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A higher body mass index and increased syndesmophytes volume are associated with facet joints ankylosis on thoracic spine in patients with ankylosing spondylitis: a retrospective cohort study

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Abstract

Objective To investigate the association between syndesmophytes and facet joint (FJ) lesions in patients with ankylosing spondylitis (AS), and to identify clinical factors associated with FJ ankylosis (FJA) in thoracic segment.

Methods Ninety-seven patients with AS who underwent thoracic spine computed tomography (CT) or chest CT and without completely thoracic spine fusion were included. FJ lesions were analyzed for the numbers and distribution of normal, ankylosis, erosions, joint-space narrowing, osteophytes, and subchondral sclerosis. The volume of vertebral syndesmophtes unit (VSU) and total thoracic syndesmophtes volume were separately calculated by Mimics software. Clinical factors associated with FJA were investigated using generalized estimation equation (GEE). The association between syndesmophtes volume and numbers of FJ structural lesions was analyzed using generalized additive mixed model (GAMM).

Results 2328 FJ and 1164 VSUs in thoracic spine were assessed. The majority FJ structural lesions were ankylosis (32.39%). FJA was more frequently seen in vertebrae with syndesmophytes formation ($p < 0.001$). GEE showed that patients with normal BMI (18.5–24.9 kg/m^2) and high BMI (> 24.9 kg/m^2) were more likely to have FJA in thoracic spine (odds rations [95% confidence interval]: 0.27(0.12–0.59), 1.45(1.03–8.57), respectively). GAMM showed that syndesmophytes volume increase the numbers of FJA (standard $\beta = 0.009$, $p < 0.05$) and decreased the numbers of normal FJ (standard $\beta = -0.07$, $p < 0.01$).

Conclusion FJA was the most common FJ structural lesion in thoracic spine, and it increases linearly with syndesmophytes before the bridging syndesmophytes formed. A higher BMI (especially > 24.9 kg/m^2) and increased syndesmophytes volume are associated with FJA in thoracic spine.

Keywords Facet joints, Syndesmophytes, Clinical associated factors, Ankylosing spondylitis, Computed tomography

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Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory disease that involves predominantly the sacroiliac joints and spine, leading to structural and functional impairments [1]. Inflammation and subsequent abnormal new bone formation are hallmark features of AS. Both vertebral bodies and facet joints (FJ) can be engaged in the inflammation and process of bone proliferation [2]. Ossification grows vertically along or near the annulus fibrosus in the intervertebral disc form the syndesmophtes [3]. Similarly, pathological bone formation in the facet joint can cause facet joint ankylosing (FJA) [4]. Many studies have revealed that vertebral corner inflammation and subsequent syndesmophtes could induce pain and restriction of spinal mobility in AS. However, FJ involvement has been less intensively investigated than syndesmophtes and was underestimated. Since FJA in AS is also associated with functional impairment, reduced spinal range of motion and loss of quality of life [5]. Therefore, more attention should be given to FJ involvement in AS.

The impetus for exploring the link between FJA and syndesmophytes stems from clinical observations that have consistently pointed to a significant interaction between these two phenomena. There is debate about whether syndesmophytes develop precedes FJA or vice versa [6, 7]. Bridging syndesmophytes is a strong predictor for FJA [8]. Whereas, the quantitative relationship between syndesmophytes and FJA has yet to be fully delineated. In AS, structural lesions of FJ involvement include erosions, osteophytes and joint-space narrowing when compared with non-radiographic axial spondyloarthritis (nr-AxSpA) and normal [2]. Whether and how syndesmophytes impact on other forms of FJ structural changes remains enigmatic. Besides, to the best of our knowledge, the associations between clinical factors related to FJA other than syndesmophytes have not been investigated in patients with AS. Given that FJA is predominantly observed in the thoracic spine [5], a detailed investigation of FJs in this region is warranted. While mSASSS, the most widely used scoring system for assessing radiographic damage and progression on conventional radiography (CR) of AS, does not include the thoracic spine and posterior parts of the vertebrae. Contrary to CR, computed tomography (CT) is able to visualize and evaluate all spinal elements. And CT is considered best for FJ structural damage assessment due to its superb spatial resolution [2, 9]. In summary, to address the aforementioned inquiries, this study employs quantitative thoracic CT to investigate the quantitative impact of syndesmophytes on FJ structural lesions in patients with AS. Clinical factors that associated with the occurrence of FJA in thoracic segment were analyzed in this retrospective study as well.

Method

Patients and clinical data

This study presents the findings of a retrospective analysis, which involved a thorough review of imaging and clinical data of hospitalized patients in The First Medical Center of Chinese PLA General Hospital from September 2020 to January 2022. Inclusion Criteria: 1) Patients diagnosed with AS according to the 1984 Modified New York Criteria. 2) Patients aged 18 years or older. 3) Complete chest CT or thoracic spine CT imaging data available. Exclusion Criteria: 1) Absence of syndesmophytes in the thoracic spine. 2) Complete fusion of syndesmophytes in the thoracic spine. 3) History of thoracic spine fractures or thoracic spine surgery. 4) Presence of thyroid disease or other conditions affecting bone remodeling.

Age, sex, disease duration, history of inflammatory back pain, achilles enthesitis, peripheral arthritis, uveitis and ulcerative colitis, smoking status, body mass index (BMI), presence of human leucocyte antigen (HLA)-B27, C-reacting protein (CRP), erythrocyte sedimentation rate (ESR) were collected.

CT scanning and reconstructions

Thoracic spine CT or chest CT was performed on 64-slice multiple spiral CT (Siemens Company, German). Patients were in a supine position. Chest CT images were acquired during inspiratory breath-hold. CT parameters were as follows: tube voltage 120 kV, automatic tube current, matrix 512–512. Axial and coronal with 1.25 mm slice thickness from C7 to L1 were acquired and saved in format of DICOM. The 3D reconstructions were then made in Mimics Research 21.0 software (Materialise NV, Leuven, Belgium) according to the step-by-step approach.

Imaging assessments

Syndesmophtes volume were automatically calculated by Mimics software (Fig. 1A-D). Syndesmophtes volume in anterior aspect of thoracic vertebrae and the corresponding intervertebral disc space (IDS) were summed to the volume of vertebral syndesmophtes unit (VSU). The volume of 12 thoracic VSU (T1-T2, T2-T3, T3-T4, T4-T5, T5-T6, T6-T7, T7-T8, T8-T9, T9-T10, T10-T11, T11-T12, T12-L1) were individually calculated. Patient's total syndesmophtes volume in thoracic region was then calculated as the sum of 12 thoracic VSU volume.

CT analysis of FJ was evaluated using bone window on the axial images. It was independently assessed by two experienced CT reading rheumatologists and by a musculoskeletal radiologist in the event of discrepancy.

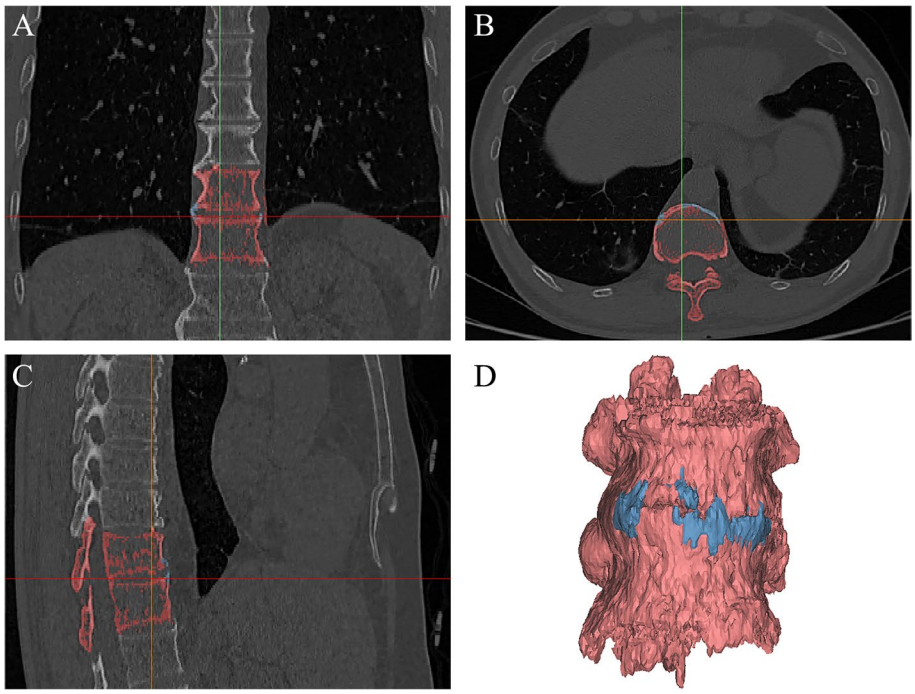

Fig. 1 Thoracic CT and 3D reconstruction of a 53-year-old male patient with AS. (ABC) Syndesmophtes in T11-T12 were marked in blue in coronal, axial, sagittal, respectively. Vertebrae were marked in red. **D** The 3D reconstruction of syndesmophtes were automatically made in Mimics software according to the marked blue area in ABC

FJ structural changes were divided into disease-specific (ankylosis, erosions) and non-specific (joint-space narrowing, osteophytes and subchondral sclerosis) changes according to the classification mentioned in previously literature [2]. Numbers of FJ structural lesions in each thoracic vertebrae were calculated.

Statistical analysis

IBM SPSS Statistics for windows, version 25.0 and R 4.2.2 were used for the data analyses. Two-sided *p*-value less than 0.05 was considered statistically significant. Normal distribution and variance homogeneity tests were performed on all continuous data. Continuous data were expressed as mean ± standard deviation or median (range). Categorical data were expressed as percentages. Statistical comparisons of the results between different vertebrae were performed in Chi-square test, Pearson's Chi-square test and nonparametric Kruskal–Wallis (K-W) test. Univariate and multivariate regression models were used to determine risk factors for total thoracic syndesmophtes volume.

In this study, repeated measurement data were VSU volume and numbers of each FJ structural lesion in 12 thoracic vertebrae. Both data were non-normal, homoscedastic and non-independent. A generalized estimation equation (GEE) Poisson loglinear model was used to estimate odds ratios (ORs) and associated 95% confidence interval (CI) for the potential clinical risk factors for FJA. Since VSU volume and numbers of FJ structural lesions varied as vertebrae change, confounding effect of thoracic vertebrae needed to be considered when exploring the influence of syndesmophtes volume on FJ structural changes. Generalized additive mixed models (GAMMs) have the advantage of relaxed independence assumptions and are ideal tools for analyzing repeated measurement data [10]. Therefore, GAMM were applied to investigate the relationships between syndesmophtes volume and FJ structural changes in vertebrae level. Intercept and thoracic vertebrae were included as random terms. The graphs were created in R.4.2.2 and were arranged in Adobe Illustrator.

Results

Characteristics of patients

The demographic and clinical characteristics of 97 AS patients are shown in Table 1. Eighty-six (88.66%) patients were male and 11 were female. The mean age of the patients was 50.86 ± 12.36 years and the mean disease duration was 18.1 years. Ninety-six (98.97%) patients had inflammatory back pain when having the thoracic spine CT or chest CT. The average level of inflammatory

Table 1 Characteristics of the 97 patients with ankylosing spondylitis

Variables	N(%) or mean ± sd or median(range)
Age, years	50.86 ± 12.36
Male	86(88.66%)
Disease duration, years	18.1(1–50)
Inflammatory back pain	96(98.97%)
Ever Achilles enthesitis	14(14.43%)
Ever peripheral arthritis	45(46.39%)
Ever uveitis	17(17.53%)
Ever ulcerative colitis	9(9.28%)
Current smoker	33(34.02%)
Body mass index, kg/m^2	24.72 ± 4.07
CRP, mg/dl	3.0(0.01–18.68)
ESR, mm/h	33.37(2–111)
HLA-B27 positive	88(90.72%)

markers including CRP and ESR were both above the normal range.

CT findings of thoracic FJ changes and syndesmophytes

Interreader agreement was 0.81–0.89 in disease-specific changes and was 0.53–0.62 in non-specific changes, respectively. In total, 2328 thoracic FJ were assessed in 97 AS subjects. The majority were ankylosis (32.39%). Joint-space narrowing, subchondral sclerosis, osteophytes and erosion were seen in 6.27%, 4.51%, 5.28%, and 6.01%, respectively (Fig. 2A). A greater percentage of normal FJ was found in T5-T8 ($p < 0.01$). In contrast, FJA and erosion were less frequently seen in T5-T8 ($p < 0.01$). No statistical differences were found in the distribution of FJ osteophytes, joint-space narrowing, sclerosis between T5-T8 and other thoracic vertebrae except T5-T8. Their p-values were 0.15, 0.89 and 0.94, respectively.

Ninety-seven subjects contributed data on 1164 VSUs (Fig. 2B). No syndesmophytes formation were found in 98 (8.42%) VSUs. The average volume of VSU was 1.73 cm^3. Compared to the lower thoracic vertebrae (T8-L1), the upper thoracic vertebrae (T1-T8) significantly developed decreased syndesmophytes volume ($p < 0.01$). Of these, the smaller volume of syndesmophytes grew in T5-T8, especially in T6-T7 with an average volume of 0.95 cm^3.

We divided 1164 vertebral units into two groups according to the presence or absence of syndesmophyte formation. FJA was more common in vertebral units with syndesmophytes formation (34.57% vs 8.67%, $p < 0.001$). Nevertheless, normal FJ was less frequently exhibited in the aforementioned group (42.49% vs 78.57%, $p < 0.001$).

Associated factors for total syndesmophytes volume in thoracic spine

Table 2 summarizes the outcomes of univariate and multivariate linear regression analyses. Firstly, each demographic and clinical characteristic was tested in univariate linear regression model. Results revealed a significant correlation between age, disease duration, ever peripheral arthritis and BMI with total syndesmophytes volume in thoracic spine. The standard β values were 0.11, 0.43, 1.51, 0.96, respectively ($p < 0.05$). Then, variables with p-value less than 0.2 in univariate linear regression model were included in the multivariate linear regression model to identify the independent associated factors for total thoracic syndesmophytes volume. Results showed current smoking and BMI positively associated with total thoracic syndesmophytes volume. The standard β values were 1.33 and 1.18, respectively ($p < 0.05$).

Associated factors for FJA in thoracic spine

Results confirmed that BMI was significantly associated with the numbers of FJA in thoracic spine (Table 3). Patients with normal BMI (BMI within 18.5–24.9 kg/m^2) and high BMI (> 24.9 kg/m^2) were more likely to have FJA ($p < 0.05$). The odds rations (ORs) of FJA per 1 number increase in patients with normal-BMI and high-BMI were 0.27 and 1.45, respectively.

Relationship between syndesmophytes volume and FJ changes

Analyses of splines revealed a U-shaped relation of numbers of FJA and syndesmophytes volume with thoracic vertebrae (Fig. 3A, B). FJA was less common in T5-T8. Similarly, syndesmophytes volume was smaller in T5-T8. Therefore, the confounding factor of vertebrae needed to be taken into account when studying the association between FJA and syndesmophtes volume. After adjustment, the GAMM showed that syndesmophytes volume had positive impacts on the numbers of FJA (standard β = 0.009, $p < 0.05$) and negative impacts on the numbers of normal FJ (standard β = -0.07, $p < 0.01$) in all patients. While in analyzing the impacts of syndesmophytes volume on FJ erosion, joint-space narrowing, osteophyte and sclerosis, the results were not statistically significant. The standard β values were -0.104($p = 0.07$), -0.01($p = 0.63$), 0.02($p = 0.51$), 0.01($p = 0.71$), respectively.

Discussion

In this study, we used CT to assess the FJ structural lesions in thoracic spine of patients with AS, and investigated the relationship between syndesmophytes volume and FJ structural lesions using GAMM. Our results revealed that only FJA and normal FJ were significantly

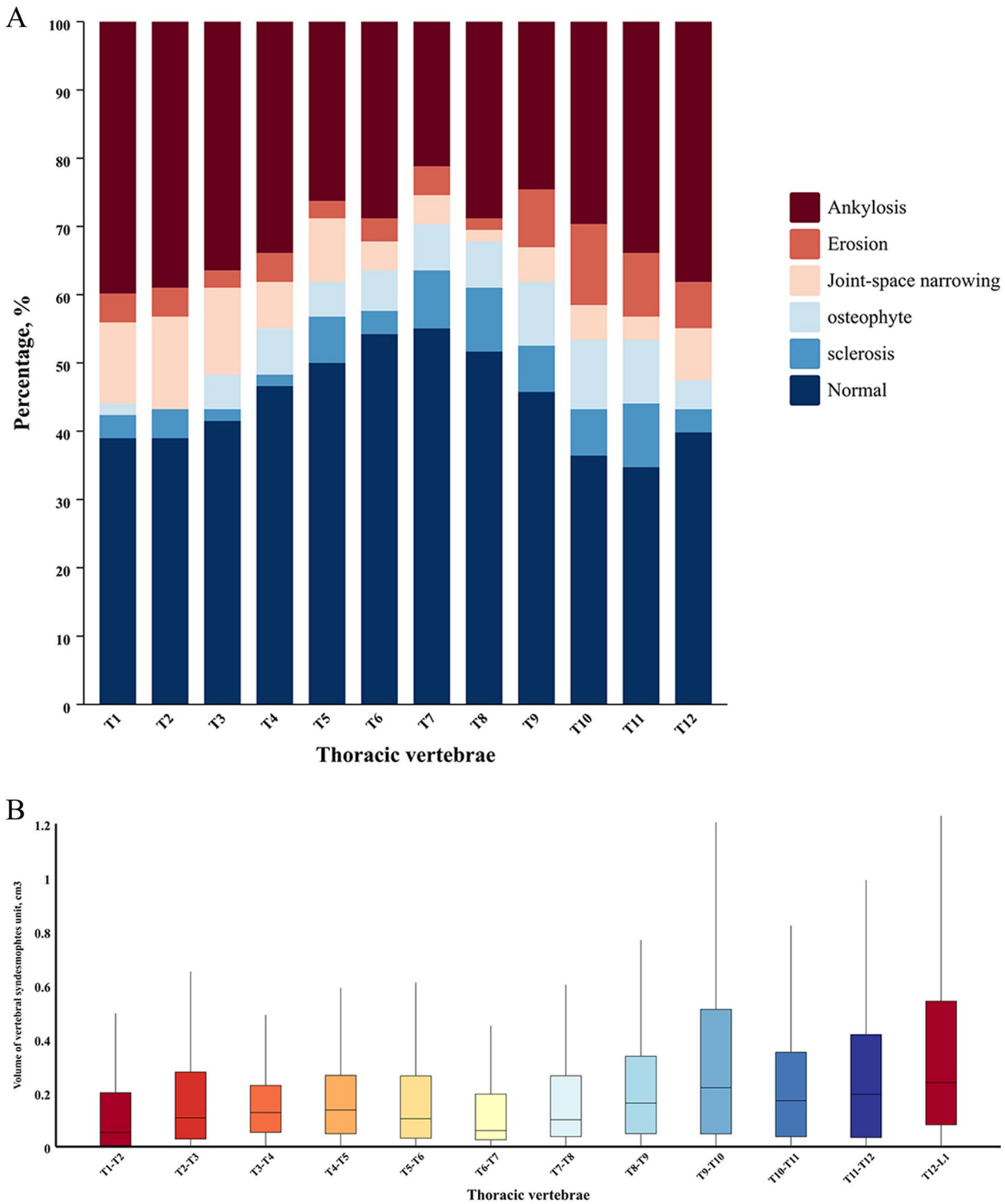

Fig. 2 The distributions of facet joints structural changes and vertebral syndesmophytes volume in each thoracic spine. **A** facet joints structural changes; **B** vertebral syndesmophytes volume

Table 2 Associations between clinical variables and total thoracic syndesmophtes volume

Variables	Univariate analysis		Multivariate analysis	
	Standard β (95%CI)	*p*-value	Standard β (95%CI)	*p*-value
Sex	4.83(-4.91, 8.63)	0.63		
Age, years	0.11(0.02, 0.41)	0.02*	0.28(-0.89, 0.32)	0.35
Disease duration, years	0.43(0.15, 0.77)	0.04*	0.43(-0.28, 1.14)	0.23
Inflammatory back pain	-0.88(-7.11, 5.34)	0.78		
Ever Achilles enthesitis	-1.63(-3.51, 1.63)	0.86		
Ever peripheral arthritis	1.51(0.29, 2.74)	0.04*	0.28(-0.31, 2.22)	0.56
Ever uveitis	0.72(-9.31, 2.36)	0.86		
Ever ulcerative colitis	0.32(-2.13, 2.19)	0.98		
Current smoker	1.23(-0.76, 2.53)	0.06	1.33(0.97, 5.65)	0.04*
BMI, kg/m^2	0.96 (0.58, 2.49)	0.02*	1.18(0.31, 2.69)	0.01*
CRP, mg/dl	0.31(-1.34, 1.96)	0.71		
ESR, mm/h	-0.02(-0.24, 0.19)	0.82		
HLA-B27 positive	-0.85(-2.51, 2.82)	0.94		

BMI Body mass index, *CRP* C-reacting protein, *ESR* Erythrocyte sedimentation rate, *HLA* human leucocyte antigen

* $p < 0.05$

** < 0.01

associated with syndesmophytes volume in thoracic spine. The regression coefficient value of FJA and normal FJ were 0.009 and -0.07 with 1 cm^3 thoracic syndesmophytes volume increase.

This study has several strengths. First, to our knowledge, it is the first study to investigate the clinical associated factors for FJA in thoracic spine of patients with AS. The results identified increasing BMI serves as a strong associated factor with thoracic FJA. Second, our study quantitatively explored the impact of syndesmophytes on the structural changes of the FJs beyond FJA for the first time. Third, our study pioneered the use of a novel CT analysis technique to quantify the volume of syndesmophytes, thereby facilitating an exploration of the relationship between syndesmophytes volume and FJA. The findings indicated that FJA commonly occurs in vertebral bodies with syndesmophytes, and intriguingly, this can happen even before the bridging syndesmophytes formed. As the volume of syndesmophytes increases, so too does the likelihood of FJA development. Thus, controlling the growth of osteophytes could be instrumental in mitigating the incidence of FJA.

However, our study also has several limitations. Giving this was a retrospectively study, indicators related to the disease activity such as ASDAS and spinal motion had not been measured and included. Thus, the potential influence from confounders of disease activity could not be excluded from the present study. Besides, our study included only a small number of AS patients with thoracic spine CT. It is not certain whether there are similar results in other segments of the spine. Also, generalized models used in analyzing the small samples size cohort may not be powered enough. Large sample size analyses need to be conducted in the future to give more evidence for the associations between FJ structural lesions and syndesmophytes in whole spine of patients with AS.

FJ locate in the posterior region of the vertebral column and are one of the commonly involved sites in AS. Due to the difficulty to visualizing abnormalities of FJ on radiographs, there are not so many studies of FJ involvement in AS. Low dose CT (ldCT) has been used over the years to study structural lesions in spine of AS [11, 12]. Despite ldCT having the advantages of low radiation, image quality is not perfectly clear. Jung et al. [5] used whole spine ldCT to assess the FJ structural lesions at different sites in the spine of patients with AS. FJ abnormalities were graded into ankylosis and no ankylosis. Irregularities like erosion, joint-space narrowing and subchondral sclerosis were hard to assess on ldCT images and were scored 0 as same as normal. Limits may exist when studying the progression of FJ structural lesions and the correlation with other clinical variables using ldCT. CT has the advantages to clearly display structural lesions of spine in patients with AS. In our study, conventional CT was used in assessing the spectrum of FJ involvement. So far, only two existing studies have been dedicated on reporting details of FJ structural changes in AS using CT [2, 7]. As were mentioned in previous cross-sectional study, FJ structural changes were divided into disease-specific and disease non-specific lesions [2]. In our study, we found that the most common lesions of FJ in thoracic spine of

Table 3 Risk factors for facet joints ankylosis in thoracic spine

Variables	ORs (95%CI)	*p*-value
sex		
Female	1	
Male	1.09(0.56, 2.11)	0.79
Age, years		
(~, 30)	1	
(30, 40)	0.59(0.14, 2.47)	0.47
(40, 50)	0.57(0.22, 1.49)	0.25
(50, 60)	1.27(0.49, 3.26)	0.62
(60, 70)	0.31(0.09, 1.12)	0.08
(70, ~)	0.51(0.16, 1.63)	0.26
Disease duration, years		
(~, 10)	1	
(10, 20)	1.66(0.82, 3.35)	0.16
(20, 30)	1.15(0.48, 2.79)	0.75
(30, 40)	1.46(0.54, 3.96)	0.45
(40, 50)	1.56(0.95, 4.56)	0.21
Inflammatory back pain	0.39(0.17, 1.87)	0.23
Ever Achilles enthesitis	1.03(0.58, 1.82)	0.93
Ever peripheral arthritis	1.18(0.77, 1.79)	0.45
Ever uveitis	1.26(0.66, 2.43)	0.48
Ever ulcerative colitis	0.46(0.21, 0.99)	0.05
Current smoker	1.03(0.63, 1.69)	0.89
BMI, kg/m^2		
< 18.5	1	
18.5–24.9	0.27(0.12, 0.59)	< 0.01**
> 24.9	1.45(1.03, 8.57)	0.02*
Elevated level of CRP	1.02 (0.96, 1.08)	0.58
Elevated level of ESR	0.99(0.98, 1.01)	0.28
HLA-B27 positive	0.90(0.56, 1.45)	0.67

BMI Body mass index, *CRP* C-reacting protein, *ESR* Erythrocyte sedimentation rate, *HLA* Human leucocyte antigen

* $p < 0.05$

** $p < 0.01$

AS was ankylosis. And it was seen almost exclusively in thoracic vertebrae with syndesmophytes growth. These findings are not exactly the same as Slobodin et al. [2] research results. Slobodin et al. found that FJA were very prevalent in patients with AS with syndesmophytes. But in AS without syndesmophytes, the majority were osteophyte formation, followed by joint-space narrowing and normal. The discrepancy could be due to the methodological differences. The differences of FJ structural lesions between groups with or without syndesmophytes in our study were analyzed in vertebral-level. Whereas, the differences were compared in individual patient-level in Slobodin et al. research. Besides, all the 97 included patients in our study had syndesmophytes growth in at least one vertebral-level. Eleven of the 49 enrolled patients in Slobodin et al. research had no syndesmophytes formation in whole spine.

Another interesting finding in the present study was that the distribution of FJA in thoracic spine displayed a U-shape. FJA occurred less commonly in T5-T8. Our results are in accordance with Jung et al. research [5]. Similarly, syndesmophytes volume in T5-T8 was smaller. In addition to FJA, FJ erosion was found statistically less common in T5-T8. As were mentioned in previous studies, ankylosis and erosion had been defined as disease-specific FJ structural changes in AS [2, 13]. No study to date has specifically explored the correlation between mechanical stress and FJ structural lesions. Considering that the anatomical position of the heart is located in the anterior aspect of T5-T8, the mobility of the spine in such segment is restricted. Whether the impact of from heart's pulsation may influence AS-specific FJ structural lesions and the formation of syndesmophytes in such vertebral segments needs further study. Even though it is not yet known how mechanical stress influences bone formation at the molecular level. Evidences suggest that the development of syndesmophytes may be influenced by mechanical stress [14]. Tan et al. [15] had demonstrated that mechanical effects from aorta results in less frequent development of syndesmophytes in AS. Even more, the "dose–response" association was found in patients whose aorta was closer to the spine. In addition, ossification in DISH was found developed mainly on the right side of the spine in thoracic segment, which verified the 'aortic pulsation protective effect' theory [16, 17].

Several studies have been dedicated to exploring the related factors with syndesmophytes. Stal et al. using MRI and ldCT identified that vertebral corner inflammation and vertebral corner fat deposition were positively associated with syndesmophytes development [18]. Beyond that, gender, age, disease duration, smoking, BMI and AS disease activity score (ASDAS) have also been reported to be associated with syndesmophytes formation [19, 20]. In our study, liner regression models revealed that current smoking and BMI associated with increased total thoracic syndesmophytes volume. In addition, clinical factors associated with FJA in thoracic spine were firstly investigated in AS patients using GEE model in our study. Increased BMI was found to be a significant associated factor with FJA, especially in patients with a BMI > 24.9 kg/m^2. A recent review concluded that a higher BMI was an independent risk factor for the presence of syndesmophytes in patients with SpA [21]. While to our knowledge, no studies have been conducted to evaluate the associated factors for thoracic FJA in patients with AS. Only one research has elaborated that the whole spine ankylosed FJ score was significantly

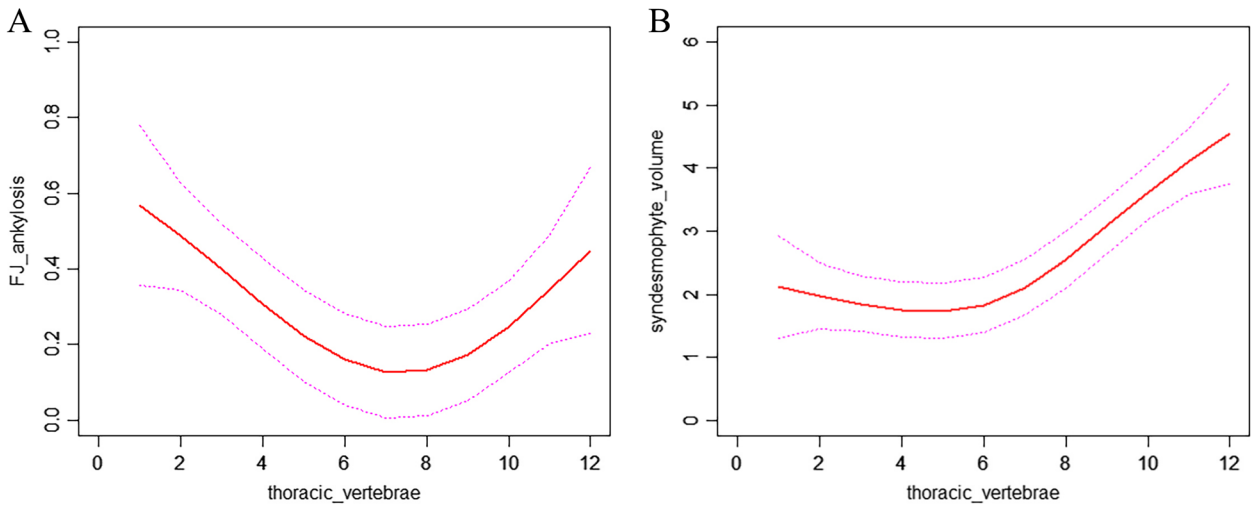

Fig. 3 Facet joints ankylosis and syndesmophytes volume in 12 thoracic vertebrae. **A** facet joints ankylosis; **B** syndesmophytes volum

associated with a history of uveitis, ASDAS, sacroiliitis and syndesmophyte score in patients with axSpA in Korea [22]. It is well known that adipose tissue not only is a storage organ but also produces a wide variety of adipokines that participate in inflammation and immunity processes [23–25]. Adipokines mediate multiple signaling pathways that play important roles in regulating bone metabolism [26, 27]. Therefore, maintaining an ideal BMI may help attenuate the progression of syndesmophytes and FJA.

The issue of whether syndesmophytes development precedes FJA has been debated with controversial results. The findings in our study were that FJA was almost exclusively encountered in vertebrae with syndesmophytes growth, and were in line with previous study [7]. However, the quantitative relationship between syndesmophytes volume and FJA and the effects of syndesmophytes on other structural lesions of FJ were not assessed till now. Syndesmophytes volume and FJ structural lesions both can vary with change in thoracic vertebrae. The GAMM approach represents an extension of GEE model, which is used to process data that both independent and dependent variables are repeated measurement data [28]. The results showed that syndesmophytes volume significantly influenced the numbers of normal and ankylosing FJ in thoracic spine of patients with AS. The regression coefficient value of FJA and normal FJ were 0.009 and -0.07 with 1 cm^3 thoracic syndesmophytes volume increase. Whereas the effects of syndesmophytes volume on the numbers of FJ erosion, osteophytes, joint-space narrowing and sclerosis were not significant. Consequently, we conclude that even before the bridging syndesmophytes are formed, ankylosing FJ also increases linearly with syndesmophytes in thoracic spine. It has previously been shown that FJ disease in patients with AS result in functional impairment and restriction of spinal mobility [5]. In light of these points, more attention on FJ structural lesions would be demanded when assessing and monitoring spinal structural damage in AS in addition to syndesmophytes.

Conclusion

Our study elaborates the details of FJ structural lesions in AS. FJA was the most common structural lesion in thoracic spine, and it increases linearly with syndesmophytes before the bridging syndesmophytes formed. Additionally, the distribution of FJA and the volume of syndesmophytes in thoracic spine displayed a U-shape. AS-related lesions (FJA and FJ erosion) were less common in T5-T8 specially. Also, a higher BMI was identified as an independent associated factor for the presence of FJA in thoracic segment.

Abbreviations

AS	Ankylosing spondylitis
axSpA	Axial spondyloarthritis
nr-AxSpA	Non-radiographic axial spondyloarthritis
SpA	Spondyloarthritis
FJ	Facet joint
FJA	FJ ankylosis
CT	Computed tomography
VSU	Vertebral syndesmophtes unit
GEE	Generalized estimation equation
GAMM	Generalized additive mixed model
BMI	Body mass index
CR	Conventional radiography
HLA	Human leucocyte antigen
CRP	C-reacting protein
ESR	Erythrocyte sedimentation rate
IDS	Intervertebral disc space
ORs	Odds ratios
CI	Confidence interval
ldCT	Low dose CT
DISH	Diffuse idiopathic skeletal hyperostosis

ASDAS AS disease activity score

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Authors' contributions
Demographic and clinical data were collected by Simin Liao and Jian Shang. Imaging assessments were conducted by Simin Liao, Jian Shang and Liuquan Cheng. The first draft of the manuscript was written by Simin Liao. Jian Zhu contributed to the conceptualization and design of the study, as well as supervise the data collection. Feng Huang contributed to the conceptualization and design of the study, supervise the data collection, writing – review & editing. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was reviewed and approved by 'Ethics Committee of Chinese PLA General Hospital' (S2023-168–01). Informed consent was waived by 'Ethics Committee of Chinese PLA General Hospital' because this study retrospectively reviewed the electronic medical records and imaging data.

Consent for publication
None.

Competing interests
The authors declare no competing interests.

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