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RESEARCH ARTICLE

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Decreases in lung volume and lung height among ankylosing spondylitis patients with pulmonary function impairment: a 3D CT investigation

Jianshou Zhou[1*], Qiuyi Cai[1], Zhengkai Zhao[1], Maoliang Dai[1] and Yijian Liang[2]

Abstract

Background Respiratory compromise among ankylosing spondylitis (AS) patients is characterized by restrictive pulmonary function, leading to the need for a meticulous assessment of lung volume. Compared with conventional pulmonary function tests (PFTs), CT-based lung volume measurements have superior accuracy and are crucial for understanding functional limitations in AS. This study investigated the correlation between CT lung volume and PFT parameters in AS patients, with a focus on changes in CT parameters and lung volume in patients with compromised pulmonary function.

Methods A total of 79 AS patients were included, and their full-length radiographs, thoracic CT scans, and PFT data were analysed. Specialized software was used to estimate the total and lobar lung volumes from the CT scans. The relationship between lung volume and PFT results was examined, and a multiple linear regression model was constructed to determine the influence of radiographic and CT parameters on total lung volume (TLV). Patients were classified into normal or impaired pulmonary function groups based on PFT outcomes, thus facilitating comparative analyses of radiographic and CT parameters and lung volumes between these groups.

Results Among the 79 AS patients, 19 had normal function, 4 had mixed dysfunction, and 56 experienced restrictive dysfunction. PFT parameters, including FVC, FEV1, TLC, FEV1%, and TLC%, showed varying correlations with TLV and individual lobe volume. Patients with compromised pulmonary function exhibited more pronounced spinal kyphosis and experienced a decline in TLV. Multiple regression analysis revealed that lung height and horizontal and vertical lung diameters independently influenced TLV. Notably, a decrease in lung height was observed in patients with impaired pulmonary function, whereas the horizontal and vertical diameters of the lungs remained stable.

Conclusions In AS patients, TLV was found to be correlated with pulmonary function, particularly parameter such as FVC, FEV1, and TLC. A significant reduction in TLV was observed in those with impaired pulmonary function, with the primary contributing factor being a decrease in lung height.

Keywords Ankylosing spondylitis (AS), Lung volume, Computed tomography (CT), Pulmonary function test (PFT)

*Correspondence:
Jianshou Zhou
zhoujianshou@126.com
Full list of author information is available at the end of the article

Introduction

In rheumatology, ankylosing spondylitis (AS), a chronic inflammatory disorder, frequently coexists with thoracolumbar kyphosis and respiratory complications. Restrictive pulmonary function is a critical marker of pulmonary dysfunction that is commonly observed in AS patients [1]. To accurately assess this impairment, it is necessary to examine lung volume [2]. Computed tomography (CT) technology is characterized by reliability and precision with respect to quantifying lung volume, and it has been extensively employed to study structural lung changes associated with respiratory limitations, particularly in individuals with spinal deformities [3–6].

Nonetheless, few studies have employed CT to investigate structural modifications and lung volume alterations in AS patients experiencing compromised pulmonary function. This study aimed to bridge this gap by investigating the correlation between CT-measured lung volumes and PFT results in AS patients, with a particular focus on identifying structural and volumetric changes in those with impaired pulmonary function.

Materials and methods

Patients

This study included 68 males and 11 females, with an average age of 40.0 ± 9.4 years. A retrospective analysis was conducted based on the medical records of patients diagnosed with AS who had undergone orthopaedic surgery. The inclusion criteria were as follows: (1) a confirmed AS diagnosis in accordance with the modified New York criteria and (2) availability of preoperative radiographs, thoracic CT scans, and PFT. The exclusion criteria were as follows: (1) history of spinal or cardiothoracic surgery, (2) active bronchial asthma or recent lung infections, and (3) inability to reconstruct CT lung volumes. Comprehensive data were collected for each patient, including disease duration and demographic characteristics such as sex, age, height, arm span, and body mass index (BMI). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Approval for the study was obtained from the ethics committee of the Third People's Hospital of Chengdu. Individual consent for this retrospective analysis was waived.

Radiographic parameters

Preoperative standard full-length standing anteroposterior and lateral radiographs were acquired for comprehensive analysis. Thoracic height was precisely measured on anteroposterior views, whereas thoracic kyphosis (TK) from T5 to T12 and global kyphosis (GK) were determined from lateral radiographs, as illustrated in Fig. 1A. Thoracic height was quantified by calculating the vertical distance between the T1 and T12 vertebrae [7, 8]. To calculate the GK, the angle was measured between the superior endplate of the vertebra with the greatest inclination (upper-end vertebra) and the inferior endplate paramount to the vertebra with the greatest inclination (lower-end vertebra) [9].

CT scanning and quantitative image analysis

The preoperative thoracic CT scans were performed via a Philips 256-slice Brilliance iCT scanner with low-dose settings, 0.625 mm collimation, and autoexposure control adjusted for patient size. All participants were instructed to hold their breath at end-inspiration. The following measurements were derived through multiplane image reconstruction:

1. ***Lung Height (LH)*** A vertical sagittal reconstruction of the right lung from its apex (Fig. 1B) was conducted for lung dimension evaluation. A reference line, depicted by the red arrow in Fig. 1C, connects the lung apex to the mid-diaphragm to determine the right lung height (RLH). The left lung height (LLH) was measured via the same method. The LH value was calculated as the mean RLH and LLH.
2. ***Lung Horizontal Diameter (LHD), Lung Vertical Diameter (LVD), and Thoracic Ratio*** Axial CT images were reconstructed at the midpoint of the RLH, thus ensuring a perpendicular orientation. The LHD and LVD were precisely quantified by determining the maximal horizontal and vertical dimensions of the inner thoracic border (Fig. 1D), thus enabling the calculation of the thoracic ratio, defined as the ratio of the LHD to the LVD.

CT lung volumes

The 3D reconstructions of the lung parenchyma were generated via Lung Doc software, version 1.19.1 (Shu Kun Network Technology, Beijing, China), as depicted in Fig. 1E. To ensure the exclusion of extraneous soft tissue and large vessels, a threshold range of 400 to 1024 Hounsfield units (HUs) was employed. The trachea and main bronchi were deliberately excluded from the 3D model to facilitate the segmentation of individual lobe volumes and the calculation of the total lung volume (TLV). A total of eight computed parameters were derived: left lung volume (LLV), left upper lobe volume (LULV), left lower lobe volume (LLLV), right lung volume (RLV), right upper lobe volume (RULV), right middle lobe volume (RMLV), right lower lobe volume (RLLV), and TLV.

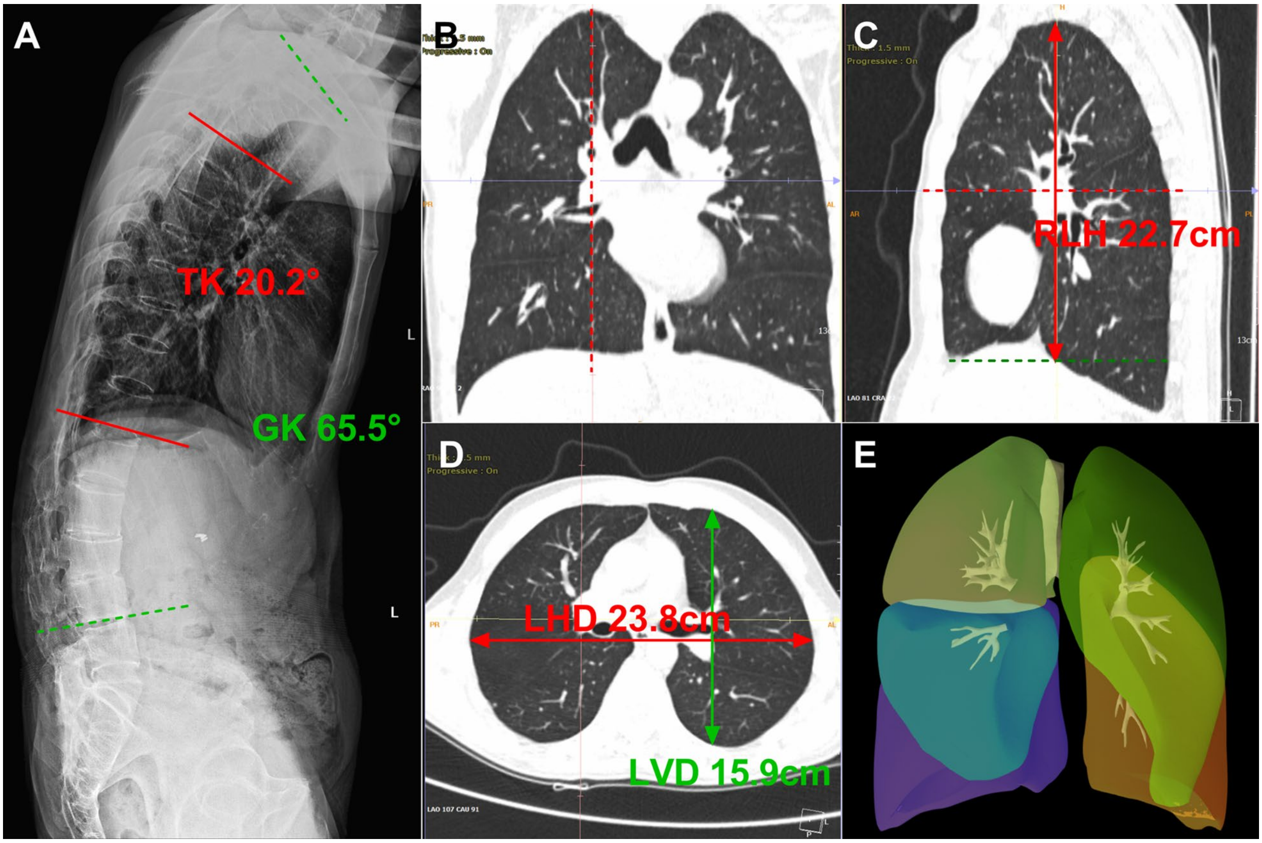

Fig. 1 A 38-year-old male patient diagnosed with AS with normal pulmonary function. The lateral radiograph (**A**) showed mild spine kyphosis. A vertical sagittal reconstruction of the right lung from its apex (**B**) was conducted for lung dimension evaluation. A reference line, depicted by the red arrow in **C**, connects the lung apex to the mid-diaphragm for determining the RLH. The LLH was measured using the same method. The LH value was calculated as the mean of RLH and LLH. The axial CT image (**D**) was reconstructed at the midpoint of the RLH, as indicated by the red dotted line in **C**, with a perpendicular orientation. Maximal horizontal and vertical dimensions of the inner thoracic border were measured to obtain the LHD and LVD, respectively, as depicted by the red and blue arrows in **D**. The Thoracic Ratio was determined by calculating the ratio of LHD to LVD. End-inspiratory 3D volumetric reconstructions (**E**) were utilized to compute TLV and individual lobe volumes. AS, ankylosing spondylitis; RLH, right lung height; LLH, left lung height; LH, lung height; LHD, lung horizontal diameter; LVD, lung vertical diameter; TLV, total lung volume

Pulmonary function test

Preoperative PFTs were conducted on all patients in the study. An experienced physician's assistant took each measurement via a digital spirometer (Renaissance II; Puritan Bennett, Boulder, CO) with the patients in the seated position. The collected pulmonary function parameters included forced vital capacity (FVC), percent predicted forced vital capacity (FVC%), forced expiratory volume in the first second (FEV1), percent predicted forced expiratory volume in the first second (FEV1%), the FEV1/FVC ratio, total lung capacity (TLC), and percent predicted total lung capacity (TLC%). These predicted percentages were calculated based on normative values adjusted for age and arm span. The study categorized the patients into four distinct ventilatory patterns: normal (FVC% > 80%, FEV1/FVC > 70%), restrictive (FVC% ≤ 80%, FEV1/FVC > 70%), obstructive (FVC% > 80%, FEV1/FVC ≤ 70%), and mixed (FVC% ≤ 80% and FEV1/FVC ≤ 70%) [10–12]. Pulmonary impairment severity was categorized according to the American Thoracic Society guidelines: 'no' impairment for FVC% > 80% of the predicted value, 'mild' for FVC% ≤ 80% but > 65%, 'moderate' for FVC% ≤ 65% but > 50%, and 'severe' for FVC% ≤ 50% [13].

Statistical analysis

Statistical analyses were performed via SPSS software, version 27.0 (SPSS Inc., Chicago, IL, USA). The data are presented as the means ± standard deviations. Patients were categorized into either a normal or an impaired pulmonary function group based on PFT results. Group differences were evaluated via an independent sample t test or Fisher's exact probability test, as applicable. Pearson's correlation coefficients were computed to determine the associations between lung volume and PFT parameters.

A multiple linear regression model was utilized to estimate the predictive power of radiographic and CT parameters for TLV in AS patients. A P value < 0.05 indicated a statistically significant difference.

Results

Among 79 AS patients, 19 exhibited normal pulmonary function, 4 had mixed ventilatory impairment, and the remaining 56 experienced restrictive ventilatory dysfunction. Among the restrictive patients, 20, 30, and 6 were determined to have mild, moderate, and severe restrictions, respectively (Fig. 2).

Based on FPT results, the 79 patients were categorized into two groups: the normal pulmonary function group (n = 19) and the damaged pulmonary function group (n = 60). The comparative characteristics of the two groups are presented in Table 1. All the parameters, except height, were found to be consistent between the two groups.

Table 2 presents comparative analyses of radiographic and CT characteristics, lung volumes, and PFT outcomes between the study groups. Radiographic and CT characteristics, including TK, GK, thoracic height, and LH, were analysed, and the groups were differentiated.

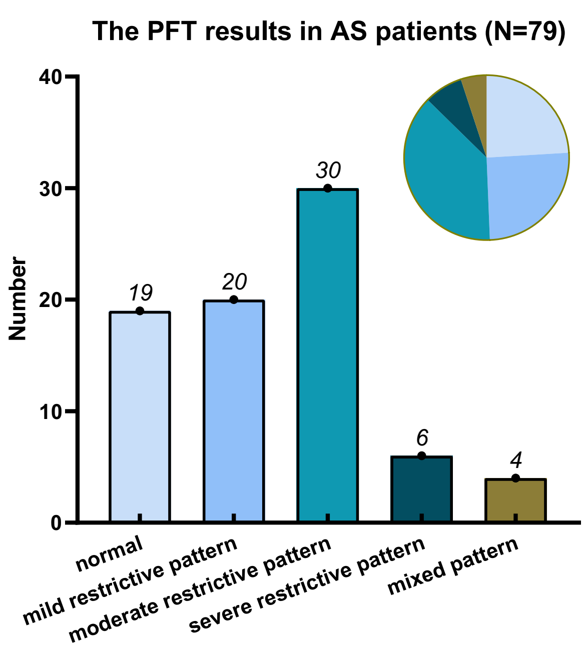

Fig. 2 The PFT results for 79 AS patients. A total of 19 patients exhibited normal pulmonary function, 4 showed mixed ventilatory impairment, and the remaining 56 experienced restrictive ventilatory dysfunction. Among the restrictive cases, 20, 30, and 6 patients were classified with mild, moderate, and severe restrictive ventilatory dysfunction, respectively. PFT, pulmonary function test; AS, ankylosing spondylitis

Table 1 The characteristics of AS patients with normal pulmonary function group versus damaged pulmonary function group

Index	Total	Group N	Group D	*P* value
Patients (N)	79	19	60	
Sex (male/female)	68 /11	16/3	52/8	0.720
Age (year)	40.0 ± 9.4	38.2 ± 9.2	40.6 ± 9.5	0.340
Arm span (cm)	164.0 ± 7.7	161.9 ± 7.0	164.7 ± 7.8	0.173
Height (cm)	151.3 ± 11.7	157.8 ± 8.8	149.3 ± 11.8	0.005*
Body weight (kg)	59.6 ± 11.6	63.7 ± 9.6	58.3 ± 11.9	0.074
BMI (kg/m^2)	26.1 ± 4.5	25.6 ± 3.9	26.2 ± 4.7	0.655
Duration of AS (year)	14.3 ± 7.1	13.4 ± 7.7	14.6 ± 6.9	0.519

The data are presented as the means ± standard deviations.

AS, ankylosing spondylitis; Group N, normal pulmonary function group; Group D, damaged pulmonary function group; BMI, body mass index.

The asterisk (*) denotes statistical differences

Notably, no significant differences were observed in the LHD, LVD, or thoracic ratio. This finding implies that patients with impaired pulmonary function exhibited more pronounced kyphosis and reduced thoracic height and LH, with LHD and LVD remaining stable (Fig. 3). Furthermore, the TLV and individual lobe volume were compromised in the group with impaired pulmonary function, in contrast to the unchanged RLLV (Fig. 4).

A multiple regression model was employed to predict TLV variations in AS patients, utilizing radiographic and CT variables. The analysis revealed that LH, LVD, and LHD were significant and independent predictors of TLV variations (P < 0.001), with the model explaining 90.1% of the TLV variance (Fig. 5). The standardized equation is expressed as TLV (mL) = -7649.0 + 208.5 * LH (cm) + 238.0 * LVD (cm) + 169.7 * LHD (cm), where the coefficients assigned to LH, LVD, and LHD are 0.68, 0.47, and 0.29, respectively.

Table 3 shows the correlations between the CT lung volumes and PFT results. Multiple PFT parameters, such as FVC, FEV1, TLC, FEV1%, and TLC%, demonstrated varied relationships with TLV and individual lobar volume. Notably, FVC, FEV1, and TLC exhibited moderate correlations with TLV, as illustrated in Fig. 6. Additionally, FVC% and the FEV1/FVC ratio were associated with both TLV and the majority of lobar volumes.

Discussion

Among the 79 AS patients enrolled, 19 exhibited normal pulmonary function, 4 presented with mixed dysfunction, and 56 suffered from restrictive dysfunction. Our analysis of PFT parameters, including FVC, FEV1, TLC, FEV1%, and TLC%, revealed varying correlations with TLV and individual lobe volume. Patients with impaired

Table 2 Comparative analyses of radiographic and CT parameters, CT lung volumes, and PFT results between two groups

Index		Total (n = 79)	Group N (n = 19)	Group D (n = 60)	*P* value
Radiographic parameters	TK (°)	43.5 ± 18.0	35.1 ± 18.8	46.1 ± 17.0	0.019*
	GK (°)	74.3 ± 17.7	63.2 ± 18.6	77.8 ± 16.1	0.001*
	Thoracic height (cm)	20.0 ± 3.8	22.1 ± 2.3	19.3 ± 3.9	0.004*
CT parameters	RLH (cm)	18.0 ± 3.2	19.5 ± 3.2	17.5 ± 3.0	0.015*
	LLH (cm)	19.0 ± 3.0	20.5 ± 2.7	18.5 ± 2.9	0.009*
	LH (cm)	18.5 ± 3.0	20.0 ± 2.9	18.0 ± 3.0	0.011*
	LHD (cm)	22.4 ± 1.6	23.0 ± 1.3	22.2 ± 1.6	0.057
	LVD (cm)	15.9 ± 1.8	16.1 ± 2.0	15.8 ± 1.8	0.499
	Thoracic Ratio	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.2	0.659
CT lung volumes	LLV (mL)	1767.5 ± 470.6	2031.1 ± 465.0	1684.1 ± 444.3	0.004*
	LULV (mL)	939.4 ± 251.2	1087.7 ± 214.0	892.4 ± 245.1	0.003*
	LLLV (mL)	828.2 ± 269.4	943.3 ± 266.4	791.7 ± 262.0	0.032*
	RLV (mL)	2014.4 ± 488.8	2310.5 ± 478.8	1920.6 ± 456.9	0.002*
	RULV (mL)	763.4 ± 224.2	897.2 ± 187.8	721.1 ± 219.3	0.002*
	RMLV (mL)	340.9 ± 121.8	402.5 ± 104.8	321.3 ± 121.1	0.010*
	RLLV (mL)	910.1 ± 270.7	1010.8 ± 264.9	878.2 ± 266.7	0.062
	TLV (mL)	3781.9 ± 930.1	4341.6 ± 928.4	3604.7 ± 864.8	0.002*
PFT parameters	FVC(L)	2.7 ± 0.7	3.5 ± 0.5	2.5 ± 0.5	< 0.001*
	FVC%	68.3 ± 14.9	89.4 ± 8.6	61.5 ± 9.0	< 0.001*
	FEV1(L)	2.4 ± 0.6	3.1 ± 0.5	2.2 ± 0.5	< 0.001*
	FEV1%	71.3 ± 15.8	93.6 ± 9.5	64.3 ± 9.6	< 0.001*
	FEV1/FVC (%)	88.0 ± 9.0	88.3 ± 6.1	87.9 ± 9.8	0.879
	TLC(L)	4.7 ± 0.8	5.4 ± 0.7	4.4 ± 0.7	< 0.001*
	TLC%	80.1 ± 11.8	94.3 ± 8.0	75.6 ± 9.0	< 0.001*

The data are presented as the means ± standard deviations.

PFT, pulmonary function test; Group N, normal pulmonary function group; Group D, damaged pulmonary function group; TK, thoracic kyphosis; GK, global kyphosis; RLH, right lung height; LLH, left lung height; LH, lung height; LHD, lung horizontal diameter; LVD, lung vertical diameter; LLV, left lung volume; LULV, left upper lobe volume; LLLV, left lower lobe volume; RLV, right lung volume; RULV, right upper lobe volume; RMLV, right middle lobe volume; RLLV, right lower lobe volume; TLV, total lung volume.

The asterisk (*) denotes statistical differences

pulmonary function displayed more significant spinal kyphosis and a corresponding decrease in TLV. Our multiple regression analysis indicated that LH, LVD, and LHD independently influenced TLV, with a decline in LH being particularly pronounced in patients with impaired pulmonary function.

The prevalence of restrictive lung disease in patients with AS varies widely, ranging from 18 to 57% according to previous studies [1, 14]. In our investigation, a significantly greater proportion of patients experienced restrictive ventilatory impairment (70.9%, 56 out of 79 patients), whereas 5.1% (4 patients) displayed mixed ventilatory impairment. This disparity might be attributed to the severity of kyphosis, potentially requiring corrective surgery, which was more prevalent in our sample. A closer examination of the thoracic CT scans of the mixed dysfunction patients revealed emphysema in all patients, suggesting that AS is not the sole cause of their ventilatory limitations.

Investigating the lung volume via CT offers more precise results than conventional PFT does [2, 11]. The CT TLV has been found to be significantly correlated with the TLC, vital capacity (VC), and FEV1 in patients with pulmonary nodules or neoplasms [15, 16], thus validating the reliability of 3D CT volumetry for evaluating lung function. Our findings revealed a moderate correlation between PFT parameters, including FVC, FEV1, TLC, and TLV, in AS patients. Intriguingly, these correlations were stronger in the upper lobes than in the lower lobes, which contrasts with the observations of Keiji Matsuo et al., who favoured the lower lobes [15]. A weak correlation was observed between the percentage values of FVC%, FEV1%, TLC%, and TLV, indicating that TLV serves as an absolute measure, reflecting a stronger connection to absolute pulmonary function values rather than predicted percentages.

Spinal kyphosis is a prominent characteristic in AS patients [17], and as kyphosis advances, lung structural

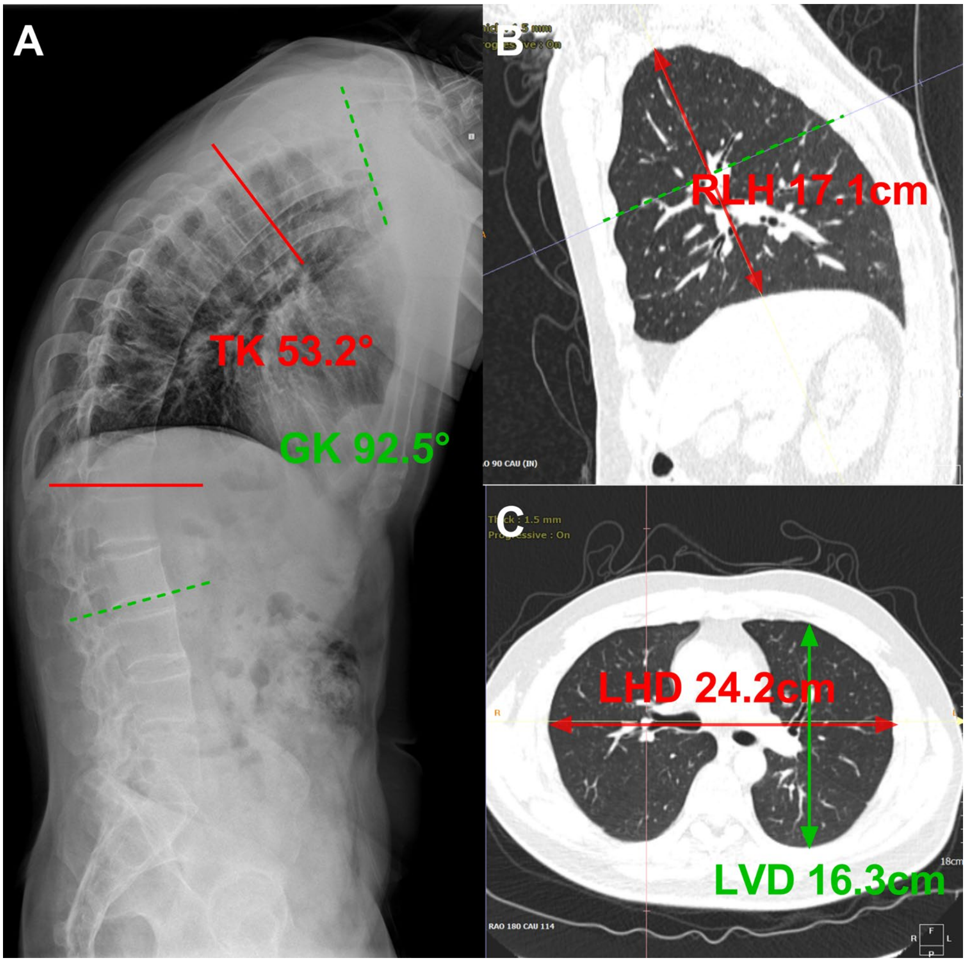

Fig. 3 A 42-year-old male patient with AS experienced moderate restrictive ventilatory dysfunction. Notably, this patient exhibited a more pronounced spinal kyphosis (**A**) and a lower RLH (**B**) of 17.1 cm compared to 22.7 cm in Fig. 1, despite having similar other lung dimensions including LHD, LVD, and Thoracic Ratio, as illustrated in **C**. AS, ankylosing spondylitis; RLH, right lung height; LHD, lung horizontal diameter; LVD, lung vertical diameter

adaptations occur. Therefore, it is necessary to develop a method to quantify these changes. To analyse pulmonary alterations in CT scans, we employed three key measurements: LH, LHD, and LVD. LH is defined as the mean right and left lung height and the distance from the apex to the mid-diaphragm, a standard reference in chest X-ray analyses for TLC determination in lung transplant candidates [18]. Previous studies have employed the vertical distance from the pulmonary apex to the base, as determined by CT slice thickness [19]. However, it is essential to recognize that this measurement may be influenced by kyphotic deformity and lung displacement. To provide a comprehensive assessment of lung dimensions in AS patients, we focused on the midplane of the right lung, quantifying both the horizontal and vertical dimensions. A multiple regression model was constructed to investigate the predictive power of CT-based TLV. The analysis revealed that all three variables contributed independently and significantly, with the model explaining 90.1% of the TLV variation. This finding highlights the effectiveness of our diameter measurement technique in lung volume prediction, with LH being the most influential factor, as indicated by its highest coefficient.

In our study, participants were classified into two distinct categories based on their PFT results: the normal pulmonary function group and the group with impaired pulmonary function, which included four patients

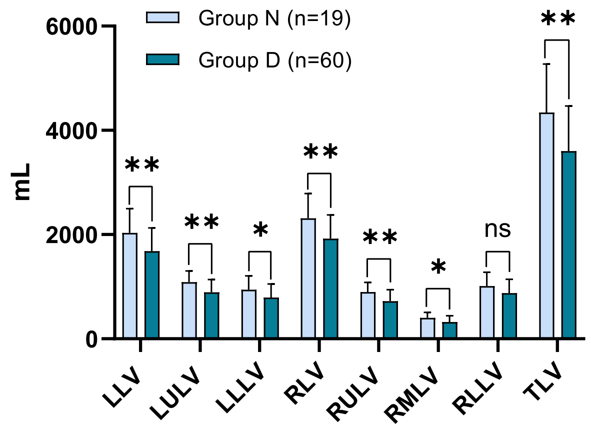

Fig. 4 A comparative analysis of TLV and each lobe volumes between two groups. Patients with pulmonary function impairment experienced a decline in TLV and most lobe volumes, except the RLLV. Group N, normal pulmonary function group; Group D, damaged pulmonary function group; LLV, left lung volume; LULV, left upper lobe volume; LLLV, left lower lobe volume; RLV, right lung volume; RULV, right upper lobe volume; RMLV, right middle lobe volume; RLLV, right lower lobe volume; TLV, total lung volume

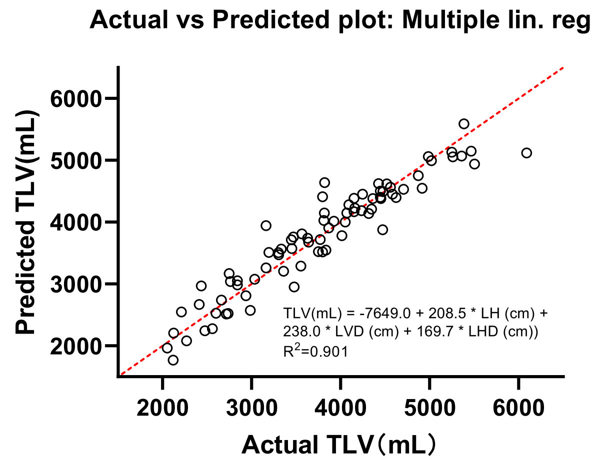

Fig. 5 A multiple regression analysis revealed that LH, LVD, and LHD independently contributed to TLV. LH, lung height; LVD, lung vertical diameter; LHD, lung horizontal diameter; TLV, total lung volume

displaying mixed ventilatory impairment. Notably, PFT parameters are susceptible to various anthropometric factors, including weight, height, sex, and age [20]. Despite the variation in height between the groups, consistency of arm spans was observed, enabling effective control of these baseline characteristics in the analysis of study outcomes.

Our study revealed significant differences in the radiographic measurements between the two groups. A previous study [21] linked GK in AS patients to pulmonary function, findings that were supported based on the increases in TK and GK among the impaired pulmonary function group. In line with prior research [8] that revealed a positive correlation between thoracic height and lung function in adolescent idiopathic scoliosis patients, we detected a decrease in thoracic height in patients with compromised lung function. The direct pressure exerted by kyphosis and the ankylosed thoracic cage contributes to reduced lung volume [22], which was confirmed in our studies based on the decline in TLV and individual lobe volumes, except for RLLV. The relative stability of the RLLV might be attributed to a diaphragmatic compensation mechanism [23, 24].

As previously discussed, the three dimensions of the lung—LH, LVD, and LHD—independently contribute to TLV in CT scans. Notably, a decline in LH was observed in patients with impaired pulmonary function, whereas LHD and LVD remained stable. This finding suggests that a decrease in LH plays a pivotal role in the observed volume reduction. The mechanism likely involves the extrusion of abdominal organs and diaphragmatic compression due to spinal kyphosis, ultimately resulting in a decline in LH and subsequent volume loss [21]. Consequently, we propose that the direct pressure exerted by the kyphotic deformity, rather than the stiffness of the chest and spine, is the primary cause of this decrease in volume.

The strengths of our study are the utilization of CT scans for lung volume measurement, which offers superior accuracy compared with conventional PFT. Additionally, the novel application of LH, LHD, and LVD as key metrics to quantify lung structural changes in AS patients is a significant advantage, as these measurements have demonstrated predictive power in TLV variation.

The limitations of our study include the fact that the cohort was limited to patients who underwent orthopaedic surgery, which may introduce bias towards those with severe kyphosis deformities. Additionally, the study did not address the potential differences in lung volume decline over time between AS patients with normal pulmonary function and the general population, which requires further investigation.

Table 3 Pearson correlation coefficients between CT lung volumes and PFT parameters in AS patients

Index	FVC	FVC %	FEV1	FEV1%	FEV1/FVC	TLC	TLC%
LLV	0.485**	0.179	0.589**	0.342**	0.352**	0.571**	0.355**
LULV	0.582**	0.227*	0.620**	0.334**	0.200	0.584**	0.264*
LLLV	0.305**	0.101	0.451**	0.287*	0.428**	0.454**	0.374**
RLV	0.532**	0.264**	0.597**	0.383**	0.243*	0.585**	0.373**
RULV	0.556**	0.305**	0.497**	0.300**	-0.072	0.513**	0.236*
RMLV	0.405**	0.261*	0.494**	0.383**	0.291**	0.481**	0.426**
RLLV	0.318**	0.106	0.444**	0.271*	0.367**	0.414**	0.287*
TLV	0.525**	0.229*	0.612**	0.374**	0.306**	0.596**	0.376**

PFT, pulmonary function test; AS, ankylosing spondylitis; LLV, left lung volume; LULV, left upper lobe volume; LLLV, left lower lobe volume; RLV, right lung volume; RULV, right upper lobe volume; RMLV, right middle lobe volume; RLLV, right lower lobe volume; TLV, total lung volume.

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

Conclusions

In AS patients, TLV was found to be correlated with pulmonary function, particularly FVC, FEV1, and TLC. A significant reduction in TLV was observed in those with impaired pulmonary function, with the primary contributing factor being the decline in LH.

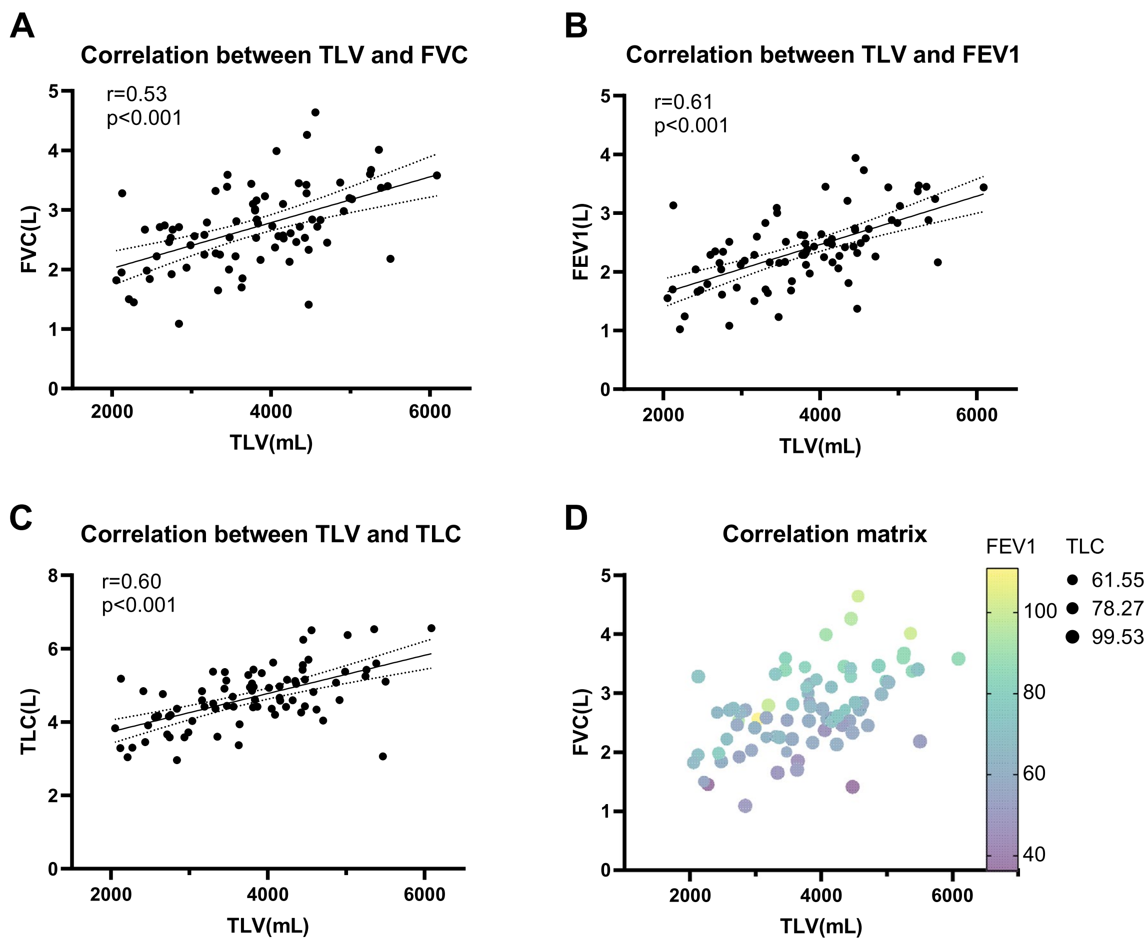

Fig. 6 Scatter plot for correlations between TLV and PFT parameters. A moderate positive correlation is evident between TLV and three absolute pulmonary function values: FVC (**A**), FEV1 (**B**), and TLC (**C**). To provide a comprehensive understanding of these relationships, a correlation matrix (**D**) is also presented, offering an overview of the interconnections. TLV, total lung volume; PFT, pulmonary function test

Author contributions
Conception and design: Jianshou Zhou, and Yijian Liang; Administrative support: Zhengkai Zhao, Qiuyi Cai, and Maoliang Dai; Provision of study materials or patients: Jianshou Zhou, Zhengkai Zhao, and Qiuyi Cai; Collection and assembly of data: Jianshou Zhou, Maoliang Dai, and Qiuyi Cai; Data analysis and interpretation: All authors; Manuscript writing: All authors. All authors reviewed the 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

Competing interests
The authors declare no competing interests.

Ethical approval and consent to participate
The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of the Third People's Hospital of Chengdu and individual consent for this retrospective analysis was waived.

Consent for publication
Not applicable.

Author details
[1]Department of Radiology, The Third People's Hospital of Chengdu, Chengdu 610014, Sichuan, China. [2]Department of Orthopaedics, The Third People's Hospital of Chengdu, Chengdu 610014, Sichuan, China.

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