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Can ultrasound be an assessment tool for sagittal spine mobility and chest expansion in patients with ankylosing spondylitis?

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Abstract

We aimed to examine whether ultrasound (US) is useful for evaluating spinal mobility and chest expansion in ankylosing spondylitis (AS) patients and determine a cutoff value to identify reduced sagittal lumbar mobility.

Our cross-sectional study included 50 AS patients and 50 controls. Metric measurements and Bath AS indices were measured in AS patients. The distance between C6-C7, T11-T12, and L4-L5 vertebrae was measured, and the difference and percentage of difference between erect position and maximal cervical and lumbar flexion was calculated ($T11\text{-}T12_{dif}$, T11-T12%, $L4\text{-}L5_{dif}$, L4-L5%, $T+L_{dif}$, T+L%). Intercostal divergence was measured 1.5 cm away on the left from the sternocostal space during maximum inhalation and maximum exhalation, and the difference and percentage of difference between them was calculated (IC_{dif}, IC%).

All metric measurements were lower in the AS group except for tragus-to-wall distance. $T11\text{-}T12_{dif}$, T11-T12%, $L4\text{-}L5_{dif}$, $T+L_{dif}$, and T+L% values were higher in the control group, while other US measurements did not differ between the groups. All US measurements except IC_{dif} and IC% correlated with the Bath AS Metrology Index.

Thus, US may be used for assessing spinal mobility in patients with AS. $T11\text{-}T12_{dif} < 0.79$ cm may show decreased lumbar sagittal mobility.

Abbreviations: AS = ankylosing spondylitis, ASAS = Assessment of Spondyloarthritis International Society, AUC = area under the curve, BASDAI = Bath Ankylosing Spondylitis Disease Activity Index, BASFI = Bath Ankylosing Spondylitis Functional Index, BASMI = Bath Ankylosing Spondylitis Metrology Index, BMI = body mass index, C = cervical, CE = chest expansion, CI = confidence interval, CR = cervical rotation, CSD = chin-to-sternum distance, dif = difference, FFD = finger-to-floor distance, IC = intercostal, IMD = intermalleolar distance, L = lumbar, LLF = lateral lumbar flexion, MRI = magnetic resonance imaging, MST = Modified Schober test, ROC = receiver operating characteristic, T = thoracic, TWD = Tragus-to-wall distance, US = ultrasound.

Keywords: ankylosing spondylitis, metric measurements, modified Schober test, ultrasound, vertebrae mobility

1. Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory disease with a prevalence of 2.41 to 3.89/10.000, affecting spinal mobility and chest expansion (CE), thus leading to functional disability.[1–3] The modified New York Criteria indicate decreased spinal mobility and CE as cardinal findings for diagnosing AS.[4] The disease primarily affects ligamentous insertions or entheses and joints, limiting spinal mobility, and bony ankylosis in the joints surrounding the thorax may reduce CE.[5] Monitoring these restrictions is mandatory as the disease progresses. Spinal mobility not only supports the diagnosis of AS but is also commonly assessed during follow-up.[6] Techniques for measuring spinal mobility vary from metric measurements to various inclinometer and radiographic methods. Even though radiographic methods are considered the gold standard for assessing spinal mobility, concerns about cost-effectiveness and risk of radiation exposure are limitations of this method.[6] Consequently, noninvasive and practical low-cost tests, such as the modified Schober test (MST), finger-to-floor distance (FFD), tragus-to-wall distance (TWD), lumbar lateral flexion (LLF), cervical rotation (CR), chin-to-sternum distance (CSD), and CE, are widely used.[7,8] Limitation of these methods is difficulty in locating the landmarks precisely.[6] For example, the MST, first described by Macrae and Wright,[9] requires determination of the Venus dimples as a landmark for lumbosacral junction. However, a subsequent study demonstrated that 26% of individuals do not have visible Venus dimples, and the inter-dimple line is rarely at the lumbosacral junction; rather, it is usually over the proximal sacrum, around S1 or S2.[10]

Ultrasonography/ultrasound (US) is widely used by clinicians for assessing the inflammation of peripheral arthritis and enthesitis in daily practice.[11] US is recommended for monitoring activity and response to treatment,[11] but it is not sufficiently utilized for monitoring any other structures besides joints. The limitations and concerns regarding the metric measurements mentioned above make US a good candidate and easy-to-use tool for evaluating spinal mobility and CE.

Recent studies have evaluated the reliability of metric measurements and their correlation with the structural damage assessed by computed tomography and magnetic resonance

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imaging (MRI).[6,7,12–14] However, no study has evaluated whether US may be used in assessing spinal mobility and CE. Therefore, our aim was to determine the utility of US for evaluating spinal mobility and CE in AS patients and determine a cutoff value that may be used in high coherence with MST, which is one of the most studied and utilized metric tests. We also sought to determine the correlation between US measurements and disease activity, patient functionality, and structural changes.

2. Methods

2.1. Study design and patient enrollment

This cross-sectional trial included 100 patients (50 AS, 50 healthy controls). All AS patients were recruited from the tertiary health center of the author. Control patients were either employees of the hospital or patients admitted to outpatient clinic and meeting the eligibility criteria. Sex distribution among groups was considered during recruitment. The study was performed in accordance with the Declaration of Helsinki–Ethical Principles for Medical Research Involving Human Subject, and approval was obtained from the Institutional Ethics Committee (No: 2017–17436). All patients provided written informed consent before participating in the study. Inclusion criteria for the AS group were as follows: age 18 to 50 years and diagnosis of AS according to the modified New York Criteria.[4] The inclusion criteria for the control group were as follows: age 18 to 50 years and no spinal complaints. Exclusion criteria for both groups included those unable to consent; having severe systemic disease (e.g., cardiac failure, renal failure); having acute or chronic pulmonary disease (e.g., chronic obstructive pulmonary disease); having collagen tissue disorder; and undergoing spinal surgery. Each relevant movement was performed 3 times before taking the measurements. Because there is no study similar to the present study, effect sizes were calculated on the basis of the data after preliminary analysis with 20 patients in each group. A minimum of 50 patients was considered to be sufficient for each group [for intercostal difference (IC_{dif})], with 80% power and 0.05 significance. IC_{dif} was chosen for showing the most significant dispersion.

2.2. Metric measurements

The same physician performed the following metric measurements, except MST, of all participants using a measurement tape as described by the Assessment of Spondyloarthritis International Society (ASAS).[8] MST was performed according to the original definition by Macrae and Wright [9] with the patient standing erect with an imaginary line between the dimples of Venus. A second and third mark was placed 10 cm above and 5 cm below the inter-dimple line, respectively. The patient was asked to bend forward maximally, and the increase was recorded. LLF was evaluated while the patient's back was resting against the wall in which the investigator measured the distance between the patient's middle fingertip and the floor before and after the patient bent sideways and recorded the difference. TWD was assessed with the patient's back against the wall while the patient performed maximal effort to touch the head against the wall, and the investigator recorded the distance between the tragus and the wall. CR was assessed while the patient was sitting in a chair and a goniometer was placed at the top of the head in line with the nose. The assessor recorded the angle between the sagittal plane and the new plane after the patient maximally rotated the neck, and the mean of the right and left angles was determined. Intermalleolar distance (IMD) was performed as the patient stood and separated the legs as far apart as possible and the distance between the medial malleoli was measured. CE was evaluated by measuring the difference of the circumferential distance of the thorax from the 4th intercostal level in maximum inhalation and maximum exhalation.

2.3. Bath indices

Bath Ankylosing Spondylitis Disease Activity Index (BASDAI), Bath Ankylosing Spondylitis Functional Index (BASFI), and Bath Ankylosing Spondylitis Metrology Index (BASMI) were obtained from the AS patients. The BASDAI consists of a 1 through 10 scale (1 = no problem and 10 = the worst problem), which is used to answer 6 questions pertaining to the 5 major symptoms (fatigue, spinal pain, joint pain/swelling, areas of localized tenderness, morning stiffness duration, morning stiffness severity) of AS.[15] On the contrary, BASFI examines the functional status of the patient by NRS (0 = easy and 10 = impossible) with 10 questions. The first 8 questions evaluate activities related to functional anatomical limitations due to the course of AS, and the final 2 questions evaluate the patients' ability to cope with everyday life. The mean of the 10 answers yields the BASFI score, a value between 0 and 10.[16] BASMI is a combined index comprising 5 assessments of spinal mobility in patients with AS and includes assessments of LLF, TWD, MST, IMD, and CR. As there are variations of BASMI, we used the variation based on 3-point answer scale (with a final score between 0 and 10).[17] A worsened patient condition was indicated with a higher Bath index.

2.4. US evaluation

US was performed by a certified physiatrist using a 7 to 13 MHz linear array probe with a calibrated device (LOGIQ P5; GE Healthcare, Chicago, IL) immediately after performing the metric measurements. The probe was initially placed transversely on the lumbosacral region to identify the tip of the spinous process of the 1st sacral vertebra by using the 1st sacral hiatus as a landmark. Next, the probe was rotated longitudinally on the spinous processes over the lumbosacral sagittal plane, and the L4-L5 and T11-T12 interspinous spaces were marked with a skin marker by upwardly counting the vertebral tips of the spinous processes. The correct locations were verified as per the method described by Chang et al.[18] After assessing the locations of L4-L5 and T11-T12 interspinous spaces, the distance between the lowest margin of the L4 spinous process and the upper margin of the L5 spinous process was measured by drawing a straight line using the machine's software in erect posture and maximal forward flexion. Participants tried their best to use their fingertips to touch the toes for attaining the maximal flexion. The difference between the distances in maximal flexion and erect posture was recorded as L4-$L5_{dif}$ (Fig. 1). The same procedure was applied to the interspinous space at T11-T12, the difference of the distances between maximal flexion and erect posture was recorded as T11-$T12_{dif}$ (Fig. 2), and the sum of L4-$L5_{dif}$ and T11-$T12_{dif}$ was considered as T+L_{dif}. Next, the bony protuberance of the C7 spine was located by palpation, which was verified as per the method described by Chang et al,[19,20] and the US probe was placed longitudinally over the sagittal plane to visualize the interspinous space of C6-C7. Because the spinous processes of the cervical vertebrae are small, the assessor performed a tip-to-tip distance measurement by drawing a line using the machine's

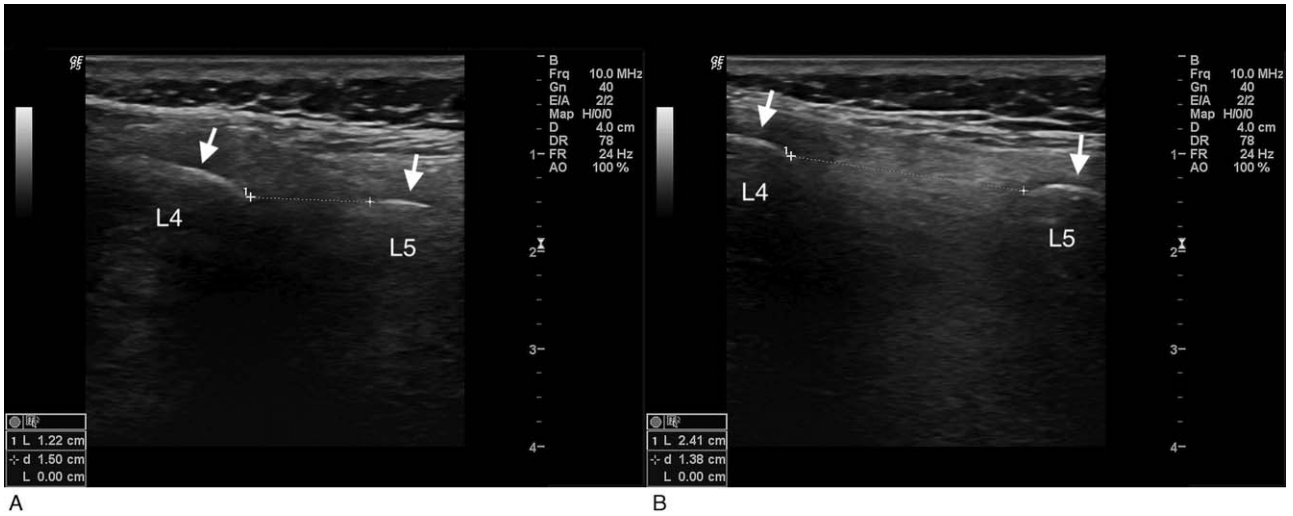

Figure 1. Distance between L4-L5 spinous processes in upright position (A) and maximal forward flexion (B). Arrows, spinous processes; dotted lines, distance between spinous processes.

software. The difference between the distances in erect posture and maximal cervical flexion was recorded as C6-$C7_{dif}$ (Fig. 3). The percentage of the differences (L4-L5%, T11-T12%, and C6-C7%) indicating how many percentages the interspinous distance changed according to erect posture was calculated as:

$$[(\text{distance in maximal flexion} - \text{distance in erect posture})/\text{distance in erect posture}] \times 100$$

The 4th intercostal space difference (IC_{dif}) was measured by placing the probe 1.5 cm from the sternocostal space, which was determined on US, on the left 4th intercostal space longitudinally on the sagittal plane, and the difference of the distance between the cartilaginous part of the 4th and 5th costae at maximal inhalation and maximal exhalation was recorded (Fig. 4). IC% was calculated using the same method mentioned above.

2.5. Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics v22.0 statistical software (SPSS Inc., Armonk, NY). Variable distribution was tested with the Shapiro–Wilk test. Descriptive statistics were indicated as "mean ± standard deviation" for variables with normal distribution; "median, minimum −maximum" for non-normal distributed variables; and "frequency and percentage [n (%)]" for categorical variables. Independent sample *t* test was used to compare 2 groups with continuous normally distributed variables, and the Mann–Whitney *U* test was used to compare 2 groups with continuous non-normal distributed variables. Pearson Chi-squared test was used for categorical variables, and receiver operating characteristic (ROC) curve analysis was performed for detecting the cutoff values for T11-$T12_{dif}$, T11-T12%, L4-$L5_{dif}$, L4-L5%, T+L_{dif}, and T+L%, and the data were presented with area under the curve (AUC), standard error, 95% confidence intervals (95%

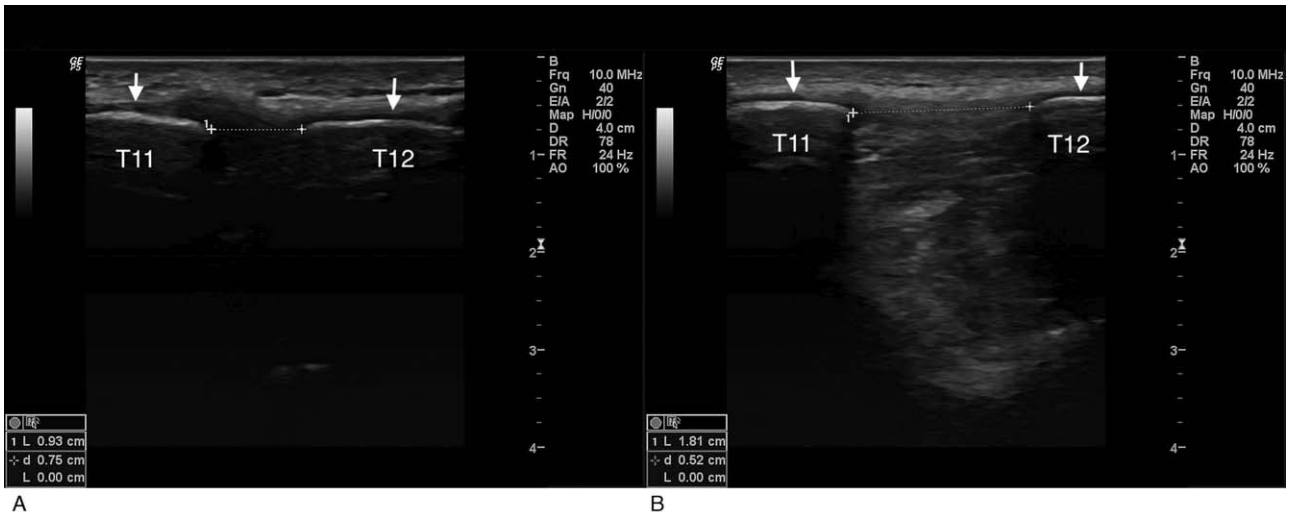

Figure 2. Distance between T11-T12 spinous processes in upright position (A) and maximal forward flexion (B). Arrows, spinous processes; dotted lines, distance between spinous processes.

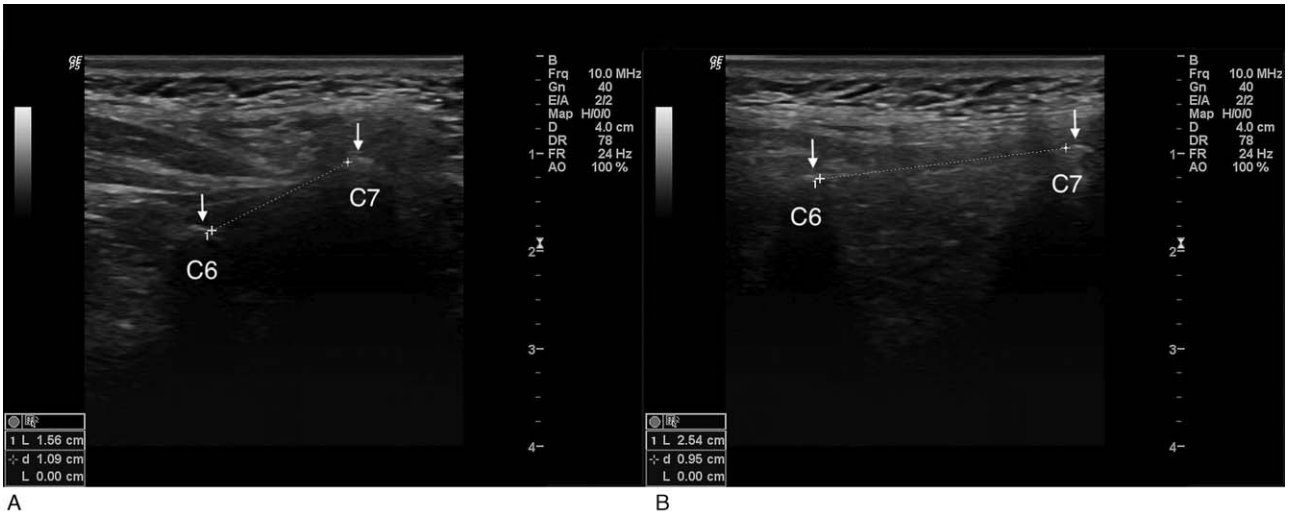

Figure 3. Tip-to-tip distance between C6-C7 spinous processes in upright position (A) and maximal cervical forward flexion (B). Arrows, spinous processes; dotted lines, distance between spinous processes.

CIs), sensitivity, and specificity values. Relevant cutoff values were calculated according to the Youden index, and the Spearman rank correlation analysis was used to assess correlations between continuous non-normal distributing variables. Statistical significance was indicated with significance level $\alpha = 0.05$ and 95% CI.

3. Results

3.1. Patient characteristics

The control group included 50 individuals (37 males, 13 females) aged 36.12 ± 7.48 years with a body mass index (BMI) of $25.93 \pm 4.04\,kg/m^2$. The AS group included 50 patients (37 males, 13 females) aged 36.58 ± 7.53 years, with a BMI of $26.23 \pm 3.49\,kg/m^2$. There were no differences between the 2 groups in terms of age, sex, height, weight, BMI, and exercise habits ($P > .05$). Demographic characteristics of the AS patients and healthy volunteers are presented in Table 1.

3.2. Between-group comparisons of metric measurements

The values of all metric measurements except TWD (MST, CSD, CR, LLF, FFD, CE, IMD) were less in the AS group than in controls, and there was no difference regarding TWD values among the 2 groups. A comparison of metric measurements among the 2 groups is presented in Table 2.

3.3. Between-group comparisons of US measurements

A comparison of ultrasonographic measurements among the 2 groups is presented in Table 3. $T11\text{-}T12_{dif}$, T11-T12%, $L4\text{-}L5_{dif}$, $T+L_{dif}$, and T+L% values were greater in the control group than in the AS patients. $C6\text{-}C7_{dif}$, C6-C7%, L4-L5%, IC_{dif}, and IC% did not differ between the 2 groups.

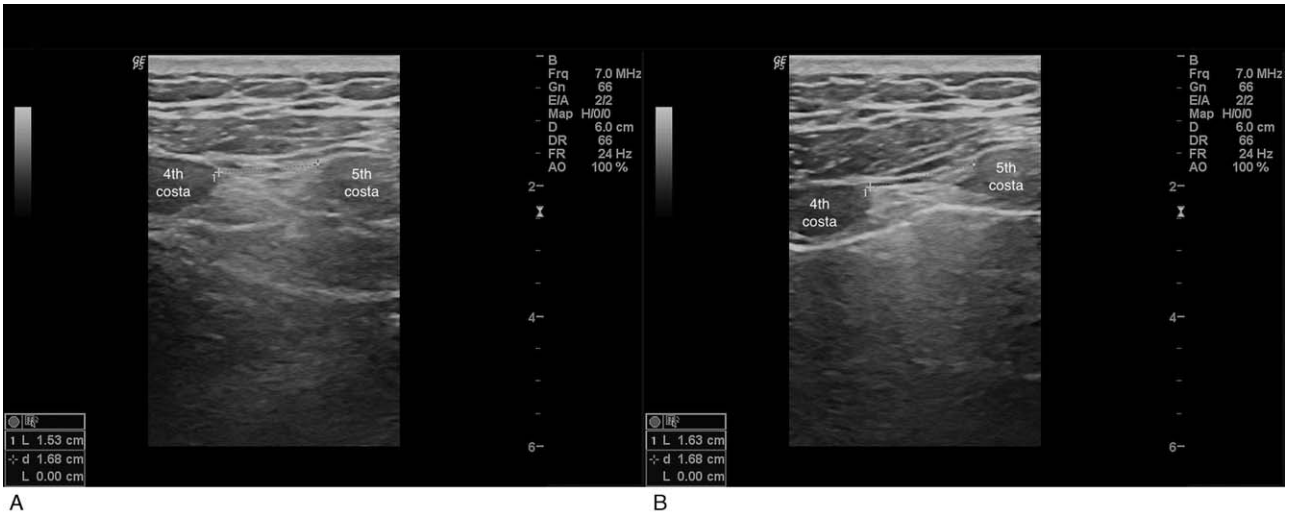

Figure 4. Distance between the cartilaginous part of the 4th and 5th costae at maximal exhalation (A) and maximal inhalation (B). Dotted lines, distance between spinous processes.

Table 1

Demographic features of groups.

Variable		Control (n=50)	AS (n=50)	P*
Age, y (Mean±SD)		36.12±7.48	36.58±7.53	.760
Gender [n (%)]	Female	13 (26%)	13 (26%)	>.999
	Male	37 (74%)	37 (74%)	
Height, m (Mean±SD)		1.73±0.09	1.71±0.08	.157
Weight, kg (Mean±SD)		78.54±15.16	76.82±12.04	.531
BMI, kg/m^2 (Mean±SD)		25.93±4.04	26.23±3.49	.695
Symptom duration, y [Median (Min–Max)]		—	9.50 (0.50–30.00)	—
Exercise habit [n (%)]	None	35 (70%)	33 (66%)	
	1–2/wk	12 (24%)	8 (16%)	.145
	≥3/wk	3 (6%)	9 (18%)	
BASDAI [Median (Min–Max)]		—	2.90 (0.00–9.00)	—
BASFI [Median (Min–Max)]		—	1.74 (0.00–8.40)	—
BASMI [Median (Min–Max)]		—	0.00 (0.00–6.00)	—

AS=ankylosing spondylitis, BASDAI=Bath Ankylosing Spondylitis Disease Activity Index, BASFI=Bath Ankylosing Spondylitis Functional Index, BASMI=Bath Ankylosing Spondylitis Metrology Index, BMI=body mass index.

* *P*: Mann–Whitney *U* test/independent-sample *t* test/χ^2 test.

Table 2

Comparison of metric measurements among 2 groups.

Variable	Control (n=50)	AS (n=50)	P*
MST, cm (Mean±SD)	6.32±1.41	5.03±2.18	**.001**
TWD, cm [Median (Min–Max)]	11.45 (9.00–14.00)	12.00 (9.00–24.00)	.053
CSD, cm [Median (Min–Max)]	0.00 (0.00–4.00)	1.50 (0.00–5.00)	**.001**
CR (°) [Median (Min–Max)]	87.50 (69.00–97.50)	86.25 (25.00–100.00)	**.012**
LLF, cm [Median (Min–Max)]	19.87 (13.50–30.50)	15.87 (4.25–23.50)	**<.001**
FFD, cm [Median (Min–Max)]	5.75 (0.00–29.50)	11.00 (0.00–50.00)	**.002**
CE, cm [Median (Min–Max)]	7.00 (4.00–10.00)	5.00 (1.50–9.00)	**.001**
IMD, cm (Mean±SD)	113.06±8.71	106.08±16.48	**.010**

AS=ankylosing spondylitis, CE=chest expansion, CR=cervical rotation, CSD=chin-to-sternum distance, FFD=finger-to-floor distance, IMD=intermalleolar distance, LLF=lateral lumbar flexion, MST=Modified Schober test, TWD=Tragus-to-wall distance.

* *P*: Mann–Whitney *U* test/independent-sample *t* test.

3.4. Correlations among indices, metric measurements, and US measurements

Correlations for C6-C7$_{dif}$ and C6-C7% with symptom duration, BASDAI, BASFI, BASMI, and relevant metric measurements (TWD, CSD, and CR) in the AS group are presented in Table 4. C6-C7$_{dif}$ showed a negative correlation ($r=-0.530$) with CSD and a positive correlation ($r=0.360$) with CR as well as a negative correlation ($r=-0.367$) with BASMI. C6-C7% showed a negative correlation with CSD, a positive correlation ($r=0.332$) with CR, a negative correlation ($r=-0.309$) with BASFI, and a negative correlation ($r=-0.430$) with BASMI.

Correlations for T11-T12$_{dif}$, T11-T12%, L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% values with symptom duration, BASDAI, BASFI, BASMI, and relevant metric measurements (MST, LLF, FFD) in the AS group are summarized in Table 5. T11-T12$_{dif}$, L4-L5$_{dif}$, T+L $_{dif}$, and T+L% showed a negative correlation ($r=$-0.313, -0.300, -0.364, -0.307, respectively) with symptom duration, while T11-T12% did not show a correlation. T11-

Table 3

Comparison of ultrasonographic measurements among 2 groups.

Variables	Control (n=50)	AS (n=50)	P*
C6-C7$_{dif}$, cm [Median (Min–Max)]	0.57 (0.04–1.40)	0.54 (0.04–1.19)	.508
C6-C7% [Median (Min–Max)]	37.31% (1.77–115.70%)	29.94% (2.29–85.61%)	.164
T11-T12$_{dif}$, cm (Mean±SD)	0.89±0.37	0.65±0.40	**.002**
T11-T12% [Median (Min–Max)]	92.45% (6.48–267.95%)	67.57% (0.56–303.70%)	**.024**
L4-L5$_{dif}$, cm (Mean±SD)	1.09±0.46	0.83±0.47	**.007**
L4-L5% [Median (Min–Max)]	87.16% (16.80–338.78%)	80.97% (1.27–252.87%)	.062
T+L$_{dif}$, cm (Mean±SD)	1.99±0.71	1.49±0.80	**.001**
T+L% [Median (Min–Max)]	176.09% (42.92–468.88%)	164.58% (13.31–556.58%)	**.019**
IC$_{dif}$, cm [Median (Min–Max)]	0.23 (-0.29 to 0.85)	0.16 (-0.09 to 1.24)	.322
IC% [Median (Min–Max)]	11.41% (-15.59% to 53.45%)	10.40% (-5.26% to 182.35%)	.677

AS=ankylosing spondylitis, C=cervical, dif=Difference, IC=intercostal, L=lumbar, T=thoracic.

* *P*: Mann–Whitney U test/independent-sample *t* test.

Table 4

Correlation between variables.

Variable		Symptom duration	TWD	CSD	CR	BASDAI	BASFI	BASMI
C6-C7$_{dif}$, cm	r^*	−0.057	−0.122	−0.530	0.360	−0.094	−0.246	−0.367
	P	.695	.398	**<.001**	**.010**	.514	.086	**.009**
C6–7%	r^*	−0.069	−0.185	−0.566	0.332	−0.183	−0.309	−0.430
	P	.634	.198	**<.001**	**.018**	.202	**.029**	**.002**

BASDAI = Bath Ankylosing Spondylitis Disease Activity Index, BASFI = Bath Ankylosing Spondylitis Functional Index, BASMI = Bath Ankylosing Spondylitis Metrology Index, C = cervical, CR = cervical rotation, CSD = chin-to-sternum distance, dif = difference, TWD = Tragus-to-wall distance.

* *r*: Spearman correlation coefficient.

Table 5

Correlation between variables.

Variable		Symptom duration	MST	LLF	FFD	BASDAI	BASFI	BASMI
T11-T12$_{dif}$, cm	r^*	−0.313	0.658	0.691	−0.237	−0.280	−0.418	−0.580
	P	**.027**	**<.001**	**<.001**	.097	**.049**	**.002**	**<.001**
T11-T12%	r^*	−0.248	0.470	0.466	−0.127	−0.223	−0.319	−0.427
	P	.083	**.001**	**.001**	.380	.120	**.024**	**.002**
L4–5$_{dif}$, cm	r^*	−0.300	0.475	0.446	−0.346	−0.054	−0.139	−0.423
	P	**.034**	**<.001**	**.001**	**.014**	.709	.337	**.002**
L4–5%	r^*	−0.380	0.648	0.619	−0.428	−0.170	−0.248	−0.535
	P	**.007**	**<.001**	**<.001**	**.002**	.237	.082	**<.001**
T+L$_{dif}$, cm	r^*	−0.364	0.706	0.698	-0.404	−0.249	−0.348	−0.599
	P	**.009**	**<.001**	**<.001**	**.004**	.081	**.013**	**<.001**
T+L%	r^*	−0.307	0.491	0.444	−0.296	−0.178	−0.246	−0.458
	P	**.030**	**<.001**	**.001**	**.037**	.217	.086	**.001**

BASDAI = Bath Ankylosing Spondylitis Disease Activity Index, BASFI = Bath Ankylosing Spondylitis Functional Index, BASMI = Bath Ankylosing Spondylitis Metrology Index, dif = difference, FFD = finger-to-floor distance, L = lumbar, LLF = lateral lumbar flexion, MST = Modified Schober test, T = thoracic.

* *r*: Spearman correlation coefficient.

T12$_{dif}$, T11-T12%, L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% showed a positive correlation (r = 0.658, 0.470, 0.475, 0.648, 0.706, 0.491, respectively) with MST. T11-T12$_{dif}$, T11-T12%, L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% showed a positive correlation (r = 0.691, 0.466, 0.446, 0.619, 0.698, 0.444, respectively) with LLF. L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% showed a negative correlation (r = -0.346, -0.428, -0.404, -0.296, respectively) with FFD. T11-T12$_{dif}$ showed a negative correlation (r = 0.280) with BASDAI, while other parameters did not show a correlation. T11-T12$_{dif}$, T11-T12%, and T+L $_{dif}$ showed a negative correlation (r = -0.418, -0.319, -0.348, respectively) with BASFI. T11-T12$_{dif}$, T11-T12%, L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% showed a negative correlation (r = -0.580, -0.427, -0.423, -0.535, -0.599, -0.458), respectively, with BASMI. None of the parameters, including symptom duration, BASDAI, BASFI, BASMI, or CE correlated with IC$_{dif}$ or IC%.

3.5. Diagnostic performance of US measurements

Cidem et al[21] investigated the lower limit of MST in a healthy young Turkish population and indicated that 5.46 cm was the lowest limit for normal lumbar spinal mobility. For individuals with MST <5.46 cm considered as decreased lumbar sagittal mobility, the results of ROC analysis to determine an optimal cutoff value for T11-T12$_{dif}$, T11-T12%, L4-L5$_{dif}$, L4-L5%, T+L $_{dif}$, and T+L% measurements are summarized in Table 6. T11-T12$_{dif}$ <0.79 cm distinguishes patients with decreased lumbar sagittal mobility from those with normal sagittal lumbar mobility with 70.97% sensitivity, 73.68% specificity, and an AUC of 0.761.

4. Discussion

In this study, we aimed to assess sagittal spinal mobility and CE using US in AS patients. We also sought a cutoff value for some

Table 6

Results of ROC analysis.

Variable	AUC	Standard error	95% CI	*P*	Cut-off	Sensitivity (%)	Specificity (%)
T11–T12$_{dif}$, cm	0.761	0.051	0.665–0.840	**<.001**	0.74	70.97	73.68
T11–12%	0.699	0.057	0.599–0.787	**<.001**	69.23%	69.35	68.42
L4–L5$_{dif}$, cm	0.681	0.056	0.580–0.770	**.001**	0.70	80.65	50.00
L4–L5%	0.590	0.062	0.487–0.687	.152	—	—	—
T+L$_{dif}$, cm	0.731	0.055	0.633–0.815	**<.001**	1.38	88.71	52.63
T+L%	0.646	0.061	0.544–0.739	**.018**	72.5%	98.39	36.84

AUC = area under the curve, CI = confidence interval, dif = difference, L = lumbar, ROC = receiver operating characteristic, T = thoracic.

ultrasonographic measures to specify decreased sagittal lumbar mobility. US is widely used in rheumatology practice; however, it is not sufficiently used to evaluate mobility restrictions, which are the ultimate result of AS. The limitations of radiographic methods for assessing spinal mobility have incited practitioners to use the more practical metric measurements.[6] US is a cost-effective, objective method that may be used in musculoskeletal imaging. Our results indicate that US measurements may be used to monitor sagittal spinal mobility and CE in patients with AS, and that T11-$T12_{dif}$ <0.79 cm may refer to decreased lumbar sagittal mobility.

Miller et al[10] raised concerns about MST and observed a limitation of MST by suggesting that 10 cm above the Venus dimples usually correlates with the L2–3 interspace and thus does not measure the thoracolumbar junction.[10] US addresses this concern by precisely locating the T11-T12 interspinous space. It has been speculated that most of the structural damage occurs adjacent to the thoracolumbar junction.[7,12] In the present study, T11-$T12_{dif}$ showed a correlation with BASMI and MST, while L4-$L5_{dif}$ demonstrated only a weaker correlation. Accordingly, we suggest that AS patients are primarily affected by thoracolumbar junction mobility, and it may be possible to assess the restrictions in thoracolumbar sagittal mobility with T11-$T12_{dif}$ alone.

All of the US measurements showed a negative correlation with BASMI. BASMI is an index consisting of cervical and lumbar spinal movements and IMD, which is an assessment of hip range of motion.[17] In this manner, correlations with the US measurements we evaluated appear to be reasonable and expected. Interestingly, our results showed a negative T11-$T12_{dif}$ correlation with BASDAI ($r=-0.280$, $P=.049$); however, considering that BASDAI only addresses the spinal mobility aspect of spinal pain, it does not assess spinal mobility directly, and the weak correlation of this relevance leads us to the conclusion that this result is coincidental. Our results showed that 3 of the US parameters containing thoracic measurements (T11-$T12_{dif}$, T11-T12%, and T+L_{dif}) as well as C6-C7% showed a moderate negative correlation with BASFI. BASFI queries CR with 1 question (directly with the 8th question) and spinal forward flexion with 2 questions (directly with the 2nd question and indirectly with the 1st question)[16]; therefore, the correlation between these US measurements and BASFI is consistent. However, we could not definitively conclude that US may be used instead of BASFI, but may be used as a supportive parameter, as there are 7 additional questions about other daily activities in the questionnaire.

Romagnoli et al[22] suggested that diaphragm and abdominal muscles increase their activity to compensate for restricted rib cage expansion in patients with AS. We expected an increased distance between the costae in the sagittal plane because of the downward force via augmented activity of the diaphragm or a decrease in the distance in the same plane due to the restricted rib cage expansion. However, we found no differences in intercostal distance in the sagittal plane between AS patients and healthy controls. Unlu et al[23] investigated the motion of the diaphragm in AS patients using US. They compared the diaphragmatic motion of 33 AS patients with 14 healthy controls and concluded that there was no difference in the diaphragmatic motion in AS patients versus control patients, which is consistent with the results of the study. Nevertheless, the results of our study did not indicate a correlation between IC_{dif}, IC%, and CE, possibly because the measurements are made in different planes. CE was significantly lower in AS patients than in controls, but IC_{dif} and IC% did not differ between the 2 groups, which may indicate the significance of costovertebral, sternoclavicular, and costosternal involvement in patients with AS.[24,25]

It has been speculated that skin changes occur in both the cutaneous and subcutaneous layers in patients with AS.[26] Previous studies have shown that skin does not obey the Hooke law, which states that the length of the elastic material is directly in proportion to the applied force, and thus has limited flexibility.[27,28] Moreover, no correlation between joint mobility and skin elasticity has been reported, and skin may not match the maximum lumbar sagittal flexibility for reaching its elasticity limit.[6,29] These are disadvantages of measurements such as MST that rely upon skin distraction. We believe there is a major advantage to using US, as it excludes the structure of the skin and directly evaluates bones.

Our study has some limitations. First, the decreased sagittal lumbar mobility was based on results from a prior study; we calculated the cutoff values in reference to this assumption, but that study included only men.[21] Because the literature does not agree on the exact discrimination of MST values for women and essentially uses the same values for assessing both men and women, we assumed that the value from Cidem et al[21] may be applied to both sexes.[17,30,31] Also, the reliability of these measurements was not tested in this study, Furthermore, our results would be different with radiographic angular assessment.

In conclusion, our study demonstrates that US may be used to assess spinal mobility in patients with AS. T11-$T12_{dif}$ <0.79 cm may show a decrease in lumbar sagittal mobility; however, we could not confirm whether CE may be evaluated via US with the method we used. US is a feasible method allowing real-time dynamic assessment, unlike other imaging methods and may be used to examine any part of the spine. Further studies with larger sample sizes are required to assess the reliability of these measurements and modify our suggested methods.

Author contributions

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