Thoracic Deformity Correction and Changes of Vital Capacity, Forced Expiratory Volume in 1 Second, and Expiratory Flow in Adolescent Idiopathic Scoliosis Five Years or More after Posterior Spinal Fusion with Thoracoplasty

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Abstract:

Introduction: The purpose of this study is to investigate thoracic deformity correction and pulmonary function changes in patients with adolescent idiopathic scoliosis (AIS) five years or more after undergoing posterior spinal fusion with thoracoplasty for correction of a thoracic deformity.

Methods: Subjects were 57 patients with AIS who underwent posterior spinal fusion between 2004 and 2010. 24 patients who had undergone thoracoplasty at least five years earlier agreed to participate in this research. X-rays, pulmonary function tests, and thoracic cage computed tomography (CT) were performed, and the Scoliosis Research Society Outcomes Questionnaire (SRS-22) was administered. CT axial images were used at the apex of the main thoracic (MT) curve. Apical vertebral rotation was evaluated using rotation angle to the sagittal plane (RA_{sag}). Thoracic deformities were evaluated using the rib hump index (RHi) and the posterior hemithoracic symmetry ratio (PHSr).

Results: There were no significant differences between the preoperative and the final observation forced vital capacity (FVC) or the preoperative and the final observation %FVC. The forced expiratory volume in 1 s (FEV1) and %FEV1 were significantly improved at the final observation: FEV1 (preoperative: 1.88 L, final observation: 2.05 L, p = 0.045) and %FEV1 (preoperative: 57.1%, final observation: 66.2%, p = 0.001). FEV1/FVC was also significantly improved at the final observation (preoperative: 83.0%, final observation: 86.4%, p = 0.019). The peak expiratory flow (PEF) was significantly improved at the final observation (preoperative: 3.67 L/s, final observation: 4.38 L/s, p = 0.029). On the CT assessment for thoracic deformities, there were no significant changes in RA_{sag} or RHi. PHSr was significantly increased at the final observation compared with the preoperative period.

Conclusions: With posterior spinal fusion in combination with thoracoplasty for AIS, although the correction of deformities was limited, the pulmonary function testing demonstrated the preservation of vital capacity (VC) and improvements in the forced expiratory volume in 1 s and expiratory flow.

Keywords:
Thoracoplasty, Adolescent idiopathic scoliosis, Thoracic cage deformity, Pulmonary function

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Introduction

Thoracic deformities are an important concern in adolescent idiopathic scoliosis (AIS). Their impact on the self-image should also be noted. Thoracoplasty is a method of correcting thoracic deformities by resecting the ribs of the

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thoracic vertebrae[1]. As thoracic deformities have been poorly corrected by Harrington instrumentation based on a distraction force[2,3], a method of thoracoplasty combined with posterior spinal fusion has been attempted[4].

Recently, pedicle screw instrumentation has become widely used, and many surgeons believe that thoracoplasty is no longer necessary. Nevertheless, because thoracic deformities tend to remain even with pedicle screw instrumentation, other surgeons have reported superior rib hump correction with pedicle screw instrumentation in conjunction with thoracoplasty[5-7]. There are also concerns that since thoracoplasty entails an invasive procedure upon the thorax itself, the respiratory function may decrease following surgery. There are many reports that although the respiratory function slightly decreases in the immediate postoperative period, it returns to the preoperative baseline within two years[5,6].

Since patients with AIS often undergo surgery during their teenage years, it is necessary to conduct a long-term follow-up. Nevertheless, the respiratory function and thoracic deformity have not been investigated in patients with AIS who underwent thoracoplasty for follow-up periods longer than two years.

The purpose of this study is to investigate thoracic deformity correction and pulmonary function changes in patients with AIS five years or more after undergoing combined posterior spinal fusion and thoracoplasty for correction of a thoracic deformity. We hypothesized that thoracoplasty would improve the long-term respiratory function in postoperative patients by the improvement of thoracic deformities and that it would have a positive effect on the self-image.

Materials and Methods

This study was approved by the institutional review board. Subjects were 57 patients with AIS who underwent posterior spinal fusion with thoracoplasty between 2004 and 2010. The inclusion criteria were (1) AIS, (2) age 10-19 years at the time of operation, and (3) thoracoplasty performed at the time of posterior spinal fusion. The exclusion criteria were (1) neuromuscular scoliosis, congenital scoliosis, and syndromic scoliosis; (2) any history of pulmonary disease, such as interstitial pneumonia, bronchial asthma, chronic bronchitis, emphysema, or diffuse panbronchiolitis; or (3) reoperative case. We tried to contact all the 57 patients via postal mail. The following patients were excluded: 20 patients who failed to respond to the mails, 10 patients who refused to participate in this research, 2 patients who had undergone reoperation, and 1 patient who did not undergo a preoperative pulmonary function test. Finally, 24 patients who had undergone thoracoplasty at least five years earlier agreed to participate in this research. There were 23 females and 1 male. The average age at the time of surgery was 15.5 years (range: 12-19 years); the average age at follow-up was 23.6 years (range: 19-28 years); the average follow-up interval was 7.7 years (range: 5-11 years). Lenke types were type 1 in 13 patients, type 2 in 8 patients, and type 6 in 3 patients. The apex vertebrae were T7 in 1 patient, T8 in 10 patients, T9 in 10 patients, and T10 in 3 patients. The upper instrumented vertebrae (UIVs) were T1 in 1 patient, T2 in 1 patient, T3 in 2 patients, T4 in 14 patients, and T5 in 6 patients. The lower instrumented vertebrae (LIVs) were T11 in 1 patient, T12 in 2 patients, L1 in 10 patients, L2 in 5 patients, L3 in 3 patients, and L4 in 3 patients. For all patients, X-rays of the whole spine, pulmonary function tests, and thoracic cage computed tomography (CT) were performed and the Scoliosis Research Society Outcomes Questionnaire (SRS-22) was administered at the time of the final observation with a minimum five-year follow-up.

Plain X-ray films of the whole spine, including frontal and lateral views, were taken in the standing position. These were evaluated from before surgery, one week postoperatively, two years postoperatively, and at the time of the final observation. From the frontal view, the upper thoracic (UT) curve, main thoracic (MT) curve, and lumbar (L) curve were measured. From the lateral view, thoracic kyphosis (TK: T5-T12 angle), and lumbar lordosis (LL: L1-S1 angle) were measured.

For pulmonary function testing, the forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), peak expiratory flow (PEF), maximum expiratory flow at 50% FVC (V50), maximum expiratory flow at 25% FVC (V25), and the ratio of V50 to V25 (V50/V25) were measured. The tests were performed with the patient in the sitting position, and the evaluation test was repeated three times, with the best effort selected. These were evaluated before surgery and at the final observation. In order to take into consideration the loss of height due to scoliosis, we used the correction developed by Kono et al. That is, the following formula was used for all scoliotic curves of 30° or more[8]:

$$\Delta H\ (\mathrm{mm}) = 0.6 \times X + 2.6,\ X = \Sigma\ (\text{Cobb's angle} - 30°).$$

The predicted vital capacity (VC) was calculated from the corrected height, sex, and age. The formula developed by Baldwin et al. was used to predict the VC for subjects aged 18 or older: for males, predicted VC (L) = (27.63 − 0.112 × age) × corrected height (cm)/1,000; for females, predicted VC (L) = (21.78 − 0.101 × age) × corrected height (cm)/1,000[9]. The formula developed by Nishima et al. was used for subjects under 18 years of age: for males, predicted VC (L) = 0.0481 × corrected height (cm) − 4.240; for females, predicted VC (L) = 0.0410 × corrected height (cm) − 3.480[10]. In addition, the predicted FEV1 was calculated on the basis of the corrected height, sex, and age. The formula developed by Berglund et al. was used for predicting FEV1: for males, predicted FEV1 (L) = 0.0344 × corrected height (cm) − 0.033 × age − 1.00; for females, predicted FEV1 (L) = 0.0267 × corrected height (cm) − 0.027 × age − 0.54[11]. Percent-predicted values were defined as follows: %FVC = (FVC/predicted VC) × 100; %FEV1 = (FEV1/predicted FEV1) × 100. We used Gaensler's equation for the propor-

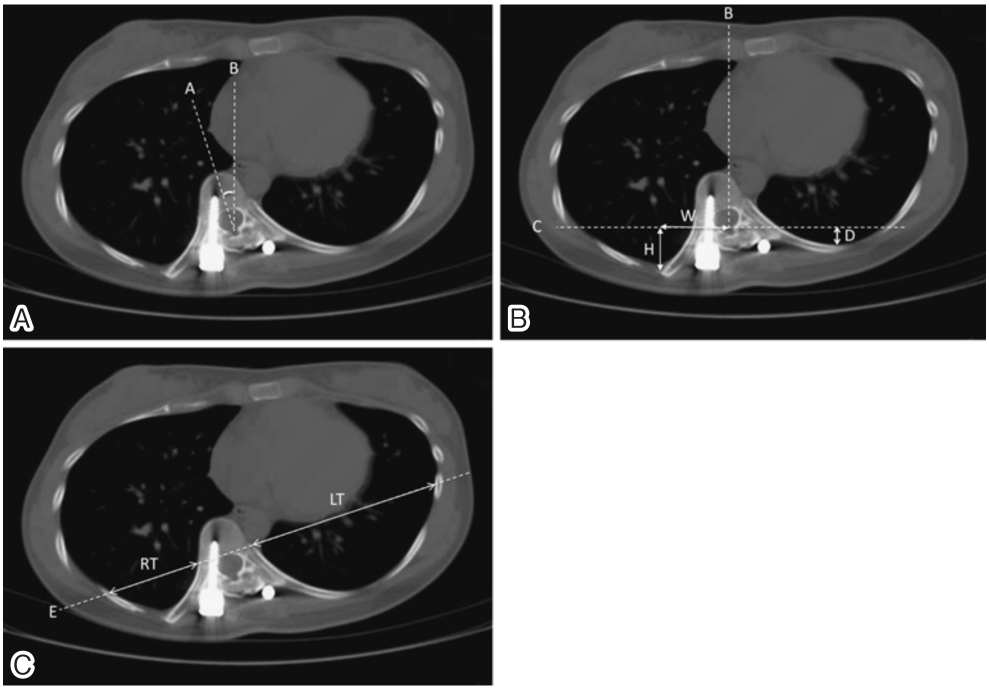

Figure 1. Thoracic deformities were evaluated on CT by previously described methods[3,12,13]. Axial CT images at the apical vertebral level of the MT curve were used to measure RA_{sag}, RHi, and PHSr. (A) For apex vertebra rotation, RA_{sag} was measured according to the method developed by Aaro et al.[12] (B) For thoracic deformities, RHi was measured according to the method developed by Aaro et al.[12] (C) PHSr was measured according to the method developed by Campbell et al.[13]

tion of air expelled in 1 s = (FEV1/FVC) × 100.

The SRS-22 was administered at the final observation.

CT was performed in order to evaluate vertebral body rotation and thoracic cage deformity. The used CT was LightSpeed 16 (General Electric Company, Windsor, CT, USA). 10 patients had no CT imaging from before surgery or one week after surgery. Therefore, we were able to evaluate 14 patients who underwent CT imaging preoperatively, one week postoperatively, and at the final observation. Thoracic deformities were evaluated on CT by previously described methods (Fig. 1)[3,12,13]. Axial CT images of the apex of the MT curve were obtained. For the apex vertebra rotation, the rotation angle to the sagittal plane (RA_{sag}) was measured according to the method developed by Aaro et al.[12] Line A is a line through the posterior central aspect of the vertebral foramen and the middle of the vertebral body, and Line B is a perpendicular line drawn from the posterior central aspect of the vertebral foramen on the image. The angle formed by Lines A and B is RA_{sag} (Fig. 1A). For thoracic deformities, the rib hump index (RHi) was measured according to the method developed by Aaro et al.[12], and the posterior hemithoracic symmetry ratio (PHSr) was measured according to the method developed by Campbell et al.[13] Line B is a perpendicular line drawn from the posterior central aspect of the vertebral foramen on the image, and Line C is drawn parallel to the posterior central aspect of the vertebral foramen on the image. H measures the distance between Line C and the peak of the inner rib cage on the convex side (rib hump). D measures the distance between Line C and the peak of the inner rib cage on the concave side. W measures the horizontal distance from the posterior central aspect of the vertebral foramen to the rib hump. H−D/W is the RHi (Fig. 1B). Line E connects both of the anterior tips of the rib heads. RT measures the distance between the right rib head to the thoracic inner border on Line E. LT measures the distance from the left rib head to the thoracic inner border on Line E. LT/RT is the PHSr (Fig. 1C). CT measurements were performed independently using image analysis software (ImageJ Version 1.50; National Institutes of Health, Bethesda, MD, USA) by two expert orthopedic surgeons who were blinded to the clinical data[14]. The average value between the two examiners (IM and KS) was taken.

For statistical analyses, SPSS Statistics Version 22.0 (IBM Corp., Armonk, NY, USA) was used. Paired *t*-test was used to compare preoperative and postoperative values. Unpaired *t*-test or chi-squared test was used to compare participants and nonparticipants. Spearman's correlation coefficient was used to check for correlations between parameters of CT images and SRS-22 subdomain scores. Intraclass correlation coefficients (ICCs) were used to determine reliability among CT examiners. The level of significance was set at less than 5%.

Surgical procedure

Surgery was performed in the prone position with a midline incision. Normally, the range of the surgical field extends from the UIV to the LIV. Hooks or pedicle screws are placed at the UIV, and four pedicle screws are placed at the lowermost vertebrae to undergo fixation. In the vicinity of the apex, three or four pedicle screws are placed on the convex side. On the concave side, ultrahigh-molecular-weight polyethylene tapes are installed using a sublaminar wiring method. We corrected the scoliosis with a derotation maneuver of the concave rod. After installing the convex rod, we used distraction on the concave side and compressive force on the convex side for correction.

Following the correction of scoliosis, thoracoplasty was performed in accordance with the method reported by Yang et al.[7] Using the same midline incision, thoracoplasty was performed on the residual rib hump. After the lateral retraction of muscles, three ribs were exposed, preserving the periosteum as much as possible. In three ribs on the convex side of the thoracic curve apex, starting at 3-4 cm from the costovertebral joint, 3 cm was resected from each rib (Fig. 2).

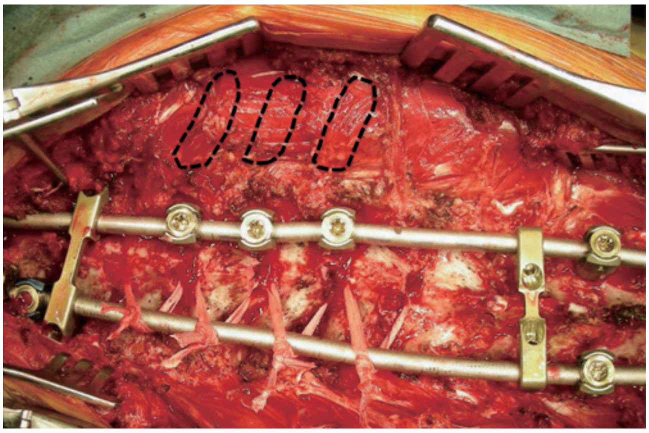

Figure 2. Following the correction of scoliosis, thoracoplasty was performed on the residual rib hump using the same midline incision. In three ribs on the convex side of the thoracic curve apex, 3 cm was resected from each rib.

Results

No patients suffered from any respiratory illness. 23 patients had no smoking history, and one was becoming a smoker at the final observation. In 23 out of the 24 patients, new ribs had grown at the resection site at the time of the final observation (Fig. 3). The MT curve was 55.7 ± 10.6° before surgery, 22.4 ± 8.3° one week postoperatively, 24.4 ± 9.5° two years postoperatively, and 25.1 ± 8.3° at the final observation. The MT curve was significantly improved at the final observation compared to the preoperative value ($p < 0.001$). The UT curve was 32.2 ± 9.3° before surgery, 20.5 ± 7.7° one week postoperatively, 20.2 ± 7.0° two years postoperatively, and 19.9 ± 6.9° at the final observation. The UT curve was significantly improved at the final observation compared to the preoperative value ($p < 0.001$). The L curve was 33.5 ± 10.1° before surgery, 12.7 ± 6.1° one week postoperatively, 14.2 ± 6.7° two years postoperatively, and 13.6 ± 6.5° at the final observation. The L curve was significantly improved at the final observation compared to the preoperative value ($p < 0.001$). TK was 15.1 ± 9.4° before surgery, 13.9 ± 4.3° one week postoperatively, 17.6 ± 7.6° two years postoperatively, and 19.8 ± 8.0° at the final observation. TK was significantly increased at the final observation compared to the preoperative value ($p = 0.009$). LL was 47.9 ± 11.0° before surgery, 39.5 ± 10.5° one week postoperatively, 51.2 ± 8.5° two years postoperatively, and 54.5 ± 9.8° at the final observation. LL was significantly increased at the final observation compared to the preoperative value ($p = 0.018$).

There were no significant differences between the preoperative and the final observation FVC or the preoperative and the final observation %FVC: FVC (preoperative: 2.27 ± 0.64 L, final observation: 2.38 ± 0.50 L, $p = 0.240$); %FVC (preoperative: 74.5 ± 18.6%, final observation: 76.4 ± 16.4%, $p = 0.441$). FEV1 and %FEV1 were significantly

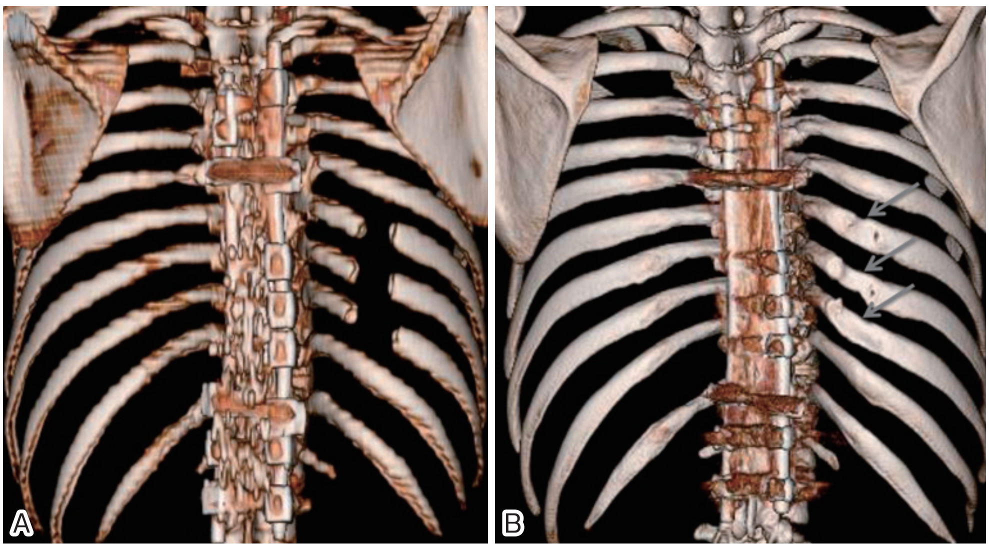

Figure 3. Postoperative 3D CT at one week (A) and at the final observation (B). New ribs grew at the resection site (arrows) at the time of the final observation.

Table 1. Pulmonary Function Changes of FVC and FEV1.

	Preoperative value	Final observation value	Changes	*p*-value
FVC (L)	2.27±0.64	2.38±0.50	0.11	0.240
%FVC (%)	74.5±18.6	76.4±16.4	1.9	0.441
FEV1 (L)	1.88±0.52	2.05±0.42	0.17	0.045*
%FEV1 (%)	57.1±16.0	66.2±13.9	9.1	0.001*
FEV1/FVC (%)	83.0±7.9	86.4±7.3	3.4	0.019*

Values are mean (±standard division). *Significant difference.
FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s

Table 2. Pulmonary Function Changes of Expiratory Flow.

	Preoperative value	Final observation value	*p*-value
PEF (L/s)	3.67±1.51	4.38±1.18	0.029*
V50 (L/s)	2.30±0.93	2.62±0.72	0.047*
V25 (L/s)	1.01±0.50	1.23±0.44	0.022*
V50/V25	2.50±0.92	2.22±0.45	0.081

Values are mean (±standard division). *Significant difference.
PEF: peak expiratory flow; V50: maximum expiratory flow at 50% FVC; V25: maximum expiratory flow at 25% FVC; V50/V25: ratio of V50 to V25

improved at the final observation: FEV1 (preoperative: 1.88 ± 0.52 L, final observation: 2.05 ± 0.42 L, p = 0.045); % FEV1 (preoperative: 57.1 ± 16.0%, final observation: 66.2 ± 13.9%, p = 0.001). FEV1/FVC was also significantly improved at the final observation (preoperative: 83.0 ± 7.9%, final observation: 86.4 ± 7.3%, p = 0.019) (Table 1). PEF, V 50, and V25 were significantly improved at the final observation: PEF (preoperative: 3.67 ± 1.51 L/s, final observation: 4.38 ± 1.18 L/s, p = 0.029), V50 (preoperative: 2.30 ± 0.93 L/s, final observation: 2.62 ± 0.72 L/s, p = 0.047), and V25 (preoperative: 1.01 ± 0.50 L/s, final observation: 1.23 ± 0.44 L/s, p = 0.022). V50/V25 was improved at the final observation, but this difference was not statistically significant (preoperative: 2.50 ± 0.92, final observation: 2.22 ± 0.45, p = 0.081) (Table 2).

On the CT assessments for thoracic deformities, there were no significant changes in RA_{sag} (16.3 ± 6.1° before surgery, 18.4 ± 6.6° one week after surgery, and 19.0 ± 7.9° at the final observation) or RHi (0.37 ± 0.20 before surgery, 0.36 ± 0.23 one week after surgery, and 0.35 ± 0.32 at the final observation). PHSr was significantly increased at the final observation compared with the preoperative period (1.90 ± 0.37 preoperatively, 1.91 ± 0.36 one week after surgery, and 2.16 ± 0.43 at the final observation; p = 0.007) (Table 3).

The SRS-22 subdomain scores at the time of the final observation were as follows: function 4.7 ± 0.3, pain 4.5 ± 0.5, self-image 3.7 ± 0.6, mental 4.1 ± 0.8, and satisfaction 4.2 ± 0.6. There were no significant correlations between the self-image score of the SRS-22 and the final observations for RA_{sag} (r = 0.295, p = 0.306), RHi (r = 0.131, p = 0.656), or PHSr (r = 0.353, p = 0.216). There were, likewise, no significant correlations between the other SRS-22 domains and any CT parameters.

Reliability of CT readings among examiners

The interexaminer reliability was calculated using ICCs. All the results were in excellent agreement with the ICC for RA_{sag} at 0.764 (95% confidence interval (95% CI): 0.598-0.867), the ICC for RHi at 0.870 (95% CI: 0.772-0.928), and the ICC for PHSr at 0.866 (95% CI: 0.764-0.926).

Comparison between participants and nonparticipants

The demographics of the 24 participants enrolled in this survey were compared to those of the 33 nonparticipants. No statistically significant differences were noted in the patients' age at surgery (participants: 15.5 ± 2.0 years, nonparticipants: 15.4 ± 1.9 years; p = 0.948), number of fused vertebral bodies (participants: 10.7 ± 1.4, nonparticipants: 10.1 ± 1.5; p = 0.145), and number of fused thoracic vertebral bodies (participants: 9.0 ± 1.0, nonparticipants: 8.9 ± 1.0; p = 0.820). When the percentages of participants and nonparticipants were compared by sex, no significant difference was found between these groups in the percentage of females (participants: 95.8%, nonparticipants: 93.9%; p = 0.752). Therefore, the patients who participated in this study can be considered representative of the entire 57 patients.

Discussion

In this study, we investigated thoracic deformity correction and pulmonary function changes in patients with AIS five years or more after undergoing combined posterior spinal fusion and thoracoplasty for correction of a thoracic deformity. There was no change in the rib hump as a result of the operation; in fact, right-to-left imbalance and asymmetry appeared to worsen. In terms of pulmonary function testing, FVC and %FVC were the same as before the surgery, FEV1 improved by 0.17 L, %FEV1 improved by 9.1%, and FEV1/FVC improved by 3.4%. There were no correlations between the thoracic deformity as noted by CT and the self-image domain score of SRS-22. Correction of thoracic deformities by thoracoplasty was poor, but it did not adversely affect the lung function, and it improved FEV1, %FEV1, and FEV1/FVC.

As AIS progresses and deformities worsen, respiratory deficiencies can often ensue due to a decrease in the FVC[15).

Table 3. Thoracic Deformity Correction Evaluated on CT.

	Preoperative	One week postoperatively	*p*-value	Final observation	*p*-value
RA_{sag} (°)	16.3±6.1	18.4±6.6	0.155	19.0±7.9	0.148
RHi	0.37±0.20	0.36±0.23	0.922	0.35±0.32	0.791
PHSr	1.90±0.37	1.91±0.36	0.870	2.16±0.43	0.007*

Values are mean (±standard division). *Significant difference.

RA_{sag}: rotation angle to the sagittal plane; RHi: rib hump index; PHSr: posterior hemithoracic symmetry ratio

Many studies have pointed out a relationship between the degree of deformation and restrictive respiratory impairment with a decline in the FVC[3,16], There are also studies that describe a relationship between spinal deformities and an obstructive respiratory impairment with a decline in FEV1[17]. In this study, FVC and %FVC did not change for more than five years, from before to after thoracoplasty, but FEV1, % FEV1, and FEV1/FVC improved following surgery. Furthermore, the PEF is affected by the respiratory muscle strength and airway obstruction, and it decreases during obstructive respiratory impairments. Hwangbo et al. stated that the increased mobility of the thorax ameliorates pulmonary functions with increasing PEF[18]. V50 and V25 reflect the occlusion and stenosis of the peripheral airways, and a V50/V25 of 3 or more indicates airflow obstruction in the peripheral airway. In this study, the PEF, V50, V25, and V50/V25 were improved after surgery. We presume that intrathoracic airflow obstruction is improved by scoliosis correction or thoracoplasty. Since there was no control group treated by posterior spinal fusion without thoracoplasty, the effect of thoracoplasty could not be revealed in this study.

This research had several limitations. Since we were not comparing our group with patients who did not undergo thoracoplasty, we could not verify whether our demonstrated pulmonary function improvements are effects that can be singularly attributed to thoracoplasty. We plan to compare these results with the pulmonary function tests of patients without thoracoplasty. There were a small number of patients (14 cases) with longitudinal CT evaluations because of a concern of radiation exposure. Since we did not perform pulmonary function testing following the administration of a bronchodilator, we could not determine whether the obstructive pattern is reversible or not. The follow-up rate was very low (42.1%). In the future, we will make additional attempts to follow-up patients who did not reply or refused to participate in this survey.

Conclusions

Rib hump and thoracic asymmetry as evaluated by CT in patients with AIS who underwent posterior fusion combined with thoracoplasty did not improve compared with preoperative assessments. In pulmonary function testing, FVC and % FVC did not significantly improve, but FEV1 improved by 0.17 L, %FEV1 improved by 9.1%, and FEV1/FVC improved by 3.4%. PEF, V50, and V25 were significantly improved at the final observation. In summary, with posterior spinal fusion in combination with thoracoplasty for AIS, although the correction of deformities was limited, the pulmonary function testing demonstrated the preservation of VC and improvements in the forced expiratory volume in 1 s and expiratory flow.

Disclaimer: Sumihisa Orita is one of the Editors of Spine Surgery and Related Research and on the journal's Editorial Committee. He was not involved in the editorial evaluation or decision to accept this article for publication at all.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Author Contributions: Tsutomu Akazawa wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

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