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Clinical Relevance of Axial Radiographic Damage in Axial Spondyloarthritis: Evaluation of Functional Consequences by an Objective Electronic Device

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ABSTRACT. ***Objective.*** Axial spondyloarthritis (axSpA) is associated with decreased function and mobility of patients as a result of inflammation and radiographic damage. The Epionics SPINE device (ES), an electronic device that objectively measures spinal mobility, including range of motion (RoM) and speed (ie, range of kinematics [RoK]) of movement, has been clinically validated in axSpA. We investigated the performance of the ES relative to radiographic damage in the axial skeleton of patients with axSpA.

Methods. A total of 103 patients with axSpA, 31 with nonradiographic axSpA (nr-axSpA) and 72 with radiographic axSpA (r-axSpA), were consecutively examined. Conventional radiographs of the spine (including presence, number, and location of syndesmophytes) and the sacroiliac joints (SIJs; rated by the modified New York criteria) were analyzed with the ES. Function and mobility were assessed using analyses of covariance and Spearman correlation.

Results. The number of syndesmophytes correlated positively with Bath Ankylosing Spondylitis Metrology Index scores (r 0.38, $P = 0.02$) and correlated negatively with chest expansion (r −0.39, $P = 0.02$) and ES measurements ($-0.53 \le r \le -0.34$, all $P < 0.03$), except for RoM and RoK regarding rotation and RoK for extension of the lumbar and thoracic spines. In the radiographic evaluation of the SIJs, the extent of damage correlated negatively with ES scores and metric measurements ($-0.49 \le r \le -0.33$, all $P < 0.001$). Patients with r-axSpA, as compared to those with nr-axSpA, showed significantly worse ES scores for RoM, RoK, and chest expansion.

Conclusion. The ES scores, in accordance with mobility measurements, correlated well with the presence and extent of radiographic damage in the spine and the SIJs. As expected, patients with r-axSpA had more severe impairments than those with nr-axSpA.

Key Indexing Terms: axial spondyloarthritis, BASMI, Epionics SPINE, radiographic changes, spinal measurements, spinal mobility

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Axial spondyloarthritis (axSpA) is a chronic rheumatic disease that includes ankylosing spondylitis (AS). AxSpA is characterized by inflammatory back pain, as well as several other articular and extramusculoskeletal disease manifestations and substantial comorbidity.[1] Based on the 2009 Assessment of SpondyloArthritis international Society (ASAS) classification criteria, radiographic axSpA (r-axSpA) and nonradiographic axSpA (nr-axSpA) are differentiated according to the presence or absence, respectively, of definite radiographic damage in the sacroiliac joints (SIJs), according to the 1984 modified New York (mNY) criteria for the purpose of classifying AS.[2,3] Axial inflammation, as assessed by magnetic resonance imaging, and radiographic damage, as assessed by conventional radiography,[4] both influence function, mobility, and pain in patients with axSpA.[5] In early disease, spinal mobility is more strongly influenced by inflammation, whereas in later stages of disease, radiographic damage is more important.[5-8] Radiographic damage in the spine includes various changes, such as erosions, sclerosis, squaring of the vertebral bodies,

joint space narrowing, and, most typically, syndesmophytes and ankylosis.[9,10]

Axial mobility and function are usually assessed by the Bath Ankylosing Spondylitis Functional Index (BASFI)[11] and the Bath Ankylosing Spondylitis Metrology Index (BASMI).[12] The correlation between radiographic damage and the BASMI seems to be stronger than with the BASFI.[13] Whereas the BASFI is a patient-reported outcome (PRO), subjectively reflecting a patient's perception, which can be influenced by different variables, BASMI scores are based on a physical examination and considered more objective.[10,14-16] In clinical trials, the BASMI is the most frequently used mobility measure in axSpA that quantifies anterior and lateral spinal flexion, cervical rotation, tragus-to-wall distance, and intermalleolar distance. However, as the BASMI does not assess thoracic mobility,[17] it has been recommended that chest expansion be used in addition to assess spinal mobility more completely.[18,19] Nevertheless, BASMI scores have limited reliability and sensitivity to change on an individual patient level but are more informative on the group level.[20-22]

The Epionics SPINE device (ES) is an electronic device evaluated to assess spinal mobility in patients with mechanical back pain[23-25] and axSpA.[26,27] The device provides objective information on spinal range of motion (RoM) and speed of motion assessed as range of kinematics (RoK) in all planes. As recently shown, ES scores correlate with BASMI results and add useful information about rotation and RoK.[27] In addition, ES scores have been shown to convincingly differentiate between patients with axSpA and healthy controls as well as between patients with r-axSpA and those with nr-axSpA.[27] Further, in patients with r-axSpA vs those with nr-axSpA, not only was mobility more limited but tasks were performed more slowly.[27] In the present study, performance of the ES was studied in relation to radiographic changes in the axial skeleton of patients with axSpA.

METHODS

The SPINEtronic study was designed as a national, noninterventional, cross-sectional, observational, multicenter trial in which consecutive patients who were ≥ 18 years and diagnosed with axSpA by a rheumatologist were prospectively included. For the present analysis, patients were only included if conventional radiographs of the SIJs were present. A detailed description of variables has already been described.[27] Ethics approval was obtained from the Independent Ethics Committee of the Medical Association of Westphalia-Lippe and the University of Münster (reference number: 2014-277-f-S; study code: 10234). Written informed consent was obtained from all patients. In regard to the clinical trial registration, the presented study is a noninterventional, observational clinical study with a licensed medical device as defined by the International Committee of Medical Journal Editors criteria.

Mobility assessments. All patients underwent electronic measurements of their spinal mobility with the ES. The ES is a noninvasive, electronic, class IIa–certified movement analysis system that consists of a sensor strip, memory unit, and docking station. The sensors were placed bilaterally along the spine. The standardized paravertebral position of the sensors allows it to record movements and rotations outside of the sagittal plane.[27] Patients had to perform predefined exercises of flexion, extension, lateral flexion, and rotation to assess and record their spinal mobility.

The ES sensors are capable of assessing RoM, which is measured and calculated in angular degrees, and RoK, which is the maximum speed when performing exercises as measured in angular degrees/second. In addition, the BASMI,[28] the BASFI, and the Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) were assessed.[19]

Imaging assessment. Conventional radiographs of the SIJs were scored according to the grading system used in the mNY criteria (grades 0-4).[29] In addition, the sacroiliitis sum score for both SIJs was calculated as the sum of grades for the left and right SIJs for each patient (sum score ranged from 0 to 8). Radiographs in the lateral view of the cervical, thoracic, and lumbar spine were taken from routine care and were evaluated to count the total number and the location of syndesmophytes. In a subset of patients included in the Rheumazentrum Ruhrgebiet, lateral radiographs of the anterior vertebral edges of the cervical and lumbar spine were scored according the modified Stoke Ankylosing Spondylitis Spine Score (mSASSS; total range 0-72).[4]

Statistical analysis. The scores of spinal measurements (ie, ES and BASMI) and the presence and quantification of radiographic damage of the SIJs and spine were directly compared using the *t* test. The correlation between ES scores and radiographic damage was calculated with the Spearman correlation coefficient.

For the analyses of demographics and ES variables to differentiate between the groups, *t* tests were used; analysis of covariance was performed for adjustments for sex, age, and BMI. The Fisher exact test was used for categorical data. All explorative statistical analyses were performed using SAS 9.4 software (SAS Institute Inc.) and were intentionally calculated to a full significance level of 5%; that is, they were not corrected with respect to multiple testing, and each P value ≤ 0.05 was considered significant.

RESULTS

Demographics. A total of 103 patients, 72 (69.9%) with r-axSpA and 31 (30.1%) with nr-axSpA, were included. Of the 103 patients, 74 (71.8%) were male and 37 (35.9%) had increased C-reactive protein (CRP) values. Overall, 72 patients (70%) were HLA-B27 positive. Patients with r-axSpA were older (mean 47.9 [SD 11.3] years) than those with nr-axSpA (mean 40.9 [SD 11.6] years). The BMI was comparable between both groups (Table 1).

Table 1. Patient demographics and baseline characteristics (N = 103).

	nr-axSpA, n = 31	r-axSpA, n = 72	*P*
Male, n (%)	17 (55)	57 (79)	0.02
Age, yrs	40.9 (11.6)	47.9 (11.3)	0.01
HLA-B27 positive, n (%)	20 (65)	52 (84)[a]	0.02
BMI	26.7 (5.5)	27.4 (5.9)	0.56
CRP	0.7 (1.0)	1.7 (5.6)	0.17
Onset of symptoms, yrs	12.3 (10.8)	19.2 (11.7)	0.01
Disease duration, yrs	4.4 (7.7)	10.9 (10.9)	< 0.001
BASDAI	4.2 (2.1)	4.3 (2.2)	0.87
BASFI	3.2 (2.3)	4.7 (2.6)	0.01
BASMI	2.0 (1.2)	3.7 (1.8)	< 0.001
Treatment with NSAIDs only, n (%)	19 (61)	26 (36)	–
Treatment with biologics, n (%)	8 (26)	35 (49)	–

Data are provided as mean (SD) unless otherwise noted. [a] HLA-B27 status was unknown in 10 patients with r-axSpA. BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylitis Metrology Index; CRP: C-reactive protein (cut-off value: > 0.5 mg/dL); nr-axSpA: nonradiographic axial spondyloarthritis; NSAID: nonsteroidal antiinflammatory drug; r-axSpA: radiographic axial spondyloarthritis.

The mean disease duration was 10.9 (SD 10.9) years among patients with r-axSpA as compared to 4.4 (SD 7.7) years among those with nr-axSpA ($P < 0.001$). The mean symptom duration was 19.2 (SD 11.7) years among patients with r-axSpA as compared to 12.3 (SD 10.8) years among those with nr-axSpA ($P = 0.01$; Table 1). The mean BASDAI was comparable in both groups (4.3 [SD 2.2] and 4.2 [SD 2.1], respectively). The mean BASFI was 4.7 (SD 2.6) in the r-axSpA group and 3.2 (SD 2.3) in the nr-axSpA group ($P = 0.01$). Spinal mobility as assessed by the BASMI was also worse in the r-axSpA group as compared to the nr-axSpA group (3.7 [SD 1.8] vs 2.0 [SD 1.2], respectively, $P < 0.001$). Additionally, BASDAI, BASMI, and BASFI results between the groups remained robust after adjustment for relevant patient demographics (Table 2; Supplementary Table S1, available with the online version of this article).

Radiographs of the SIJs were available for all patients. At least 1 radiograph of the spine was performed in each patient; specifically, 69 cervical, 61 thoracic, and 97 lumbar spine radiographs were available. Syndesmophytes were present in 43/103 patients (41.7%), with comparable percentages in the cervical (25/103, 24.3%), thoracic (27/103, 26.2%), and lumbar (25/103, 24.3%) spines and a mean of 5.9 syndesmophytes per patient. Syndesmophytes were detected in all 3 spinal segments in 11 patients (10.7%), only in the cervical spine or only in the lumbar spine in 7 patients each, and only in the thoracic spine in 6 patients (Supplementary Table S2, available with the online version of this article). In a subset of patients (n = 55) from our cohort, mean mSASSS values were 10.3 (SD 12.3) in patients with r-axSpA and 0.65 (SD 1.6) in those with nr-axSpA, with only 3 patients showing structural changes (median 0).

Table 2. ES variables in patients with r-axSpA and nr-axSpA adjusted to relevant covariables.

	Mean Difference (95% CI)	$Pr > \|t\|$
Flexion (RoK), tr	1.7 (0.79 to 2.68)	< 0.001
Flexion (RoM)	13.7 (7.56 to 19.81)	< 0.001
Extension (RoK), tr	1.4 (0.55 to 2.27)	0.002
Extension (RoM)	9.1 (3.57 to 14.63)	0.002
Rotation (RoK), tr	2.7 (1.22 to 4.15)	< 0.001
Rotation (RoM)	22.1 (14.30 to 29.94)	< 0.001
Lateral flexion (RoK), tr	2.3 (0.87 to 3.80)	0.002
Lateral flexion (RoM)	16.1 (8.65 to 23.61)	< 0.001
BASDAI	−0.1 (−1.01 to 0.85)	0.87
BASFI	−1.5 (−2.59 to −0.43)	0.01
BASMI	−1.7 (−2.30 to −1.08)	< 0.001
Lateral lumbar flexion, cm	−1.9 (−2.96 to −0.91)	< 0.001
Tragus-to-wall distance, cm	−1.4 (−2.04 to −0.73)	< 0.001
Lumbar flexion, cm	−1.9 (−3.00 to −0.73)	0.002
Intermalleolar distance, cm	−1.2 (−1.99 to −0.37)	0.01
Cervical rotation, angular degrees	−2.1 (−2.96 to −1.25)	< 0.001
Chest expansion, cm	1.0 (0.42 to 1.64)	0.001

BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylitis Metrology Index; ES: Epionics SPINE; nr-axSpA: nonradiographic axial spondyloarthritis; r-axSpA: radiographic axial spondyloarthritis; RoK: range of kinematics in angular degrees/second; RoM: range of motion in angular degrees; tr: log-transformed.

When comparing patients with and without syndesmophytes, we see a higher number of males and a higher amount of HLA-B27 positivity in patients with syndesmophytes and comparable results for BMI, CRP, and BASDAI. Patients with syndesmophytes were older (mean 51.2 [SD 10.0] years) than those without syndesmophytes (mean 42.8 [SD 11.6] years; Table 3).

The mean disease duration was 11.0 (SD 10.9) years in patients with syndesmophytes compared with 7.5 (SD 10.2) years in patients without syndesmophytes. The mean symptom duration was 19.4 (SD 12.4) years in patients with syndesmophytes compared with 15.8 (SD 11.6) years in patients without syndesmophytes (Table 3). Further, patients with syndesmophytes had worse BASFI and BASMI results. A higher number of patients (16/43, 37.2%) with syndesmophytes were smokers compared to 18/52 patients (34.6%) without syndesmophytes (Table 3).

Correlation between spinal mobility and physical function with radiographic damage in the spine and SIJs. Spinal mobility as assessed by the ES and the BASMI was associated with the presence of syndesmophytes (Table 4; Supplementary Table S3, available with the online version of this article) and the total number of syndesmophytes (Table 5). Specifically, significant correlations between ES results and the number of syndesmophytes were found for flexion (RoM and RoK), extension (RoM), and lateral flexion (RoM and RoK) of the spine (Table 5). Further, rotation (RoK and RoM) was more limited when ≥ 1 syndesmophyte was present, but there was no correlation between the

Table 3. Demographics and characteristics of patients with and without syndesmophytes.

	Patients Without Syndesmophytes, n = 52	Patient With Syndesmophytes, n = 43	*P*
Male, n (%)	35 (67)	33 (77)	0.37
Age, yrs	42.8 (11.6)	51.2 (10.0)	< 0.001
HLA-B27 (positive), n (%)	37 (74)[a]	30 (83)[b]	0.43
BMI	27.0 (5.8)	27.8 (5.9)	0.56
CRP	0.9 (1.4)	0.9 (1.4)	0.81
Onset of symptoms, yrs	15.8 (11.6)	19.4 (12.4)	0.16
Disease duration, yrs	7.5 (10.2)	11.0 (10.9)	0.12
Smoker, n (%)	18 (35)	16 (37)	0.83
BASDAI	4.5 (1.9)	4.4 (2.4)	0.88
BASFI	3.8 (2.5)	5.1 (2.7)	0.03
BASMI	2.4 (1.5)	4.2 (1.8)	< 0.001
Treatment with NSAIDs only, n (%)	28 (54)	15 (35)	–
Treatment with biologics, n (%)	16 (31)	22 (51)	–

Data are provided as mean (SD) unless otherwise noted. [a] HLA-B27 status was unknown in 2 patients without syndesmophytes. [b] HLA-B27 status was unknown in 7 patients with syndesmophytes. BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylitis Metrology Index; CRP: C-reactive protein (cut-off value: > 0.5 mg/dL); NSAID: nonsteroidal antiinflammatory drug.

Table 4. Association between presence or absence of syndesmophytes and ES, BASDAI, BASFI, BASMI, and chest expansion (*t* test).

	Mean Difference (95% CI)	*Pr*(> |*t*|)
Flexion (RoK), tr	−1.8 (−2.63 to −0.90)	< 0.001
Flexion (RoM)	−16.2 (−21.89 to −10.50)	< 0.001
Extension (RoK), tr	−1.4 (−2.11 to −0.65)	< 0.001
Extension (RoM)	−8.2 (−12.08 to −4.25)	< 0.001
Rotation (RoK), tr	−2.0 (−3.43 to −0.53)	0.01
Rotation (RoM)	−18.8 (−26.18 to −11.47)	< 0.001
Lateral flexion (RoK), tr	−2.1 (−3.57 to −0.80)	0.002
Lateral flexion (RoM)	−16.7 (−23.30 to −10.14)	< 0.001
BASDAI	−0.1 (−0.99 to 0.84)	0.88
BASFI	1.27 (0.16 to 2.38)	0.03
BASMI	1.8 (1.07 to 2.45)	< 0.001
Lateral lumbar flexion, cm	1.9 (0.78 to 2.94)	< 0.001
Tragus-to-wall distance, cm	1.6 (0.81 to 2.46)	< 0.001
Lumbar flexion, cm	2.1 (0.81 to 3.31)	0.002
Intermalleolar distance, cm	1.3 (0.39 to 2.29)	0.01
Cervical rotation, angular degrees	1.9 (0.99 to 2.85)	< 0.001
Chest expansion, cm	−1.1 (−1.73 to −0.46)	< 0.001

BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylitis Metrology Index; ES: Epionics SPINE; RoK: range of kinematics in angular degrees/second; RoM: range of motion in angular degrees; tr: log-transformed.

total number of syndesmophytes and the ES measurements for rotation of the lumbar spine to both sides (Table 4 and Table 5).

In comparison, the location of syndesmophytes appeared to be relevant for impairment of spinal mobility as measured by the ES (Supplementary Table S4, available with the online version of this article). The presence of ≥ 1 syndesmophyte in the lumbar spine resulted in a greater limitation of RoK and RoM of flexion, extension, and lateral flexion, whereas this was not seen in the cervical or thoracic spines only (Supplementary Table S4). Upper body rotation to both sides was more limited when ≥ 1 syndesmophyte was present in the thoracic and the lumbar spines as compared with in the cervical spine. Overall, the ES measurements of rotation were less strongly associated with the presence, number, and location of syndesmophytes than the ES measurements of lateral flexion, anterior flexion, and extension (Supplementary Table S4). In contrast to ES scores, individual BASMI scores showed almost no association with the location of syndesmophytes (Supplementary Table S4).

The extent of structural change in the SIJs correlated significantly with all ES measurements in RoM, RoK, and the BASMI (Table 5 and Figure 1). This correlation was similar for BASMI scores, which correlated significantly with the extent of radiographic SIJ damage: all single BASMI items, excluding intermalleolar distance, correlated well with radiographic damage of the SIJs. In addition, chest expansion showed the strongest correlations with radiographic damage of the SIJs (Table 5).

As expected, patients with r-axSpA had more severe impairments in spinal mobility than those with nr-axSpA. As shown in Table 2, patients with r-axSpA differed significantly from those with nr-axSpA in the ES variables RoM flexion, extension, rotation, and lateral lumbar flexion, as well as after adjustment for age and BMI (Table 2; Supplementary Table S1, available with the online version of this article). The extent of radiographic SIJ damage correlated less strongly with the BASFI than with most ES results and the BASMI (Table 5).

In contrast to ES scores and the BASMI, the BASFI showed no significant correlation with the number of syndesmophytes (r 0.21, $P = 0.22$; Table 5).

Chest expansion measurements were available in 102/103 patients (99%). There was a significant correlation between limitation of chest expansion with all ES scores and all individual BASMI measures (all $P < 0.001$; Table 5). Further, chest expansion results differed significantly between the r-axSpA and nr-axSpA groups. The higher the degree of radiographic damage in the SIJs (r −0.42, $P < 0.001$) and the more syndesmophytes were present (r −0.39, $P = 0.02$), the more the chest expansion of patients was impaired (Table 5).

DISCUSSION

This study shows that the ES, which objectively assesses spinal mobility, is capable of differentiating between patients with axSpA according to their degree of radiographic damage in the SIJs and the spine. Thus, after the validation of this instrument for spinal measurements in various indications including axSpA,[23-25] this is the first study that we know of to examine the performance of the ES in patients with axSpA according to the extent of radiographic damage in the axial skeleton compared with the assessment of spinal mobility by the BASMI and other measures, such as chest expansion. In our study, objective measurements of both RoM and RoK by using the ES correlated well with the BASMI, and both significantly correlated with the extent of radiographic damage of the spine and the SIJs.

The results of our study are consistent with earlier reports. The association of spinal radiographic damage with impaired spinal mobility was shown many years ago in patients with AS.[6] Both disease activity and radiographic spinal damage were determined to be causes of impairment of mobility as assessed by the BASMI and physical function as assessed by the BASFI in patients with r-axSpA,[5] which was similar in patients with relatively early axSpA (symptom duration ≤ 10 years).[13]

Thus, our data confirm that the impairment of spinal mobility is directly related to the presence and extent of radiographic damage in the axial skeleton. Further, patients in more advanced stages of r-axSpA showed more severe restrictions, not only in their range but also in their speed of motion, compared with patients with nr-axSpA. These results indicate that, especially for spinal mobility in the lumbar segments, the measurements of the ES provide additional information of mobility, including spinal RoK and kinetics. Since these measurements were in accordance with the results of spinal mobility assessments by the BASMI, these findings confirm the construct validity of the ES. They also provide additional information on relevant mobility features compared with sole BASMI measurements.

Importantly, compared with other ES measurements, rotational movements were less strongly influenced by the presence

Table 5. Correlation (*r*) of sacroiliitis sum score, number of syndesmophytes, and chest expansion with variables of ES, BASDAI, BASFI, and BASMI.

	Flexion (RoK)	Flexion (RoM)	Extension (RoK)	Extension (RoM)	Rotation (RoK)	Rotation (RoM)	Lateral Flexion (RoK)	Lateral Flexion (RoM)	BASFI	BASDAI	BASMI	Lateral Lumbar Flexion, cm	Tragus-to-Wall Distance, cm	Lumbar Flexion, cm	Intermalleolar Distance, cm	Cervical Rotation, angular degrees	Chest Expansion, cm
Sacroiliitis sum score																	
r (range)	−0.4 (−0.55 to −0.22)	−0.43 (−0.58 to −0.26)	−0.43 (−0.57 to −0.25)	−0.46 (−0.6 to −0.29)	−0.33 (−0.5 to −0.14)	−0.49 (−0.63 to −0.32)	−0.36 (−0.52 to −0.17)	−0.45 (−0.59 to −0.28)	0.26 (0.056 to 0.43)	0.02 (0.18 to 0.22)	0.49 (0.33 to 0.62)	0.38 (0.2 to 0.53)	0.43 (0.25 to 0.57)	0.33 (0.14 to 0.49)	0.16 (−0.04 to 0.34)	0.47 (0.3 to 0.61)	−0.42 (−0.56 to −0.24)
n	103	103	100	100	98	98	98	98	95	98	103	103	103	103	103	103	102
P	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.01	0.86	< 0.001	< 0.001	< 0.001	< 0.001	0.12	< 0.001	< 0.001
Number of syndesmophytes																	
r (range)	−0.34 (−0.59 to −0.03)	−0.39 (−0.62 to −0.07)	−0.2 (−0.48 to 0.14)	−0.35 (−0.6 to −0.02)	−0.12 (−0.42 to 0.21)	−0.26 (−0.53 to 0.07)	−0.39 (−0.63 to −0.07)	−0.53 (−0.73 to −0.24)	0.21 (−0.13 to 0.5)	0.02 (−0.31 to 0.34)	0.38 (0.07 to 0.62)	0.42 (0.11 to 0.64)	0.42 (0.11 to 0.65)	0.12 (−0.21 to 0.42)	0.14 (−0.16 to 0.44)	0.53 (0.24 to 0.72)	−0.39 (−0.62 to −0.07)
n	39	39	38	38	38	38	37	37	36	37	39	39	39	39	39	39	39
P	0.03	0.02	0.24	0.03	0.49	0.12	0.02	< 0.001	0.22	0.91	0.02	0.01	0.01	0.48	0.4	< 0.001	0.02
Chest expansion																	
r (range)	0.36 (0.18 to 0.52)	0.51 (0.35 to 0.64)	0.38 (0.2 to 0.54)	0.39 (0.21 to 0.55)	0.3 (0.1 to 0.47)	0.48 (0.31 to 0.62)	0.46 (0.29 to 0.61)	0.6 (0.45 to 0.71)	−0.43 (−0.58 to −0.25)	−0.14 (−0.33 to 0.07)	−0.62 (−0.73 to −0.48)	−0.55 (−0.67 to −0.39)	−0.49 (−0.62 to −0.33)	−0.49 (−0.62 to −0.32)	−0.34 (−0.5 to −0.16)	−0.43 (−0.58 to −0.26)	–
n	102	102	99	99	98	98	97	97	94	97	102	102	102	102	102	102	–
P	< 0.001	< 0.001	< 0.001	< 0.001	0.01	< 0.001	< 0.001	< 0.001	< 0.001	0.19	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	–

BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASMI: Bath Ankylosing Spondylitis Metrology Index; ES: Epionics SPINE; RoK: range of kinematics in angular degrees/second; RoM: range of motion in angular degrees; tr: log-transformed.

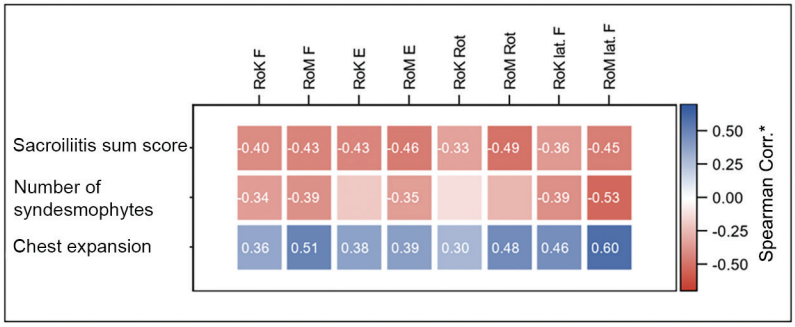

Figure 1. Heatmap with correlation (*r*) of sacroiliitis sum score, number of syndesmophytes, and chest expansion with variables of ES. * Spearman correlation (coefficients indicated for $P < 0.05$). E: extension; ES: Epionics SPINE; F: flexion; lat. F: lateral flexion; RoK: range of kinematics; RoM: range of motion; Rot: rotation.

and number of syndesmophytes. In addition, chest expansion, not included in the BASMI, showed significant correlations with all ES scores (Figure 1). These results also differed significantly between r-axSpA and nr-axSpA and after adjustment for relevant patient demographics. This finding is important because it suggests that vertical syndesmophytes, which are clearly visible on conventional radiographs, have a limited effect on rotational movements. This may be different for facet joints, which are scarcely visible on anterior-posterior and lateral radiographs but are responsible for rotational movements, as well as rib movements, which are needed for chest expansion. Further, radiographic damage in facet joints may be more pronounced in more advanced stages of the disease. This could explain the observed differences between r-axSpA and nr-axSpA, as well as the correlation with high mSASSS scores and functional impairment,[30-32] whereas inflammation of posterior spinal structures, including facet joints, has also been detected in patients with early stages of the disease.[33]

Further, chest expansion showed significant correlations with all ES scores, the BASFI, the BASDAI, and the BASMI. Overall, these data strongly emphasize the value of assessing chest expansion in addition to the BASMI, not only in clinical studies but also in routine clinical practice. As shown in this study, the ES is able to objectively confirm restrictions suggested by the clinical measurement of chest expansion.

Importantly, measurements of RoM and RoK, as well as the BASMI, were superior to the subjective PRO BASFI with respect to the extent of radiographic damage. This discrepancy may have several reasons, including that the mean BASFI was not very high in our study. Other possibilities are underreporting and the use of coping strategies of these relatively young patients.[34-36] Indeed, subjective reporting differs from the objective performance of patients.[14,15,36]

Another interesting finding of our study is the correlation of the extent of radiographic damage in the SIJs and the impairment of RoM and RoK as assessed by the ES. This is certainly not straightforward from an anatomical point of view. However, it makes sense that the degree of radiographic damage in the SIJs is associated with more advanced and longstanding spinal disease, including all sites of the vertebral bodies and the zygapophyseal joints. This knowledge is backed by data showing that both ankylosis and fat metaplasia of the SIJs have an increased propensity for radiographic progression in the spine.[37] In addition, by definition, higher grades of SIJ damage in radiographs are present in patients with r-axSpA vs nr-axSpA.[3]

Limitations of our study are the explorative character of this first assessment, the relatively low number of patients, and the missing quantification of the radiographic damage by a validated scoring system, such as the widely accepted mSASSS scoring system.[4,38] This was because a complete set of radiographs of the cervical and lumbar spines to score the mSASSS was not available for all patients included in the study because radiographic examinations were only performed based on the clinical indication, which usually was the main localization of pain. Nevertheless, the number of patients with radiographs was sufficient to perform statistically meaningful analyses. Finally, the mSASSS only assesses the anterior vertebral corners of the cervical and lumbar spines, which implies that mainly the mean mSASSS of our cohort would have provided additional information for comparison with other studies.

Recently, the measurement of spinal mobility has again been included in the ASAS–Outcome Measures in Rheumatology Clinical Trials core outcome set for axSpA.[39] Knowing the relevance of spinal mobility for the individual patient, for clinical trials and as a socioeconomic factor,[40] and knowing the limitations of the BASFI as a PRO and the BASMI, objective measurement tools are increasingly important.

In conclusion, this study shows for the first time to our knowledge that the presence and extent of structural damage in the axial skeleton of patients with axSpA are significantly associated with impairment of mobility as assessed by the BASMI and the ES but not so much with function as assessed by the BASFI. This finding is, for obvious reasons, more important for patients with r-axSpA than for those with nr-axSpA. The BASMI was confirmed to correlate well with radiographic damage in the axial skeleton. However, the ES does provide clinical information in addition to that by assessing the range and velocity of spinal movements, especially in those related to facet joints, such as rotation and chest expansion. Objective measurement of spinal mobility may lead to a more accurate assessment of mobility. Longitudinal studies before and after therapy using electronic devices are needed to better understand the effect of

different types of treatment to improve mobility and function in patients with axSpA.

DATA AVAILABILITY

AbbVie is committed to responsible data sharing regarding the clinical trials we sponsor. This includes access to anonymized, individual, and trial-level data (ie, analysis datasets), as well as other information (eg, protocols, clinical study reports, or analysis plans), as long as the trials are not part of an ongoing or planned regulatory submission. This includes requests for clinical trial data for unlicensed products and indications. These clinical trial data can be requested by any qualified researchers who engage in rigorous, independent, scientific research, and will be provided following review and approval of a research proposal, Statistical Analysis Plan (SAP), and execution of a Data Sharing Agreement (DSA). Data requests can be submitted at any time after approval in the USA and Europe and after acceptance of this manuscript for publication. The data will be accessible for 12 months, with possible extensions considered. For more information on the process or to submit a request, visit the following link: https://www.abbvie.com/our-science/clinical-trials/clinical-trials-data-and-information-sharing/data-and-information-sharing-with-qualified-researchers.html.

ONLINE SUPPLEMENT

Supplementary material accompanies the online version of this article.

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