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The risk factors for type ii respiratory failure in patients with severe scoliosis (less than 40-year old)

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Abstract

Objective To investigate the risk factors for Type II respiratory failure associated with severe scoliosis in patients under 40 years of age.

Methods Patients with severe scoliosis and pulmonary impairment treated in our hospital from January 2020 to December 2022 were recorded. We evaluated the spinal parameters in standing full spine X-rays, including the main thoracic curve, thoracic kyphosis, apical vertebrae, and distance between T1-T12. We also assessed the patient's pulmonary function test (PFT), including forced vital capacity (FVC) and the percentage of measured FVC values to predicted values (FVC%).

Results The study included 64 patients with severe and rigid scoliosis accompanied by severe pulmonary impairment. They were divided into two groups: Group 1 comprised 22 patients with Type II respiratory failure, and Group 2 comprised the remaining 42 patients without respiratory failure. The average age of onset for the two groups was 2.3 ± 2.9 years and 4.0 ± 4.5 years, respectively. The range of the apical vertebrae in Group 1 was from T6 to T11, and the range in Group 2 was the same. There was no significant difference in the main curve and kyphosis angle between the two groups. The average T1-T12 distances for the two groups were 130.3 ± 32.7 mm and 148.2 ± 37.6 mm, respectively. The PFT results indicated that all patients had severe pulmonary function impairment. Multivariate logistic regression analysis revealed that a T1-T12 distance of less than 100 mm was an independent risk factor for Type II respiratory failure.

Conclusions If not treated properly, early onset scoliosis would have a severe impact on pulmonary function. The T1-T12 distance was a risk factor for Type II respiratory failure associated with severe scoliosis in patients under 40 years old.

Keywords Severe scoliosis, Pulmonary impairment, Type II respiratory failure, Risk factor, T1-T12 distance

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Scoliosis, especially thoracic scoliosis, is often associated with rib cage deformity, which can directly affect pulmonary function. The greater the major thoracic curve, the more severe the pulmonary function impairment [1]. The pathophysiology of pulmonary dysfunction in patients with thoracic scoliosis is thought to be influenced by chest wall deformities, reduced chest wall compliance, and respiratory muscle weakness [2]. Reduced total lung capacity may reflect different pathophysiological mechanisms, depending on the age at onset of scoliosis and the degree of chronicity of the condition. Scoliosis in infants (and possibly adolescents) is more likely to be associated with true lung hypoplasia, as the thoracic deformity typically occurs during the rapid growth and development of the lungs [3, 4]. Pehrsson et al. [5] reported that the mortality rate of untreated children and adolescents with scoliosis is significantly increased, with the risk being particularly pronounced between the ages of 40 and 50. Some patients with severe scoliosis may develop respiratory failure (PaO_2<60mmHg) or even Type II respiratory failure (PaO_2<60mmHg and $PaCO_2$>50mmHg) if associated with severe pulmonary dysfunction. Guilleminault et al. [6] reported that respiratory failure was more likely to occur at night, which may be related to reduced sensitivity to low oxygen and high carbon dioxide during sleep, uncoordinated pulmonary ventilation and blood flow ratios, and upper airway obstruction.

Although many studies have investigated the relationship between scoliosis and lung function, there are still few reports on the risk factors for Type II respiratory failure in patients with severe scoliosis. The aim of this study is to analyse the risk factors for Type II respiratory failure in patients with scoliosis under the age of 40, in order to prevent potentially serious consequences through early intervention.

Material and methods

Patient data

This retrospective study was approved by the Institutional Review Board (IRB) of the Third People's Hospital of Chengdu, and all patients signed an informed consent form. We reviewed the medical records of patients with severe and rigid scoliosis combined with pulmonary dysfunction who came to our hospital for treatment from January 2020 to December 2022. The inclusion criteria were as follows: (1) severe and rigid thoracic scoliosis (with an apical vertebra ranging from T5 to T10) and a Cobb's angle greater than 110 degrees; (2) complete data, including demographic information, arterial blood gas analysis, radiographic film, and PFT results. Exclusion criteria were: (1) patients over 40 years of age, as the incidence rate of respiratory failure has been shown to be significantly increased in this age group [5]; (2) coexistence of respiratory system diseases, such as asthma or pulmonary infections, or other respiratory disorders; (3) coexistence of congenital heart disease, which could have affected the results of arterial blood gas analysis; (4) patients who had undergone surgery on the thoracic spine or chest.

Radiographic parameter and pulmonary function test

The main thoracic Cobb's angle, thoracic kyphosis, and T1-T12 distance were assessed using standing whole spine anteroposterior (AP) films. All patients underwent arterial blood gas analysis and PFT. PFT parameters included FVC and FVC%. According to the American Thoracic Society guidelines, the severity of pulmonary impairments was graded on the basis of FVC was as follows: FVC% > 80% indicated no impairment; FVC% between 65% and 80% indicated mild impairment; FVC% between 50% and 65% indicated moderate impairment; FVC% < 50% indicated severe impairment. Type II respiratory failure was defined as a PCO_2 greater than 50 mmHg and a PO_2 less than 60 mmHg in arterial blood gas analysis results.

Statistical analysis

Data analysis was performed using SPSS software (version 27.0; IBM). Each variable was presented as the mean and standard deviation. Radiological parameters were compared between two groups using independent samples t-tests and chi-square tests. Multivariate logistic regression analysis was used to determine the risk factors for Type II respiratory failure. The significance level was set at $P < 0.05$.

Results

Patient characteristics

This study involved 64 patients with severe and rigid scoliosis combined with severe pulmonary impairment. They were divided into two groups: Group 1 consisted of 22 patients with Type II respiratory failure, and Group 2 consisted of the remaining 42 patients without respiratory failure. The etiological diagnosis included idiopathic scoliosis, congenital scoliosis, and neurofibromatosis. The mean age at admission for Group 1 was 28.9 ± 6.8 years (range: 16 to 39 years), compared to 24.4 ± 7.1 years (range: 12 to 35 years) for Group 2. The mean age at onset was 2.3 ± 2.9 years (range: 0 to 12 years) for Group 1 and 4.0 ± 4.5 years (range: 0 to 15 years) for Group 2.

Radiographic parameters and PFT results

The range of the apical vertebrae was T6 to T11 for both groups. The mean main curve was 140.9 ± 25.9 degrees (range: 105 to 190 degrees) in Group 1 and 138.6 ± 21.3 degrees (range: 110 to 177 degrees) in Group 2. The mean kyphosis angle was 119.8 ± 52.7 degrees (range: 0 to 180 degrees) for Group 1 and 124.1 ± 45.0 degrees (range: -12

Table 1 The demographic data, radiographic parameters, and PFT results for both groups

Parameters	Group 1	Group 2	*P*
No of patients	22 (Male/Female, 5/17)	42 (Male/Female, 20/22)	
Age on admission	28.9 ± 6.8	24.4 ± 7.1	0.016
Age of onset	2.3 ± 2.9	4.0 ± 4.5	0.067
Apical vertebrae	7.6 ± 1.3	9.1 ± 1.3	< 0.01
Main curve	140.9 ± 25.9	138.6 ± 21.3	0.708
Kyphosis	119.8 ± 52.7	124.1 ± 45.0	0.733
T1-T12 distance (mm)	130.3 ± 32.7	148.2 ± 37.6	0.064
FVC (L)	0.58 ± 0.20	1.23 ± 0.49	< 0.01
FVC%	18.8 ± 5.4	37.1 ± 14.0	< 0.01

Table 2 Variables categorized as different grades

	Grade 1	Grade 2	Grade 4	Grade 5
Age of onset	≤ 5 years	> 5 years		
Apical vertebrae	Above T5	T6-T10	T11-T12	
Main curve	< 120	120–150	> 150	
Kyphosis	< 90	90–120	121–150	> 150
T1-T12 distance (mm)	< 100	100–140	141–180	> 180

Table 3 Comparison of grade date between the two groups

	χ^2	*P*
Age of onset	0.003	0.202
Apical vertebrae	0.026	0.873
Main curve	0.131	0.937
Kyphosis	3.831	0.280
T1-T12 distance	9.626	0.029

to 180 degrees) for Group 2. The mean T1-T12 distance was 130.3 ± 32.7 mm (range: 83 to 197 mm) for Group 1 and 148.2 ± 37.6 mm (range: 88 to 209 mm) for Group 2. PFT results showed severe impairment in all patients. Demographic data, radiographic parameters, and PFT results for both groups are detailed in Table 1.

To identify the risk factors for Type II respiratory failure complicated by scoliosis, we performed multivariate logistic regression analysis on the data described above. As all variables (including age of onset, apical vertebrae, main curve, kyphosis, T1-T12 distance) were continuous, it was complex to perform multivariate regression analysis. Therefore, we categorized the data as shown in Table 2. FVC and FVC% were PFT results and not causative factors of Type II respiratory failure. The results of the Chi-square test are shown in Table 3. Multivariate logistic regression analysis demonstrated that T1-T12 distance of less than 100 mm (95% CI = 0.001–0.479, $P = 0.014$) was independent risk factors associated with Type II respiratory failure.

Typical cases are shown in Figs. 1 and 2. These two patients are a 23-year-old female with Type II respiratory failure and a 22-year-old male without respiratory failure. However, the patient with respiratory failure has a lesser degree of scoliosis than the patient without respiratory failure.

Discussion

In our study, all patients had severe impairment of pulmonary function according to the American Thoracic Society guidelines. It demonstrated that the severe thoracic scoliosis could have a direct impact on pulmonary function. The relationship between spinal deformity and pulmonary function is a topic of considerable interest.

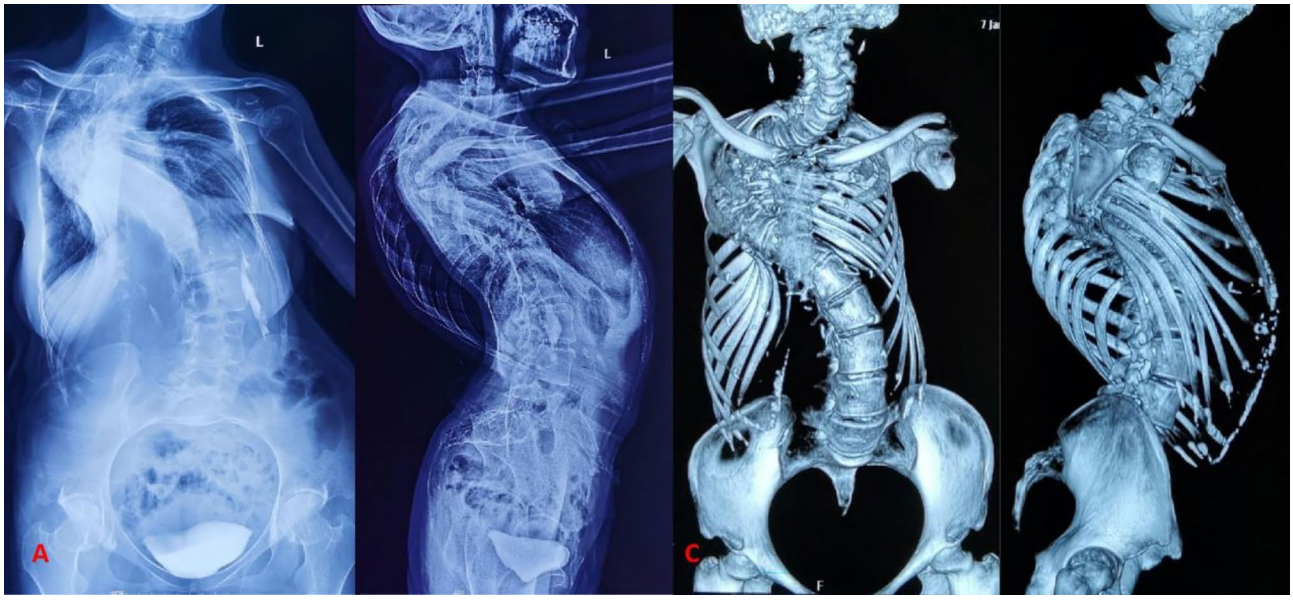

Fig. 1 A 23-year-old female patient was diagnosed with severe scoliosis accompanied by Type II respiratory failure, characterized by: (**A**) Cobb angle of approximately 110° with a measured length of T1-T12 at about 92 mm. (**B**) kyphosis angle of approximately 96° **C** & **D**. 3D CT reconstructions of the spine.

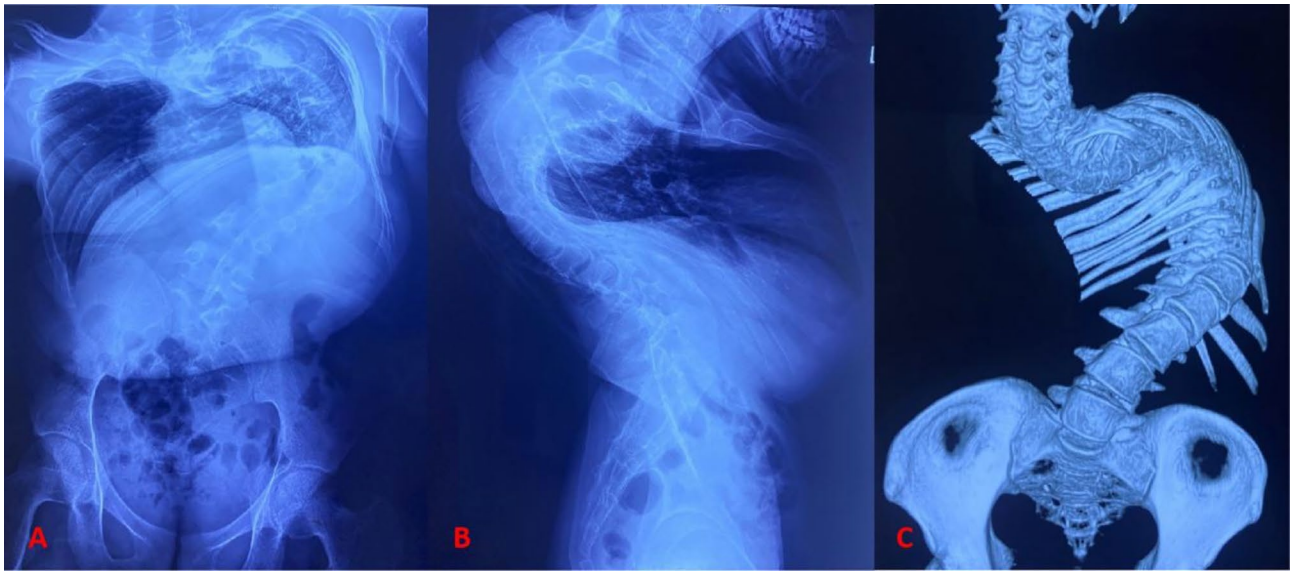

Fig. 2 A 22-year-old male patient was diagnosed with severe scoliosis, featuring: (**A**) Cobb angle of approximately 172° with a measured length of T1-T12 at about 152 mm. (**B**) kyphosis angle of 159°. (**C**) 3D CT reconstruction of the spine

The prevalence of moderate to severe pulmonary impairment in patients with adolescent idiopathic scoliosis (AIS) varies from 14 to 28% [7, 8]. Numerous studies have investigated the association between scoliosis and abnormalities in PFT, dyspnoea, thoracic morphology, bronchial narrowing, muscle dysfunction, exercise limitation, and the impact of pulmonary impairment on morbidity and mortality [2, 9–12]. Studies have indicated that risk factors reduced pulmonary function include thoracic scoliosis, hypokyphosis, the number of affected vertebrae, and the proximal extension [13]. Weinstein et al. [14] reported a direct correlation between pulmonary impairment and the severity of thoracic scoliosis curves, suggesting that clinically relevant decreases in pulmonary function only occur when the degree of thoracic scoliosis curve exceeds 100 degrees. Newton et al. [15] conducted a PFT survey of 631 AIS patients and found that the prevalence of moderate to severe pulmonary impairment increased to 74% when thoracic scoliosis curves exceeded 80 degrees. They also observed that the risk of moderate to severe pulmonary dysfunction was increased in cases with structural cephalad thoracic curves, major thoracic curves spanning eight or more vertebral levels, or thoracic hypokyphosis. However, their findings suggested that the severity of scoliosis associated with clinically relevant reductions in pulmonary function was significantly lower than previously described. In addition, many of the observed changes in pulmonary function could not be fully attributed to the radiographic characteristics of the deformity. In our study, there was no significant difference of main curve angle and kyphosis between the two groups, and the main curve angle and kyphosis were not independent risk factors for Type II respiratory failure in scoliosis cases.

In our study, the average age of onset for the two groups of scoliosis patients was 2.3 ± 2.9 years and 4.0 ± 4.5 years, respectively. There was no statistical difference in the age of onset between the two groups. This indicated that most of these patients had untreated early-onset scoliosis (EOS), which was defined as any spinal deformity occurring before the age of 10 years, regardless of etiology [16]. The progression curve of EOS demonstrated that earlier onset was associated with more severe final curvature and a poorer prognosis, potentially leading to significant deformity, cardiopulmonary deterioration, and reduced life expectancy [5]. The thoracic spine contributed to the vertical component of thoracic volume, while the thorax contributed to width and depth [17]. The growth of the spine was synchronized with the growth of the thorax, which affected the shape, volume, and circumference of the thorax, ultimately affecting the lung development [18]. Limitations in the anatomical boundaries of the deformed thoracic cage in EOS reduced the volume in early life, thereby reducing pulmonary function, as alveolar growth was most rapid in the first 8 years of life [19, 20]. Consequently, untreated EOS patients were at high risk of severe pulmonary impairment. However, there was no statistical difference in the age of onset between the two groups. Multivariate logistic regression analysis also demonstrated that age at scoliosis onset was not an independent risk factor for Type II respiratory failure.

Many articles have reported cases of severe scoliosis combined with respiratory failure [5, 6, 21–25]. For example, Ma et al. [21] reported the treatment of a 14-year-old girl with severe congenital scoliosis and

Type II respiratory failure using halo gravity traction and orthopedic surgery, which resulted in significant improvements, including correction of scoliosis and improvement in pulmonary function. Kanagaraju et al. [22] also reported a successful treatment of a patient with severe rigid congenital scoliosis and Type II respiratory failure using stepwise controlled axial traction. Gill et al. performed deformity correction surgery in 8 patients with neuromuscular scoliosis and pre-existing respiratory failure, achieving favorable results without major pulmonary complications [23]. Buyse et al. [24] recommended a combination of nocturnal intermittent nasal positive pressure ventilation and long-term oxygen therapy for chronic respiratory failure in patients with kyphosis. However, research into the risk factors for Type II respiratory failure in patients with severe scoliosis remains relatively limited.

The present study aimed to analyse the differences between the Type II respiratory failure group and the control group in terms of age of onset, apical vertebra, main curve, kyphosis, and T1-T12 distance, in order to determine the risk factors for Type II respiratory failure. The study population comprised 64 patients with severe scoliosis, of whom 22 were diagnosed with Type II respiratory failure. The results of the PFT showed significant differences between the two groups, with the Group 1 showing a more severe condition. The mean age at admission in Group 1 was higher than in Group 2 ($P<0.05$). It is recognised that patients have a greater degree of pulmonary function impairment with increasing age. Consequently, the potential of age at admission as an independent risk factor for Type II respiratory failure was not investigated. Although apical vertebra level was higher in Group 1 than in the Group 2 ($P<0.01$), regression analysis indicated that this was not a risk factor. The average T1-T12 distance in Group 1 was shorter than that of Group 2, but the difference was not significant. Multivariate logistic regression analysis demonstrated that T1-T12 distance less than 100 mm (95% CI = 0.001–0.479, $P = 0.014$) was an independent risk factor associated with Type II respiratory failure.

Spinal deformities would directly affect the height of the spine. The T1-S1 segment grows approximately 10 cm before the age of 5, about 5 cm between the ages of 5 and 10, and roughly 10 cm during puberty. Thus, the most rapid and significant growth period of the TI-S1 segment occurs before the age of 10 years [26]. The height of the thoracic spine is 12 cm at birth, 18 cm at 5 years of age, and 27 cm at skeletal maturity [18, 26]. Karol et al. [27] reported a direct relationship between thoracic spine height and pulmonary function, with a shorter thoracic spine leading to a smaller FVC. They also determined that to avoid severe restrictive lung disease (FVC < 50%), the height of the thoracic spine at skeletal maturity should exceed 22 cm. Their conclusion was consistent with our research findings. In our study, regression analysis indicated that a shorter distance between T1-T12 was associated with a stronger correlation with Type II respiratory failure.

Limitations

This study has several limitations. First, the sample size was small, which may have introduced some significant bias. Continuous variables such as age of onset, apical vertebra, main curve, kyphosis, and T1-T12 distance could not be analyzed directly because of the small sample size. We have to categorize continuous variables for regression analysis, which may lead to loss of information and potential misinterpretation of the data, and oversimplify complex relationships and reduce the statistical power of the analysis. Second, this is a retrospective study. Retrospective studies are prone to selection bias and cannot establish causality. The lack of randomisation may result in unrecognised confounding variables influencing the results. Thirdly, we could not identify the time of onset of Type II respiratory failure. Patients usually had a period of dyspnoea before they came to our hospital. Therefore, the time at which they came to our hospital may have been later than the time at which Type II respiratory failure was diagnosed. Although there was a significant difference between the age on admission of the two groups, it was still difficult to determine whether age was a risk factor for Type II respiratory failure. How to safely and effectively treat these severe scoliosis cases combined with Type II respiratory failure would be more challenging. Further studies are needed.

Conclusions

This study has highlighted the significant impact of severe thoracic scoliosis on pulmonary function and the risk factors of Type II respiratory failure. It emphasizes the critical period of spinal growth before the age of 10 and establishes a direct correlation between shorter thoracic spine height at skeletal maturity and an increased likelihood of respiratory complications. If not treated properly, early onset scoliosis would have a severe impact on pulmonary function. The T1-T12 distance was a risk factor for Type II respiratory failure associated with severe scoliosis in patients under 40 years old.

Author contributions

Zhengjun Hu and Yuanxian Leng: Conceptualization, Writing - original draft, prepared Figs. 1 and 2. Rui Zhong: Investigation, Methodology. Fei Wang: Conceptualization, Methodology. Zhong Zhang: Investigation, Conceptualization, Resources. Dengxu Jiang: Conceptualization, Formal analysis. Yijian Liang: Investigation, Conceptualization, Resources. Deng Zhao: Conceptualization, Writing - review & editing. All authors approved the final manuscript. All authors read and approved the final manuscript.

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Data availability
Data and materials contributing to this article may be provided by sending an e-mail to the corresponding author.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Institutional Review Board (IRB) of The Third People's Hospital of Chengdu. All patients involved in the study consent to participate in the study. And the written consent has been obtained from all the patients.

Consent for publication
All individual person's data consent to publish.

Competing interests
The authors declare no competing interests.

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