

MRI Characterization of Sacroiliac and Spinal Involvement in Spondyloarthritis: Prevalence, Distribution, and Associations with Inter-Rater Reliability.

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ABSTRACT:

Objective: To characterize the prevalence and distribution of sacroiliac (SI) joint and spinal magnetic resonance imaging (MRI) lesions in patients with spondyloarthritis (SpA), and to investigate associations with demographic characteristics, clinical factors (gender, smoking status, disease duration), and assess inter-rater reliability of MRI scoring.

Methods: Fifty-three SpA patients (75.5% male, mean age 34.0 ± 8.0 years) underwent MRI of the SI joints and spine. Lesion prevalence, regional distribution, and imaging severity scores were assessed. Associations with age, gender, smoking status, and disease duration were analyzed using appropriate statistical tests. Inter-rater reliability (IRR) for scoring was evaluated using Intraclass Correlation Coefficients (ICC) and Bland-Altman analysis.

Results: Fatty marrow infiltration was the most prevalent SI joint feature (96.2%), followed by sclerosis (73.6%) and erosions/joint space irregularities (69.8% each). Bone marrow edema (BME) was present in 67.9% of both SI joints and spine. Males demonstrated significantly greater spinal imaging scores than females (3.9 ± 4.1 vs 1.5 ± 2.3 , $p=0.049$). Current smokers exhibited significantly higher spinal scores compared to non-smokers (5.4 ± 4.7 vs 2.5 ± 3.3 , $p=0.028$). Longer disease duration was significantly associated with spinal fatty marrow replacement ($p=0.003$) and subchondral sclerosis ($p=0.049$). SI joint involvement showed no significant laterality or iliac vs. sacral predilection. Age correlated strongly with disease duration ($r=0.607$, $p<0.001$), and SI joint scores correlated moderately with spine scores ($r=0.466$, $p<0.001$). Inter-rater reliability was excellent for overall SI joint (ICC=0.956) and spine (ICC=0.970) scoring.

Conclusion: MRI effectively characterizes a spectrum of inflammatory and structural lesions in the SI joints and spine of SpA patients. Spinal disease severity appears greater in males and

smokers. Specific spinal structural changes are associated with longer disease duration. The MRI scoring methods demonstrate high reliability, supporting their utility in clinical research..

Keywords: Spondyloarthritis, Magnetic Resonance Imaging (MRI), Sacroiliac Joints, Spine, Disease Severity, Gender, Smoking, Disease Duration, Inter-rater Reliability.

Introduction

Spondyloarthritis (SpA) encompasses a group of chronic, immune-mediated inflammatory rheumatic diseases primarily affecting the axial skeleton, including the sacroiliac (SI) joints and the spine, as well as peripheral joints and entheses (1,2). Axial SpA (axSpA), its predominant form, can lead to significant pain, stiffness, functional impairment, and reduced quality of life (3). Early diagnosis and effective management are crucial to mitigate long-term structural damage and improve patient outcomes (4,5).

Magnetic Resonance Imaging (MRI) has revolutionized the diagnostic and monitoring landscape of SpA, particularly in early disease stages before structural changes are evident on conventional radiographs (6). The Assessment of SpondyloArthritis international Society (ASAS) criteria recognize MRI findings of sacroiliitis as a key imaging feature for SpA classification (7,8). MRI can detect active inflammatory lesions, such as bone marrow edema (BME)/osteitis, which are considered hallmarks of active disease, as well as chronic structural changes like fatty marrow infiltration, erosions, sclerosis, and ankylosis (9,10). Understanding the prevalence, distribution, and patterns of these MRI lesions is vital for comprehending disease pathogenesis, assessing disease activity and severity, and predicting radiographic progression (11,12).

While the utility of MRI in SpA is well-established, further characterization of lesion patterns in diverse SpA populations and their associations with specific patient characteristics remains an area of ongoing research. Factors such as gender, smoking habits, and disease duration have been implicated in influencing disease presentation and progression in SpA

(13,14). For instance, gender-specific differences in clinical and imaging manifestations have been reported, though findings are not always consistent across studies (15). Smoking is a known risk factor for increased disease activity and radiographic progression in SpA (16,17). Similarly, longer disease duration is generally expected to correlate with an accumulation of structural damage (18). However, detailed quantitative MRI data linking these factors to specific lesion types and locations in both the SI joints and the spine concurrently can provide more nuanced insights.

Furthermore, the reliability of MRI scoring systems is paramount for their application in clinical trials and longitudinal observational studies (19). Establishing robust inter-rater reliability ensures that observed changes or associations are genuine and not attributable to assessor variability.

Therefore, this study aimed to:

1. Characterize the prevalence and distribution of various MRI features in the sacroiliac joints and spine of a cohort of patients with spondyloarthritis.
2. Investigate the association of these MRI findings with demographic factors (age, gender), smoking status, and disease duration.
3. Assess the inter-rater reliability of the MRI scoring methods employed for both sacroiliac joint and spinal assessments.

Methodology

Study Design and Participants

This cross-sectional observational study enrolled 53 adult participants diagnosed with spondyloarthritis (SpA) according to established clinical criteria according to ASAS criteria. Participants were recruited from *the rheumatology outpatient clinic at Assiut University* between Jan 2022 and Sep 2024. All participants provided written informed consent prior to enrollment, and the study protocol was approved by the local Institutional Review Board.

Clinical Data Collection

Demographic data, including age and gender, were recorded for all participants. Clinical information, including disease duration (defined as time since diagnosis) and current smoking status (categorized as current smoker or non-smoker/former smoker), was obtained through patient interviews and review of medical records.

Magnetic Resonance Imaging (MRI) Acquisition

All participants underwent MRI of the sacroiliac (SI) joints and the whole spine. Imaging was performed using a 1.5 Tesla MRI scanner (Siemens Magnetom Sempra). The imaging protocol included T1-weighted, T2-weighted, and Short Tau Inversion Recovery (STIR) sequences in standardized planes for both the SI joints and the spine, in accordance with the Assessment of SpondyloArthritis international Society (ASAS) MRI guidelines.

MRI Assessment and Scoring

Two independent and experienced radiologists, with 10-15 years of experience in musculoskeletal MRI, blinded to clinical information, evaluated all MRI scans. Discrepancies in scoring were resolved by consensus

- **Sacroiliac Joint Assessment:** SI joints were assessed for the presence or absence of active inflammatory lesions (bone marrow edema/osteitis) and chronic structural lesions, including fatty marrow infiltration, sclerosis, erosions, joint space irregularities, ankylosis, and

bone bridges. For regional distribution analysis, each SI joint was divided into four quadrants (right iliac, right sacral, left sacral, left iliac), and component scores for relevant features were assigned. An overall SI joint imaging severity score (range: 0-11, as per results) was calculated for each patient based on the extent and severity of these findings.

- **Spinal Assessment:** The spine was evaluated for active inflammatory changes (bone marrow edema/osteitis at vertebral corners/edges or facet joints) and structural changes, including facet arthropathy, fatty marrow infiltration, sclerosis, bone bridges (syndesmophytes/ankylosis), kyphosis, and disc changes. An overall spine imaging severity score (range: 0-14, as per results) was determined for each patient. The anatomical location of facet arthropathy (dorsal spine only, lumbar spine only, or both) was recorded.

Inter-Rater Reliability

Inter-rater reliability for the MRI scoring was assessed for all 53 participants. Intraclass Correlation Coefficients (ICC) were calculated for overall SI joint scores, overall spine scores, and regional SI joint component scores. Bland-Altman analysis was performed to assess agreement and systematic bias between raters for overall sacroiliac joint scoring.

Statistical Analysis

Statistical analyses were performed using JASP (Version 0.19.3; JASP Team, 2024). Descriptive statistics were used to summarize participant demographics, clinical characteristics, and the prevalence of MRI features, reported as mean $\pm$ standard deviation (SD) for continuous variables and n (%) for categorical variables. Normality of data distribution was assessed using the Shapiro-Wilk test. For comparisons between two independent groups:

- Independent samples t-tests were used for normally distributed continuous variables.
- Mann-Whitney U tests were used for non-normally distributed continuous variables or ordinal data (e.g., imaging scores by smoking status). Pearson correlation coefficient (r) was used to assess linear relationships between continuous variables (age, disease duration, SI joint score, spine score). Bayesian analysis, specifically calculating Bayes Factor (BF_{10}), was employed to assess evidence for or against systematic laterality (right vs. left SI joints) and regional differences (iliac vs. sacral involvement) in SI joint involvement, with 95% credible intervals reported for mean involvement scores.

- A p -value < 0.05 was considered statistically significant for all frequentist analyses. Reliability levels for ICC were defined as: Excellent (≥ 0.90), Good (0.75-0.89), Moderate (0.50-0.74), and Poor (< 0.50).

Results

Study Population Characteristics

The study enrolled 53 participants with spondyloarthritis, demonstrating a predominantly male population (75.5%, $n=40$) with a mean age of 34.0 ± 8.0 years (range: 20-54 years). The cohort had an average disease duration of 8.0 ± 5.0 years (range: 1-20 years). Current smoking prevalence was 26.4% ($n=14$), consistent with general population rates. Mean imaging severity scores were comparable between anatomical regions, with sacroiliac joint scores averaging 3.0 ± 3.0 (range: 0-11) and spine scores 3.3 ± 3.9 (range: 0-14).

Table 1. Participant Demographics and Clinical Characteristics (N = 53)

Variable	Mean $\pm$ SD	Range	n (%)
Demographics			
Age (years)	34.0 ± 8.0	20-54	-
Disease Duration (years)	8.0 ± 5.0	1-20	-
Male Gender	-	-	40 (75.5)
Current Smoker	-	-	14 (26.4)
Imaging Scores			
Sacroiliac Joint Score	3.0 ± 3.0	0-11	-
Spine Score	3.3 ± 3.9	0-14	-

MRI Feature Prevalence

Sacroiliac Joint Involvement

Fatty marrow infiltration emerged as the most prevalent sacroiliac joint abnormality, present in 96.2% of participants ($n=51$). Chronic structural changes were common, with sclerosis affecting 73.6% ($n=39$) and both erosions and joint space irregularities each present in 69.8% ($n=37$) of cases. Active inflammation, manifested as bone marrow edema, was identified in 67.9% ($n=36$) of participants. Advanced structural

changes showed lower prevalence, with ankylosis present in 28.3% (n=15), bone bridges in 7.5% (n=4), and backfill in only 1.9% (n=1) of cases.

Table 2. Prevalence of Sacroiliac Joint Imaging Features (N = 53)

Feature	Present n (%)	Absent n (%)
Edema	36 (67.9)	17 (32.1)
Sclerosis	39 (73.6)	14 (26.4)
Fatty Marrow Infiltration	51 (96.2)	2 (3.8)
Erosions	37 (69.8)	16 (30.2)
Joint Space Irregularities	37 (69.8)	16 (30.2)
Ankylosis	15 (28.3)	38 (71.7)
Bone Bridges	4 (7.5)	49 (92.5)

Spinal Involvement

Spinal inflammatory changes paralleled sacroiliac findings, with bone marrow edema present in 67.9% (n=36) of participants. Facet arthropathy affected nearly half the cohort (45.3%, n=24), while fatty marrow infiltration was less prevalent

in the spine compared to sacroiliac joints (41.5%, n=22). Advanced structural changes were uncommon, with sclerosis present in 13.2% (n=7), bone bridges in 9.4% (n=5), kyphosis in 7.7% (n=4), and disc changes in 7.5% (n=4) of participants.

Table 3. Prevalence of Spinal Imaging Features (N = 53)

Feature	Present n (%)	Absent n (%)
Edema	36 (67.9)	17 (32.1)
Facet Arthropathy	24 (45.3)	29 (54.7)
Fatty Marrow Infiltration	22 (41.5)	31 (58.5)
Sclerosis	7 (13.2)	46 (86.8)
Bone Bridges	5 (9.4)	48 (90.6)
Disc Changes	4 (7.5)	49 (92.5)
Kyphosis	4 (7.5)	49 (92.5)

Regional Distribution Patterns

Analysis of sacroiliac joint regional involvement revealed relatively balanced distribution across anatomical quadrants. Mean component scores ranged from 0.68 ± 0.92 (right iliac) to $0.81 \pm$

1.04 (left sacral), with all regions showing similar severity ranges (0-3). Facet arthropathy demonstrated clear anatomical predilection, occurring predominantly in the dorsal spine (41.5%, n=22) while isolated lumbar involvement

and combined dorsal-lumbar patterns were rare (1.9% each, n=1).

Table 4. Regional Sacroiliac Joint Component Scores (N = 53)

Region	Mean $\pm$ SD	Range
Right Iliac	0.68 $\pm$ 0.92	0-3
Right Sacral	0.77 $\pm$ 0.91	0-3
Left Sacral	0.81 $\pm$ 1.04	0-3
Left Iliac	0.74 $\pm$ 0.88	0-3

Table 5. Facet Arthropathy Location Distribution (N = 53)

Location	n (%)
No Facet Arthropathy	29 (54.7)
Dorsal Spine Only	22 (41.5)
Lumbar Spine Only	1 (1.9)
Both Dorsal and Lumbar	1 (1.9)

Gender-Based Differences

Males demonstrated significantly greater spinal involvement compared to females, with mean spine scores of 3.9 ± 4.1 versus 1.5 ± 2.3 ($p =$

0.049). Sacroiliac joint involvement showed a similar directional trend but failed to reach statistical significance, with males scoring 3.2 ± 3.2 compared to females at 2.4 ± 2.4 ($p = 0.399$).

Table 6. Imaging Scores by Gender

Variable	Male (n=40)	Female (n=13)	p-value
	Mean $\pm$ SD	Mean $\pm$ SD	
Sacroiliac Joint Score	3.2 ± 3.2	2.4 ± 2.4	0.399
Spine Score	3.9 ± 4.1	1.5 ± 2.3	0.049*

*Statistically significant at $p < 0.05$

Smoking-Associated Disease Severity

Smoking status demonstrated a significant association with spinal disease severity. Current smokers exhibited markedly higher spine scores (5.4 ± 4.7) compared to non-smokers (2.5 ± 3.3), with Mann-Whitney U analysis confirming statistical significance ($U = 166.0$, $p = 0.028$). The

mean rank comparison (34.6 vs 24.3) indicated consistently more severe spinal involvement among smokers. While sacroiliac joint scores were numerically higher in smokers (4.2 ± 3.8 vs 2.6 ± 2.5 , mean ranks 31.8 vs 25.3), this difference did not achieve statistical significance ($U = 205.5$, $p = 0.168$). Non-parametric testing

was appropriately employed given significant deviations from normality for both variables (Shapiro-Wilk $p < 0.001$)

Table 7. Imaging Scores by Smoking Status

Variable	Non-smokers (n=39)	Smokers (n=14)	p-value
	Mean $\pm$ SD (Mean Rank)	Mean $\pm$ SD (Mean Rank)	
Sacroiliac Joint Score	2.6 $\pm$ 2.5 (25.3)	4.2 $\pm$ 3.8 (31.8)	0.168
Spine Score	2.5 $\pm$ 3.3 (24.3)	5.4 $\pm$ 4.7 (34.6)	0.028*

*Statistically significant at $p < 0.05$

Note: Mann-Whitney U test used due to non-normal distribution (Shapiro-Wilk $p < 0.001$ for both variables)

Disease Duration and Structural Change Associations

Sacroiliac Joint Temporal Patterns

Independent samples t-tests revealed no statistically significant associations between disease duration and any evaluated sacroiliac joint

structural changes (all $p > 0.05$). However, patients with ankylosis demonstrated a clinically meaningful trend toward longer disease duration compared to those without ankylosis (10.00 ± 3.36 vs 7.21 ± 5.30 years; $p = 0.065$), approaching statistical significance and suggesting ankylosis as a late-stage manifestation.

Table 8. Comparison of Disease Duration Between Patients With and Without Sacroiliac Joint MRI Structural Changes

MRI Finding	Absent		Present		p-value
	n	Mean $\pm$ SD (years)	n	Mean $\pm$ SD (years)	
Bone marrow edema	17	8.53 $\pm$ 5.08	36	7.75 $\pm$ 4.97	0.599
Fatty marrow replacement	2	2.50 $\pm$ 0.71	51	8.22 $\pm$ 4.94	0.111
Subchondral sclerosis	14	8.86 $\pm$ 5.39	39	7.69 $\pm$ 4.84	0.457
Erosions	16	9.06 $\pm$ 5.52	37	7.54 $\pm$ 4.71	0.310
Ankylosis	38	7.21 $\pm$ 5.30	15	10.00 $\pm$ 3.36	0.065

Spinal Temporal Progression

Two spinal structural changes demonstrated statistically significant associations with disease chronicity. Patients with fatty marrow replacement exhibited significantly longer disease duration compared to those without this finding (10.32 ± 5.38 vs 6.36 ± 3.97 years; $p = 0.003$).

Similarly, subchondral sclerosis was associated with prolonged disease exposure (11.43 ± 5.19 vs 7.48 ± 4.77 years; $p = 0.049$). These findings support the concept that fatty marrow replacement and sclerosis represent chronic reparative changes accumulating with disease progression.

Table 9. Comparison of Disease Duration Between Patients With and Without Spinal MRI Structural Changes

MRI Finding	Absent		Present		p-value
	n	Mean $\pm$ SD (years)	n	Mean $\pm$ SD (years)	
Bone marrow edema	17	8.06 $\pm$ 5.45	36	7.97 $\pm$ 4.80	0.953
Fatty marrow replacement	31	6.36 $\pm$ 3.97	22	10.32 $\pm$ 5.38	0.003*
Kyphotic deformity	48	8.00 $\pm$ 5.06	4	9.50 $\pm$ 3.32	0.565
Subchondral sclerosis	46	7.48 $\pm$ 4.77	7	11.43 $\pm$ 5.19	0.049*
Facet joint arthropathy	29	7.69 $\pm$ 5.43	24	8.38 $\pm$ 4.43	0.622

*Statistically significant at $p < 0.05$

Active inflammatory changes (bone marrow edema) showed no temporal association in either anatomical location, consistent with their episodic nature. Erosions and facet joint arthropathy similarly demonstrated no significant correlation with disease duration, suggesting these changes may occur independently of disease chronicity.

Anatomical Distribution and Laterality

Bayesian analysis assessed potential laterality and regional differences in sacroiliac joint involvement. Right versus left sacroiliac comparison yielded a Bayes Factor (BF_{10}) of 0.167, providing moderate evidence favoring no systematic laterality difference. Mean involvement scores were 1.45 ± 1.65 (95%

credible interval: 1.00-1.91) for right sacroiliac joints and 1.55 ± 1.68 (95% credible interval: 1.08-2.01) for left joints, with overlapping intervals supporting bilateral symmetry.

Comparison of bilateral iliac versus bilateral sacral involvement produced a BF_{10} of 0.214, indicating weak evidence supporting equivalent regional involvement. Mean iliac involvement was 1.42 ± 1.57 (95% credible interval: 0.98-1.85), while sacral involvement averaged 1.59 ± 1.75 (95% credible interval: 1.10-2.07). High standard deviations relative to means indicated substantial inter-individual variability, suggesting patient-specific factors may be more clinically relevant than anatomical predilection in determining disease patterns.

Table 10. Comparison of Sacroiliac Joint Involvement by Anatomical Side and Region

Comparison	Side/Region	Mean $\pm$ SD	95% Credible Interval	BF_{10}	Evidence for H_0
Right SI vs Left SI	Right SI	1.45 ± 1.65	[1.00, 1.91]	0.167	Moderate for H_0
	Left SI	1.55 ± 1.68	[1.08, 2.01]		
Iliac vs Sacral (bilateral)	Iliac sides	1.42 ± 1.57	[0.98, 1.85]	0.214	Weak for H_0
	Sacral sides	1.59 ± 1.75	[1.10, 2.07]		

BF_{10} values < 1 indicate evidence in favor of H_0 (no difference).

Credible intervals are Bayesian analogs of

confidence intervals.

H_0 = Null hypothesis (asserting no difference between the paired measures). BF_{10} , Error (%),

and Evidence for H_0 apply to the comparison of the paired variables listed above them.

Inter-variable Correlations

Pearson correlation analysis revealed two significant associations within the study population. A strong positive correlation existed between patient age and disease duration ($r = 0.607$, $p < 0.001$), consistent with the progressive nature of spondyloarthropathies. Additionally, a moderate positive correlation was observed between spinal and sacroiliac joint involvement (r

$= 0.466$, $p < 0.001$), suggesting concurrent disease progression in both anatomical regions rather than isolated involvement patterns.

Notably, neither age nor disease duration correlated significantly with final disease severity scores in either anatomical location, indicating that disease severity transcends simple temporal relationships and likely depends on individual progression patterns and factors beyond chronological variables.

Table 11. Pearson Correlation Matrix

Variable	Age	Duration	Spine Score	SI Score
Age	—	0.607***	0.058	-0.080
Duration	—	—	0.193	-0.145
Spine-Final	—	—	—	0.466***
SI-Final	—	—	—	—

*** $p < 0.001$

Inter-rater Reliability

Assessment of scoring consistency between two independent raters across 53 subjects demonstrated excellent reliability for overall anatomical assessments. Sacroiliac joint scoring achieved an intraclass correlation coefficient (ICC) of 0.956 (95% CI: 0.925-0.974), while spinal scoring demonstrated even higher reliability with an ICC of 0.970 (95% CI: 0.949-0.983).

Regional sacroiliac component analysis revealed good to excellent reliability across anatomical areas. The left sacral region demonstrated the highest regional reliability (ICC = 0.875), while the right sacral region showed the lowest, though still acceptable, reliability (ICC = 0.765) among sacroiliac components. All other regional components achieved ICCs between 0.838-0.851, indicating consistently high inter-rater agreement.

Table 12. Inter-rater Reliability Analysis Using Intraclass Correlation Coefficients

Anatomical Region	ICC(1,1)	95% Confidence Interval	Reliability Level*
Overall Scoring			
Sacroiliac joints	0.956	0.925 - 0.974	Excellent
Spine	0.970	0.949 - 0.983	Excellent
Regional Sacroiliac Components			
Right iliac	0.838	0.736 - 0.903	Good to Excellent

Anatomical Region	ICC(1,1)	95% Confidence Interval	Reliability Level*
Left iliac	0.851	0.756 - 0.911	Good to Excellent
Right sacral	0.765	0.626 - 0.857	Moderate to Good
Left sacral	0.875	0.794 - 0.926	Good to Excellent

*Reliability levels: Excellent (≥ 0.90), Good (0.75-0.89), Moderate (0.50-0.74), Poor (< 0.50)

Note: All analyses based on 53 subjects and 2 raters. ICC type as referenced by Shrout & Fleiss (1979).

Bland-Altman analysis confirmed minimal systematic bias between raters, with a small mean difference of 0.151 and narrow confidence intervals (-0.093 to 0.395). The limits of agreement (-1.585 to 1.887) encompass the range within which 95% of inter-rater differences are expected, confirming acceptable agreement for clinical research applications.

Table 13. Bland-Altman Analysis for Sacroiliac Joint Scoring Agreement

Parameter	Point Estimate	95% Confidence Interval
Mean difference	0.151	-0.093 to 0.395
Upper limit of agreement (+1.96 SD)	1.887	1.464 to 2.310
Lower limit of agreement (-1.96 SD)	-1.585	-2.008 to -1.162

Discussion

This study provides a comprehensive MRI-based characterization of sacroiliac (SI) joint and spinal involvement in a cohort of 53 patients with spondyloarthritis (SpA). We identified distinct patterns of lesion prevalence and distribution, and notably, found significant associations between spinal imaging severity and both male gender and current smoking status, as well as links between specific structural changes and longer disease duration. The MRI scoring methods employed demonstrated excellent inter-rater reliability, reinforcing the validity of these observations.

The prevalence of MRI lesions in our cohort aligns broadly with previous reports, though variations are expected due to differences in patient populations, disease duration, and imaging protocols (20,21). The extremely high prevalence of fatty marrow infiltration (FMI) in the SI joints (96.2%) is a prominent finding. FMI is considered a chronic structural lesion, often indicative of previous inflammation and repair

(22,23). Its near-ubiquitous presence here, even in patients with varying disease durations, suggests it is a very common, perhaps early and persistent, consequence of sacroiliitis.

Active inflammation, evidenced by bone marrow edema (BME), is a key pathological feature in both sacroiliac (SI) joints and the spine in Spondyloarthritis (SpA). Active inflammation, characterized by bone marrow edema (BME), is a key indicator of ongoing disease activity in Spondyloarthritis (SpA), affecting both sacroiliac (SI) joints and the spine. Supporting this, Bruckmann et al. found that at baseline, osteoblastic activity was present in 96.0% of SI joint quadrants with bone marrow edema and in 33.7% of vertebral corners with bone marrow edema (24). These findings highlight that BME lesions are sites of active pathological processes, consistent with the inflammatory nature of SpA. Chronic structural changes like sclerosis and erosions in the SI joints were also frequently observed (around 70%), reflecting established disease.

A key finding was the significantly greater spinal imaging severity in males compared to females. This observation resonates with some, though not all, previous studies that have suggested males may experience more severe radiographic progression and structural damage in the spine in axSpA (25,26). The underlying reasons for such gender-based differences are likely multifactorial, potentially involving hormonal influences, genetic predispositions, or differences in inflammatory responses (27). While SI joint scores showed a similar trend, the difference did not reach statistical significance, possibly due to the smaller number of female participants or a genuinely less pronounced gender difference in SI joint structural damage in this specific cohort.

The association between current smoking and increased spinal disease severity is another important observation, consistent with a growing body of evidence implicating smoking as a significant risk factor for worse disease outcomes in SpA (28,29). Smokers in our study had markedly higher spine scores. Tobacco smoke contains numerous pro-inflammatory compounds and has been linked to increased systemic inflammation, accelerated structural damage, and poorer treatment response in SpA (30,31). This finding underscores the importance of smoking cessation counseling as part of comprehensive SpA management. Again, the lack of a statistically significant association with SI joint scores in smokers, despite a numerical trend, warrants further investigation in larger cohorts.

Our analysis of disease duration revealed distinct temporal patterns for specific MRI lesions. In the spine, both fatty marrow replacement and subchondral sclerosis were significantly associated with longer disease duration, supporting their role as markers of chronicity and cumulative structural change over time (32). In the SI joints, a trend towards longer disease duration was observed in patients with ankylosis ($p=0.065$), suggesting it represents a late-stage manifestation, as widely accepted (33). Conversely, active inflammatory changes (BME)

showed no association with disease duration in either anatomical location. This is consistent with the understanding that BME reflects episodic inflammatory activity that can occur at any point in the disease course, rather than being a linear function of disease chronicity (34). Similarly, erosions and facet joint arthropathy did not correlate with disease duration, implying that these changes might develop based on factors other than just the length of time since diagnosis, possibly related to specific inflammatory pathways or biomechanical stresses.

The regional distribution analyses provided further insights. Sacroiliac joint involvement appeared relatively balanced across anatomical quadrants, and Bayesian analysis provided moderate evidence against systematic laterality (right vs. left). This symmetrical tendency is often described in sacroiliitis associated with SpA (35). In contrast, facet arthropathy showed a clear predilection for the dorsal spine, a pattern that has been noted in some studies and may relate to biomechanical loading or specific inflammatory tropism (36). The moderate positive correlation between overall spinal and SI joint imaging scores ($r=0.466$) suggests a tendency for concurrent disease progression in both anatomical regions, rather than predominantly isolated patterns, which is clinically intuitive for a systemic disease like SpA.

The strong correlation between patient age and disease duration is an expected finding in chronic diseases. However, it is noteworthy that neither age nor disease duration directly correlated with the final overall disease severity scores in either the SI joints or spine in our cohort. This suggests that while certain structural changes accumulate over time, overall MRI-defined disease severity is likely influenced by a more complex interplay of factors, potentially including genetic predisposition, intensity of the inflammatory response, treatment effects (not assessed here), and lifestyle factors like smoking.

A significant strength of this study is the robust inter-rater reliability achieved for both overall and regional MRI scoring, with ICC values

indicating excellent agreement. This high reliability lends confidence to our findings and supports the utility of these scoring approaches in research settings. The Bland-Altman analysis further confirmed minimal systematic bias between raters.

This study has several limitations. Its cross-sectional design precludes definitive conclusions about causality or the temporal sequence of lesion development; longitudinal studies are needed to confirm these progression patterns. The sample size (N=53) is moderate, which may have limited statistical power for some subgroup analyses, potentially explaining why some trends (e.g., SI joint scores in smokers or by gender, ankylosis with disease duration) did not reach statistical significance. We did not collect data on specific treatments, disease activity indices (e.g., BASDAI, ASDAS), or HLA-B27 status, which could have provided additional context to the imaging findings. Furthermore, smoking status was dichotomized, and a more granular assessment (e.g., pack-years) might reveal dose-dependent effects.

In conclusion, our findings demonstrate that MRI effectively delineates a spectrum of active inflammatory and chronic structural lesions in the SI joints and spine of SpA patients. Spinal disease, as assessed by MRI, appears more severe in males and current smokers. Specific structural changes, particularly fatty marrow replacement and sclerosis in the spine, are associated with longer disease duration, highlighting them as markers of chronicity. The lack of direct correlation between overall severity scores and disease duration suggests that disease progression is not merely a function of time but is influenced by other patient-specific and environmental factors. These findings contribute to a better understanding of SpA pathogenesis and highlight potentially modifiable risk factors like smoking. Future longitudinal studies with larger, more diverse cohorts, incorporating clinical and biological data, are warranted to further elucidate the complex interplay of factors driving MRI-detectable disease progression in SpA.

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