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Pulmonary function and exercise capacity in mild early-onset idiopathic scoliosis: a case–control study

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Abstract

Background Early-onset idiopathic scoliosis (EOIS) is a spinal deformity that develops before the age of 10 years with unknown etiology. Scoliosis can lead to respiratory muscle weakness and decreased motor function. Nevertheless, the effects of mild EOIS on pulmonary function and functional exercise capacity remain poorly understood. Early detection is crucial to mitigate its impact on children's health and prevent progression. The aim of this study was to investigate the characteristics of pulmonary function and exercise capacity in children with EOIS and to identify influencing factors.

Methods 52 children with mild EOIS and 52 healthy controls matched for age and sex were recruited.Participants underwent pulmonary function test, a 6-minute walk test (6MWT) and Borg score assessments to evaluate subjective fatigue before and after 6MWT. Differences in forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1/FVC, peak expiratory flow (PEF) and six-minute walking distance (6MWD) were compared between the two groups. Imaging parameters were measured from full spinal X-ray orthopantomograms taken in the standing position for the case group. Independent samples t-tests were used to analyze differences between the two groups, followed by multiple linear regression analyses to identify the influencing factors.

Results The case group exhibited significantly lower FEV1/FVC and 6MWD but a higher Borg score compared to the control group ($P=0.009$, $P=0.015$, $P<0.001$). Within the case group, the FEV1/FVC was significantly decreased in the right thoracic scoliosis subgroup compared with the left thoracic scoliosis subgroup ($P=0.006$). Height, Cobb's angle and PEF were significant factors affecting the 6MWD of EOIS ($P=0.003$, $P=0.005$, $P=0.002$), FVC was related to the height, side bend position and side bend direction ($P<0.001$, $P=0.030$, $P=0.013$), and FEV1 was affected by age, weight and type of side bend ($P=0.016$, $P=0.019$, $P=0.016$).

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Conclusions Mild pulmonary and exercise capacity restrictions appear early in mild EOIS. Exercise capacity is influenced by lung function and exhibits a negative correlation with the severity of scoliosis. Pulmonary function in right thoracic scoliosis was significantly lower than that in left thoracic scoliosis. Early identification of these functional declines is crucial for implementing timely interventions to prevent further deterioration.

Keywords Early onset idiopathic scoliosis, Pulmonary function, Exercise capacity

Background

Early-onset scoliosis (EOS) is defined as spinal curvature that develops before the age of 10 years. This condition can arise from a variety of etiologies, including congenital anomalies, neuromuscular disorders, scoliosis-associated syndromes (neurofibromatosis), or idiopathic factors [1, 2]. A multicenter retrospective cohort study revealed that the annual incidence of early-onset scoliosis was 0.019%, while its prevalence was 0.077% [3]. Approximately 95% of EOS patients experience progressive scoliotic deformity that worsens with age, with rapid progression often observed during infancy and preschool years [4, 5]. Early-onset idiopathic scoliosis (EOIS) is a subtype of idiopathic scoliosis developing before the age of 10 years, remains responsive to conservative treatment.

As an important indicator of overall health, cardiorespiratory fitness reflects the integrated performance of functional exercise capacity and respiratory function. It is considered one of the five vital signs, playing a role comparable to that of blood pressure and heart rate [6]. Previous studies have demonstrated that scoliosis can cause thoracic structural distortion, abnormal spinal morphology, and secondary impairments in respiratory function and exercise capacity [7]. These changes are likely associated with pathological alterations caused by scoliosis, such as the shortened spinal length and vertebral rotation. The severity of functional impairment correlates positively with the severity of scoliosis deformity, with moderate scoliosis causing greater impairment than mild scoliosis, including cardiopulmonary dysfunction, back pain, cosmetic deformities and neurological compromise [8, 9]. The deformity of EOIS tends to worsen with increasing age, and earlier onset is associated with more significant impacts on lung function and greater treatment challenges [9, 10]. Therefore, early detection of scoliosis complications can help mitigate the impact on healthy development before scoliosis progresses.

From birth to 8–9 years old is a critical period of lung and respiratory system development. If scoliosis develops during this stage, it can significantly impact pulmonary function development. Compared to typical adolescent scoliosis, EOIS occurs at a younger age when the spine is rapidly growing. As spinal deformity progresses, the resulting thoracic deformity can lead to lung function impairment and cardiac damage, further limiting the child's exercise capacity [11]. Research on pulmonary function and exercise capacity in patients with scoliosis has been increasing in recent years, but most studies focused on adolescents or on patients with moderate-to-severe deformities [12].Patients with EOIS are at higher risk of progression compared to adolescents with scoliosis [4]. The impact of mild EOIS on lung function remains poorly understood, as it has historically been considered negligible, leading to limited attention in this area of research. Therefore, this study aimed to explore the effects of mild EOIS on pulmonary function and exercise capacity.

Methods

Case selection

Calculation of sample size

We calculated the sample size using G*Power software. An independent samples t-test was employed for analysis. Based on prior research [13], we determined an effect size of $f = 0.8$, $\alpha = 0.05$, and power $(1 - \beta) = 0.8$, indicating that a minimum of 26 participants per group is required.

Cases

The participants were recruited from among children who visited the outpatient clinic between December 2020 and December 2021 at the Department of Rehabilitation Medicine, Xinhua Hospital, Shanghai Jiao Tong University School of Medicine, China. The inclusion criteria were (1) age below 10 years old; (2) Cobb's angle between 10 and 20 degrees; and (3) unknown onset (idiopathic scoliosis). The exclusion criteria were as follows: (1) previous skeletal muscle system diseases; (2) previous respiratory system diseases, neurological diseases, congenital heart disease, cardiac arrhythmias, and other diseases that can affect cardiopulmonary exercise endurance; (3) previous history of chiropractic treatment, lower extremity surgery, cardiopulmonary surgery; (4) recent respiratory diseases such as influenza, cold, asthma, allergic rhinitis, and lower limb trauma that affect motor function. Ultimately, excluding 8 patients already receiving exercise therapy, 52 subjects (22 males and 30 females) were enrolled as a case group (Fig. 1).

Controls

We recruited 52 healthy children matched 1:1 for age and sex of the case group with a normal cardiopulmonary physical examination and no history of other skeletal-muscular system or disease surgeries that could affect cardiopulmonary exercise tolerance (Fig. 1). The control

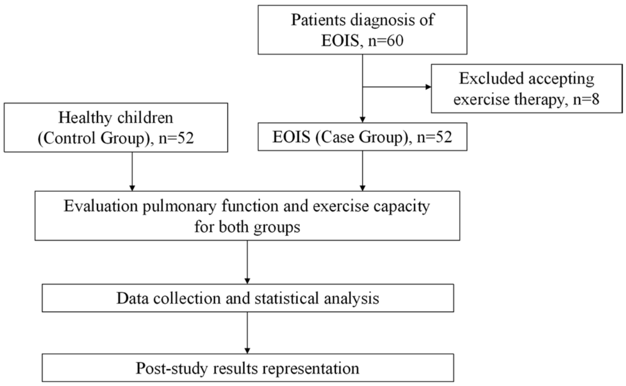

Fig. 1 Study flow chart

group were negative for the Adams test and Scoliometer measurements (ATR < 5°) [14].

Determination of pulmonary function

Pulmonary function was assessed using the Quark PFT4 system (Cosmed, Italy), an advanced medical device specifically designed for comprehensive pulmonary function testing [15]. All subjects participated cooperatively. Prior to the test, the instrument was calibrated using the software to adjust environmental and volume settings. Subject information, including height, weight, date of birth, and race, was entered into the system. Subjects stood in front of the instrument, inserted the cylindrical mouthpiece, sealed their lips around it, and wore a nose clip. The tester monitored the flow-volume curve on the computer screen, which included an animation to guide breathing actions. Subjects were instructed to breathe calmly through the mouth until at least three stable tidal breathing waveforms were observed. They then performed a maximal inhalation followed by a forceful exhalation at maximum speed. After completing the exhalation, they took another deep breath to ensure that they inhaled to total lung capacity and exhaled to residual volume, followed by another inhalation to total lung capacity. This process was repeated three times to obtain the best values. The entire procedure lasted approximately 3 min. Recorded parameters included forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), peak expiratory flow (PEF), and the FEV1/FVC.

Determination of 6MWT

The 6MWT was conducted in accordance with the 2002 guidelines of the American Thoracic Society [16]. Participants were instructed to walk as quickly as possible (without running) along a 30-meter long, flat and hard hallway. The distance covered by participants within 6 min was measured. Prior to the test, resting respiratory rate (RR) was measured for 1 min using a stethoscope, heart rate (HR) and oxygen saturation (SpO2) were assessed using a finger pulse oximeter, and the degree of fatigue was evaluated using the Borg score. During the test, if participants experienced any discomfort, they were allowed to lean against the wall for a brief rest and resume walking once they felt better. Timing was not paused during these rest periods. If the test ended prematurely before completing 6 min, the stop time, reason for early termination, and the distance walked were recorded.

Borg sore

Level 6 corresponds to an effortless state, equivalent to being at rest; Levels 7–8 represent minimal exertion, similar to dressing and undressing; Levels 9–10 indicate light effort, comparable to activities like folding clothes or sweeping the floor; Levels 11–12 involve slightly increased effort, equating to low-intensity activities; Levels 13–14 are moderately strenuous, corresponding to moderate-intensity activity; Level 15–16 represent significant exertion, equivalent to vigorous-intensity activities; Levels 17–18 are very demanding, requiring determination and concentration; Level 19–20 is extremely strenuous, akin to the intensity of a sprint, with fatigue exceeding that of any previous activity. Participants were verbally prompted to assess their subjective fatigue level and select the level that best matched their perceived exertion.

Imaging indicators measurements

In the full-spine X-ray orthopantomogram of the case group in the standing position, the vertebrae with the greatest tilt were identified as the upper and lower end vertebrae. Parallel lines were drawn along the superior edge of the upper end vertebra and the inferior edge of the lower end vertebra, followed by construction of two plumb lines parallel to these edges. The angle between the two plumb lines was defined as the Cobb's angle. Lateral bending originating from T1 to T11 was classified as thoracic curvature; lateral bending from T12 to L1 was classified as thoracolumbar curvature; and lateral bending from L2 to L5 was classified as lumbar curvature. The direction of vertebral body deflection is indicated on the coronal plane of scoliosis. Additionally, parallel lines were drawn between the superior edge of T5 and the inferior edge of T12, followed by vertical lines perpendicular to these parallel lines. The angle between the two vertical lines was defined as the thoracic kyphosis angle.

Statistical analysis

Statistical analysis was conducted using SPSS version 25. The Kolmogorov–Smirnov test was used to assess the normal distribution of the data. Variables were presented as mean ± standard deviation if the data followed a normal distribution, and as median (interquartile range) if the distribution was non-normal. Between-group comparisons were performed using independent samples

Table 1 Between-group comparisons of baseline characteristics

Characteristics	Case (N = 52)	Control (N = 52)	P value
Age (years)	8.37 ± 0.8	8.37 ± 0.69	0.861
Height (cm)	131.88 ± 6.91	131.44 ± 6.75	0.594
Weight (kg)	29.07 ± 5.42	30.44 ± 7.10	0.435
BMI (kg/m^2)	16.63 ± 2.20	17.47 ± 3.13	0.224
Cobb's angle (°)	13.49 ± 3.04	/	/
Thoracic kyphotic angle (°)	22.56 ± 10.39	/	/
Thoracic scoliosis (44.23%)			
Right	14(26.92%)	/	/
Left	9 (17.31%)	/	/
Thoracolumbar scoliosis (40.38%)			
Right	17(32.69%)	/	/
Left	4 (7.69%)	/	/
Lumbar scoliosis(15.38%)			
Right	5 (9.62%)	/	/
Left	3 (5.77%)	/	/

Note: BMI: body mass index

Table 2 Between-group comparisons of pulmonary function and the 6MWT

Variables	Case (N = 52)	Control (N = 52)	P value
FVC (L)	1.88 ± 0.35	1.91 ± 0.37	0.743
FEV1 (L)	1.60 ± 0.29	1.72 ± 0.31	0.103
FEV1/FVC (%)	85.93 ± 8.79	90.1 ± 4.72	0.009*
PEF (L/min)	3.36 ± 0.91	3.49 ± 0.63	0.407
6MWD (m)	560.42 ± 24.79	573.39 ± 25.84	0.015*
Borg	14.00 (14.00, 14.00)	13.00 (12.00, 13.00)	< 0.001**
Resting HR (bpm)	88.13 ± 5.15	88.06 ± 3.43	0.134
Post-exercise HR (bpm)	115.19 ± 12.01	112.96 ± 5.88	0.521
Resting RR (bpm)	20.12 ± 1.97	20.00 ± 1.21	0.715
Post-exercise RR (bpm)	24.73 ± 3.25	24.29 ± 1.54	0.682
Resting SpO_2 (%)	97.96 ± 0.93	97.98 ± 0.80	0.997
Post-exercise SpO_2 (%)	97.71 ± 0.96	97.58 ± 0.80	0.357

Note: 6MWT: six-minute walking test; 6MWD: six-minute walking distance; RR: respiratory rate; HR: heart rate; FVC: forced vital capacity; FEV1: forced expiratory volume in first second; FEV1/FVC: percentage of forced expiratory volume in first second to forced vital capacity; PEF: peak expiratory flow; SpO_2: saturation of peripheral oxygen. **$P < 0.001$, *$P < 0.05$

t-tests for normally distributed data and nonparametric tests for non-normally distributed data. Univariate analysis was conducted to identify potential factors influencing pulmonary function and exercise capacity. Subsequently, multiple regression models were utilized to examine the relationships between these factors and both pulmonary function parameters and 6MWD. The significance level was set at $P < 0.05$.

Results

A comparison of baseline characteristics between the case group and control group is provided in Table 1. Age, height, weight, and BMI did not differ significantly

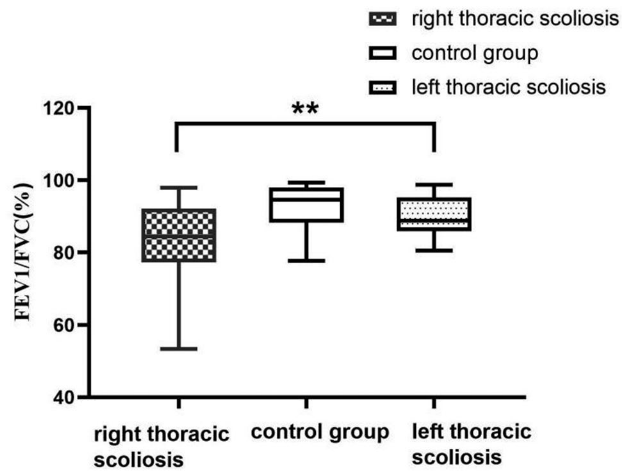

Fig. 2 Among-group comparisons of FEV1/FVC. Note: FEV1/FVC: percentage of forced expiratory volume in first second to forced vital capacity. **$P < 0.001$

between the case and control groups ($P = 0.861$, $P = 0.594$, $P = 0.435$, $P = 0.224$). The Cobb's angle of the case groups ranged from 10° to 19.7°. Among participants in the case group, the curve types were as follows: thoracic (44.23%), lumbar (15.38%), and thoracolumbar (40.38%). The curve direction was predominantly right-sided (69.23%) compared to left-sided (30.76%).

The results of the 6MWT and pulmonary function test in the two groups are summarized in Table 2. Compared to the control group, the case group had a significantly higher Borg score, lower FEV1/FVC, and shorter 6MWD ($P < 0.001$, $P = 0.009$, $P = 0.015$). No significant differences were observed in other indicators of the 6MWT or pulmonary function tests between the two groups ($P > 0.05$).

FEV1/FVC was significantly correlated with the side bend direction ($r = 0.275$, $P = 0.008$). It did not matter whether the bend was to the left side or the right side, and the FEV1/FVC in children with EOIS was significantly lower than that in the control group ($P = 0.008$). FEV1/FVC was significantly decreased in right thoracic scoliosis compared with left thoracic scoliosis ($P = 0.006$) (Fig. 2).

The analysis was carried out in the case group, as shown in Table 3, univariate analysis showed that height, weight and FEV1 were significant influencing factors of 6MWD, mutivariate analysis showed Height, Cobb's angle and PEF were significant factors influencing the 6MWD ($P = 0.003$, $P = 0.005$, $P = 0.002$). Within a certain range, with every 1 cm increase in height, the 6MWD was increased by 1.335 m ($\beta = 1.335$, 95% CI = 0.490, 2.180); with every 1° increase in the Cobb's angle, the 6MWD decreased by 1.651 m (β=-1.651, 95% CI =-2.783, -0.520); and with every 1 L/min increase in PEF, the 6MWD increased by 10.304 m ($\beta = 10.304$, 95% CI = 4.108, 16.500), and the model was established

Table 3 Univariate and multivariate linear regression analysis for 6MWD in case group

	Univariate analysis		Mutivariate analysis	
	β (95%CI)	*P*	β (95%CI)	*P*
Gender	-0.514 (-14.629, 13.602)	0.942	-	-
Age (years)	9.676 (1.367, 17.984)	0.023*	-	-
Height (cm)	1.636 (0.729, 2.543)	0.001**	1.335 (0.490, 2.180)	0.003*
Weight (kg)	1.619 (0.405, 2.833)	0.010*	-	-
FVC (L)	14.340 (-5.11-, 33.789)	0.145	-	-
FEV1 (L)	32.562 (9.748, 55.376)	0.006*	-	-
FEV1/FVC (%)	0.632 (-0.289, 1.553)	0.174	-	-
PEF (L/s)	11.183 (4.247, 18.120)	0.002*	10.304 (4.108, 16.500)	0.002*
Cobb's angle (°)	-0.955 (-2.358, 0.448)	0.178	-1.651 (-2.783, -0.520)	0.005*
Side bend position	3.946 (-5.726, 13.619)	0.416	-	-
Type of side bend	-3.160 (-29.317, 22.996)	0.809	-	-
Side bend direction	1.383 (-13.722, 16.488)	0.855	-	-
Thoracic kyphotic angle (°)	0.274 (-0.399, 0.947)	0.417	-	-

Note: 6MWD: six-minute walking distance; FVC: forced vital capacity; FEV1: forced expiratory volume in first second; FEV1/FVC: percentage of forced expiratory volume in first second to forced vital capacity; PEF: peak expiratory flow. *$P < 0.05$

Table 4 Univariate and multivariate linear regression analysis for FVC in case group

	Univariate analysis		Muti variate analysis	
	β (95%CI)	*P*	β (95%CI)	*P*
Gender	0.197 (0.003, 0.391)	0.046*	-	-
Age (years)	0.234 (0.128, 0.340)	< 0.001**	-	-
Height (cm)	0.025 (0.012, 0.038)	< 0.001**	0.024 (0.013, 0.036)	< 0.001**
Weight (kg)	0.022(0.005, 0.040)	0.014*	-	-
Cobb's angle (°)	0.015 (-0.005, 0.035)	0.136	-	-
Side bend position	0.145 (0.012,0.278)	0.033*	0.123 (0.012, 0.234)	0.030*
Type of side bend	0.098 (-0.275,0.471)	0.600	-	-
Side bend direction	-0.243 (-0.448, -0.039)	0.021*	-0.220 (-0.392, -0.048)	0.013*
Thoracic kyphotic angle (°)	-0.005 (-0.014, 0.005)	0.338	-	-

Note: FVC: forced vital capacity. **$P < 0.001$, *$P < 0.05$

Table 5 Univariate and multivariate linear regression analysis for FEV1 in case group

	Univariate analysis		Muti variate analysis	
	β (95%CI)	*P*	β (95%CI)	*P*
Gender	0.104 (-0.056, 0.264)	0.199	-	-
Age (y)	0.178 (0.090, 0.265)	< 0.001**	0.114 (0.022, 0.206)	0.016*
Height (cm)	0.020 (0.010, 0.031)	< 0.001**	-	-
Weight (kg)	0.023(0.010, 0.037)	0.001*	0.016 (0.003, 0.030)	0.019*
Cobb's angle (°)	0.013 (-0.003, 0.029)	0.112	-	-
Side bend position	0.127 (0.021,0.234)	0.020*	-	-
Type of side bend	0.071 (-0.230,0.373)	0.636	0.114 (0.022, 0.205)	0.016*
Side bend direction	-0.115 (-0.286, -0.056)	0.183	-	-
Thoracic kyphotic angle (°)	-0.004 (-0.011, 0.004)	0.343	-	-

Note: FEV1: forced expiratory volume in first second. **$P < 0.001$, *$P < 0.05$

Table 6 Univariate and multivariate linear regression analysis for PEF in case group

	Univariate analysis		Muti variate analysis	
	β (95%CI)	*P*	β (95%CI)	*P*
Gender	-0.064 (-0.616, 0.489)	0.818	-	-
Age (years)	0.192 (-0.140, 0.523)	0.251	0.470 (0.264, 0.676)	< 0.001**
Height (cm)	0.027 (-0.012, 0.066)	0.173	-	-
Weight (kg)	0.040 (-0.008, 0.089)	0.103	0.027 (0.007, 0.047)	0.008*
Cobb's angle (°)	0.022 (-0.032, 0.076)	0.417	-	-
Side bend position	0.452 (0.090,0.813)	0.015*	-	-
Type of side bend	-0.604 (-1.572,0.364)	0.216	-	-
Side bend direction	0.183 (-0.400, -0.765)	0.531	-	-
Thoracic kyphotic angle (°)	-0.008 (-0.033, 0.018)	0.552	-	-

Note: PEF: peak expiratory flow. **$P < 0.001$, *$P < 0.05$

($F = 10.303$, $P < 0.001$). In Table 4, FVC was taken as the dependent variable, and multiple analysis showed that $F = 10.617$, $P < 0.001$, the model was established, and height, side bend position and side bend direction were significantly correlated with FVC ($P < 0.001$, $P = 0.030$, $P = 0.013$). The FEV1 multiple linear regression model shown in Table 5 ($F = 10.100$, $P < 0.001$) showed that age, weight and type of side bend are significant influencing factors ($P = 0.016$, $P = 0.019$, $P = 0.016$). As shown in Table 6, multiple regression analysis was performed with

PEF as the dependent variable (F = 23.970, $P < 0.001$), and the model was established, in which the age and weight were significant influencing factors for FVC ($P < 0.001$, $P = 0.008$).

Similarly, a similar analysis was performed in the control group, The 6MWD of the healthy control group was significantly correlated with age, height, and PEF ($P = 0.033$, $P < 0.001$, $P = 0.004$) (Table S1). The FVC and FEV1 were significantly correlated with gender and height (Table S2) (Table S3).The PEF was significantly correlated with age and weight ($P < 0.001$, $P = 0.004$) (Table S4).

Discussion

The present study investigated the status and factors influencing pulmonary function and exercise capacity in children with mild EOIS. Compared to age- and sex-matched healthy children, children with mild EOIS had decreased lung function and exercise capacity, as evidenced by lower FEV1/FVC and 6MWD. Additionally, this study revealed that FEV1/FVC was related to the direction of scoliosis, and the FEV1/FVC value in patients with a right thoracic curve was significantly lower than that in patients with a left thoracic curve ($P < 0.05$). Height, Cobb's angle and PEF were identified as significant factors influencing the 6MWD of EOIS, while FVC was influenced by height, side bend position and side bend direction. Besides, FEV1 was affected by age, weight and type of side bend.

In this study, we identified mild impairments in ventilation and functional exercise capacity among children with mild EOIS. These findings align with those reported by Abdel et al. [17] in a cohort of patients aged 10–17 years with mild scoliosis, indicating that subtle pulmonary function limitations may manifest during the early stages of scoliosis development. This evidence underscores the importance for clinicians to initiate early interventions, formulate appropriate rehabilitation programs, and prevent the progression of scoliosis. Furthermore, we observed that the Borg score in the EOIS group was significantly higher than that in the control group, consistent with the findings of Alves et al. [18]. However, despite the statistical significance, a difference in Borg score of 14 compared to 13 is unlikely to be clinically meaningful. The Borg score can evaluate relative fatigue caused by physical ability tests, indicating improvement or deterioration of cardiorespiratory function [19]. The case group had a higher Borg score and lower FEV1/FVC and 6MWD than the control group, indicating that EOIS patients were more prone to abnormal exercise endurance and respiratory function restriction during physical exertion. Additionally, respiratory rate was measured using a stethoscope in this study, which may have introduced measurement errors. The Borg score is a subjective rating scale, and its results are inevitably influenced by individual psychological states, emotions, motivations, etc. These potential inaccuracies could explain why the Borg score was significantly higher in the EOIS group despite no significant difference in respiratory rate. In our study, we observed a negative correlation between the 6MWD and Cobb's angle in the case group. The 6MWD can serve as an indicator of spinal deformity severity in children with EOIS. However, FVC was not associated with the Cobb's angle. A possible explanation for this finding is the reduced ventilation may result from peripheral skeletal and respiratory muscle dysfunction. Specifically, diminished respiratory muscle strength appears to be a key factor contributing to impaired pulmonary function in patients with scoliosis [20, 21].

This study found that, compared with the control group, the FEV1/FVC in the case group was significantly decreased and correlated with the side bend direction. Specifically, the FEV1/FVC in patients with right thoracic scoliosis was significantly lower than that in those with left thoracic scoliosis. Tsiligiannis et al. [8] suggested that scoliosis can lead to a multifactorial lung capacity limitations characteristic of restrictive lung disease.This multidimensional deformity alters the position of internal organs within the thoracic cavity and affects normal rib movement. Static PFTS indicate that the severity of thoracic scoliosis may negatively impact total lung capacity and forced vital capacity [22, 23]. Another study investigated the mechanism of airway obstruction in patients with idiopathic scoliosis from an anatomical perspective. Under normal conditions, the right bronchus is parallel to the spine and is closer to the spine than the left bronchus. The sternum is located between T7 and T9 vertebrae, and the degree of compression of the bronchi in the anterior, lateral, and posterior directions is related to the position of the spinal vertebrae and the direction of scoliosis. When the apical vertebra of the scoliosis is located between T7-T9 and curves to the right, it may be more likely to obstruct the right bronchus, leading to obstructive pulmonary function disorders [24].Untreated severe thoracic scoliosis can increased mortality rates, which is associated with pulmonary hypertension and right-sided heart failure [25]. Additionally, some studies suggest that the progression rate of the right thoracic curve is the faster [26], potentially causing damage to cardiopulmonary function.

Before the age of 10 years, children are still in a critical period of development, and their heart, lungs, spine and other tissues and organs have not yet fully matured; if scoliosis deformity occurs at this time, the risk of progression is higher, and the impact on growth and pulmonary function is more significant [27, 28]. In addition, the natural history and high morbidity of untreated EOIS is closely linked to cardiopulmonary impairment, which can lead to respiratory failure and pulmonary heart disease in severe cases [29]. The mortality rate due to cardiopulmonary dysfunction in patients with EOIS by age 40 is more than twice that of the general population [30]. Therefore, it is crucial to monitor and address the decline in pulmonary function and exercise capacity in children with EOIS at an early stage, and timely intervention should be conducted to prevent further deterioration as scoliosis progresses.

Engaging in regular physical activity is crucial for promoting overall health, enhancing pulmonary function, and improving exercise capacity. Children with EOIS are at a critical growth stage and should be encouraged to engage in daily physical activity, aiming for at least 60 min of moderate-to-vigorous exercise each day. This includes a minimum of three days per week of high-intensity activities and resistance training to strengthen muscles and bones. The findings of this study indicate that 6MWD decreases as the Cobb angle increases. Preventing further deterioration of scoliosis is paramount. For mild EOIS, it is essential to focus on posture management by maintaining proper sitting and sleeping positions, establishing good habits, and promoting spinal health. Incorporating rehabilitation exercises can significantly enhance spinal stability, strengthen core musculature, and facilitate effective spinal stretching.

Some potential limitations of the present study should be acknowledged. First, this was a single-center study without randomization. Second, the study focused on children aged 7–9 years, lacking data on scoliosis in younger individuals. Third, measurements were limited to initial pulmonary function and 6MWT, with no longitudinal follow-up or evaluation of rehabilitation interventions' effects on 6MWT performance. Furthermore, since our research participants are children aged 7–9. some children were hesitant or uncooperative during blood pressure measurements, leading to incomplete data in this area. Future research should include multicenter samples, broader age ranges, and patients with varying severity levels in prospective, randomized controlled trials.

Conclusions

Mild pulmonary and exercise capacity restrictions start early in mild EOIS. Exercise capacity is influenced by pulmonary function and exhibits a negative correlation with the severity of scoliosis. Pulmonary function in right thoracic scoliosis was significantly lower than that in left thoracic scoliosis. Early detection of declining exercise and lung function is crucial. Implementing targeted interventions, such as scoliosis-specific and aerobic exercises, can enhance these functions and prevent further deterioration.

Abbreviations

EOS	Early onset scoliosis
EOIS	Early onset idiopathic scoliosis
6MWT	Six-minute walking test
6MWD	Six-minute walking distance
RR	Respiratory rate
HR	Heart rate
FVC	Forced vital capacity
FEV1	Forced expiratory volume in first second
FEV1/FVC	Percentage of forced expiratory volume in first second to forced vital capacity
PEF	Peak expiratory flow
SpO_2	Saturation of peripheral oxygen
BMI	Body mass index

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-025-05573-0.

Supplementary Material 1

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Author contributions

L.X.W., X.Z., and Q.D. designed the study. L.X.W., X.L., J.P.L., and Y.B.Z. contributed to the interpretation of data. L.X.W. wrote the main manuscript text. L.X.W. and T.T.Z. carried out the statistical analysis. L.X.W. and X.L. collected the data. X.Z. and Q.D. supervised and revised the manuscript. All authors reviewed the manuscript. The author(s) read and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Xinhua Hospital, Shanghai Jiao Tong University School of Medicine (Approval number: XHEC-C-2021-008) and adhered to the Helsinki Declaration during implementation. All children and their parents gave written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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