion cavity which is also a feature of chronicity and consistent with back-fill on top. This could be attributed to long duration of symptoms which was observed in all cases of the study (8.1 ± 7.4 years), and all of them were chronic patients diagnosed with ankylosing spondylitis years ago.

Of interest was that the present study came out with the result of superiority of T1-based Dixon sequence upon conventional T1WI in detecting and simply quantitating some aspects of the structural changes of the sacroiliac joints. First, regarding the fat deposition in the subchondral portions of the sacroiliac joints, all Dixon images, notably the fat only set, revealed that maximal depth of fat deposition was significantly different from that obtained from conventional T1WI, (mean was 10.35 ± 5.02 in Dixon, and 8.18 ± 4.04 in T1WI with P value of 0.036). This could be explained partly by intrinsic characteristics of IP/OP images of T1-based Dixon in detecting and differentiating fatty marrow from red marrow, and partly by the additional value of fat only

Table 4 Comparison between high ASDAS and very high ASDAS values

		High ASDAS N=6	Very high ASDAS N=34	P value
Effusion	Present	1 (16.6%)	1 (2.9%)	0.354
	Absent	5 (83.3%)	33 (97%)	
Edema	Present	2 (33.3%)	17 (50%)	0.457
	Absent	4 (66.7%)	17 (50%)	
Sclerosis (N%)				
T1	Present	6 (100%)	19 (55.9%)	0.013
	Absent	0	15 (44.1%)	
Dixon	Present	6 (100%)	19 (55.9%)	0.013
	Absent	0	15 (44.1%)	
CT	Present	6 (100%)	19 (55.9%)	0.013
	Absent	0	15 (44.1%)	
Ankylosis (N%)				
T1	Present	2 (33.3%)	25 (73.5%)	0.056
	Absent	4 (66.7%)	9 (26.5%)	
Dixon	Present	2 (33.3%)	25 (73.5%)	0.056
	Absent	4 (66.7%)	9 (26.5%)	
CT	Present	2 (33.3%)	25 (73.5%)	0.056
	Absent	4 (66.7%)	9 (26.5%)	

Table 5 Correlation between structural changes and ASDAS

	Cases (N=40)	
	r	P value
ASDAS versus erosions/backfill by MRI T1	0.68	0.0001*
ASDAS versus erosions/backfill by MRI Dixon	0.69	0.0001*
ASDAS versus maximal fat depth by T1	0.26	0.101
ASDAS versus maximal fat depth by Dixon	0.32	0.044*
ASDAS versus complaint duration	0.29	0.070
ASDAS versus age	0.01	0.949

* Correlation is significant at the 0.05 level (2-tailed)

r=0–0.2: very low and probably meaningless

r=0.2–0.4: a low correlation that might warrant further investigation

r=0.4–0.6: a reasonable correlation

r=0.6–0.8: a high correlation

r=0.8–1.0: a very high correlation

Table 6 Interobserver reliability

	Agreement (%)	Kappa (95% CI)	P value
Maximal depth of fat deposition	96	0.12–0.97	0.0001
Number of erosions/backfill on Dixon	95	0.89–0.97	0.0001

images in which fat signals are maximally expressed on the images on the expense of other signals. It is worth mentioning that, this is the first study utilized T1-based Dixon MRI in quantification of fat marrow deposition in sacroiliitis, the high sensitivity of T1-Dixon in detecting fat deposition with its maximal depth could be considered an imaging novel point; the accurate quantification of fat metaplasia could help in understanding mechanism of disease progression and the possible relationship of fat metaplasia with other aspect of the disease [11].

Few reports studied different Dixon sequences in sacroiliac joints weighted on T2; Özgen (2017) studied the value of the T2-weighted multipoint Dixon sequence in MRI for diagnosis of both active and chronic changes in sacroiliitis. He found that all subchondral fat deposition seen on T1-weighted images were also seen on in-phase, opposed-phase, and fat only T2-weighted multipoint Dixon. However, the opposed-phase and fat-only T2-weighted multipoint Dixon images were considered superior in detecting fat deposition in comparison with T1WI. Furthermore, Huang et al. (2020) studied sacroiliitis in axial spondyloarthritis qualitatively and quantitatively using T2-weighted Dixon sequence comparing it with the standard protocol (T1W and fat suppressed T2W sequence), they showed that fat only T2-weighted Dixon images were slightly superior to T1W sequence in detecting subchondral fat metaplasia [12, 13].

The second structural change which would express the superiority of T1-Dixon upon conventional T1WI in the current study was the subchondral erosions changes/backfills. Using CT as a standard imaging modality, Dixon imaging was more sensitive in detecting erosive changes/backfills regarding their numbers compared to the conventional T1WI, where the sensitivity in Dixon was 93.75% with overall accuracy of 97.5% compared with sensitivity of 87.5% in conventional T1WI and accuracy of 92.5%. To the authors' knowledge, this study is the first work employed 3D T1-Dixon MRI in quantitative detection of erosive sacroiliac changes. The high sensitivity of T1-Dixon in detecting the number of erosion/backfills is considered a second novel point in sacroiliac MRI; it could be explained partly by the effect of 3D volumetric acquisition in contrast to conventional 2D T1WI and partly by the synergistic performance of all four-set images of Dixon sequence in observing more and more lesions about the joint line. This point might aid any emerging staging system in the future; as increased imaging sensitivity could improve early detection of erosions and disease up or down staging. The image contrast is modified across the image sets depending on if there is concurrent subchondral fat deposition and/or sclerosis in the same region. The increase in image contrast

is aided by the hyperintensity of articular cartilage in fluid only images and the India ink artifact on the out of phase images. Interestingly, Huang et al. (2020) who utilized T2-based Dixon did not find significant difference in diagnostic performance between T2W Dixon sequence and the standard protocol in assessing the structural changes, and this could be due to the absence of the previously postulated synergistic effect of the images sets and the hypointensity of articular cartilage in contrary to T1-based Dixon [12–14].

Regarding imaging feature of active disease, the subchondral edema, they were only observed on fat-saturated T2-weighted images, but not well depicted on Dixon sequence due to insensitivity of T1-based images in detecting edema and fluid signals.

Regarding other structural changes (subchondral sclerosis and bone ankylosis) in the sacroiliac joints, both conventional MRI and T1-based Dixon sequence and the conventional T1WI were equal, and Dixon images did not result in the diagnosis of additional cases. This could be in agreement with what Özgen (2017) found in his study as he observed that both in-phase and fat-only in multipoint Dixon images could successfully show subchondral sclerosis in sacroiliac joints as conventional T1-weighted images and Dixon sequence did not show any additional cases. Likewise, the study conducted by Huang et al. (2020) observed that Dixon images had almost perfect agreement with T1WI in detecting bone ankylosis [12, 13, 15, 16].

The current study showed variable differences between the patients having high ASDAS scores and those with very high ASDAS scores regarding the structural changes. The significant difference was noted in the sub-articular sclerosis. In general, subchondral sclerosis represents a thickening and hardening of the subchondral bone, it is common in areas subjected to increased loading. It could be linked to the presence of joint pain and development of articular stiffness. In addition, the subchondral sclerosis is a feature of disease chronicity which is commonly associated with increasing stiffness and initiation of ankylosis. Depending on these data, the relation of subchondral sclerosis with increasing ASDAS values would be an expected finding. Moreover, such clinical imaging relation might be another interesting point in the study that adds a prognostic aspect to MRI in chronic AS patients [16].

On correlating the clinical data of AS and chronic structural changes of sacroiliitis, the current study inferred a significant reasonable positive correlation between increasing ASDAS and the severity of the erosion/backfill as well as the maximal fat deposition. These correlations would be generally expected,

as whenever structural changes of the joint increase in advanced disease, this in turn would be reflected on the scoring variables such as back pain and movement limitation which would be subsequently worsened.

Conclusions

Chemical shift imaging and related 3D T1-based Dixon is a helpful imaging technique in proper assessment of different structural changes in sacroiliitis. Its integration into the routine MR protocol could yield a better depiction and quantification of erosions/backfills and fat deposition. Further study with a larger number of patients may be recommended with comparative work among different Dixon techniques and with post contrast study to assess both active and structural changes of sacroiliitis.

Abbreviations

AS: Ankylosing spondylitis; ASAS: Assessment of SpondyloArthritis International Society; ASDAS: Ankylosing Spondylitis Disease Activity Score; CSI: Chemical shift imaging; IP: In-phase; OP: Out-of-phase; SI: Sacroiliitis.

Acknowledgments

Not applicable.

Author contributions

MFA carried out the study design, statistical analysis, imaging analysis in addition to editing of publications/presentation. KRGI carried out data collection. AHI carried out all clinical issues, in addition to participation in statistical analysis. SMR carried out imaging analysis in addition to participation in editing of publications/presentation. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Research Ethics Committee of the Faculty of Medicine, Minia University, on 15 June 2021; reference number of approval: N/A. All cases gave written informed consent to participate in the research.

Consent for publication

All patients included in this study gave written informed consent for data publishing contained within this study.

Competing interests

The authors declare that they have no competing interests.

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