Pulmonary Function Improves in Patients with Adolescent Idiopathic Scoliosis who Undergo Posterior Spinal Fusion Regardless of Thoracoplasty: A Mid-Term Follow-Up

Tsutomu Akazawa[1)2)], Toshiaki Kotani[2)], Tsuyoshi Sakuma[2)], Keita Nakayama[2)], Yasushi Iijima[2)], Yoshiaki Torii[1)], Masahiro Iinuma[1)], Shingo Kuroya[2)], Kota Asano[1)], Jun Ueno[1)], Atsuhiro Yoshida[1)], Kenichi Murakami[1)], Shohei Minami[2)], Sumihisa Orita[3)], Kazuhide Inage[3)], Yasuhiro Shiga[3)], Junichi Nakamura[3)], Gen Inoue[4)], Masayuki Miyagi[4)], Wataru Saito[4)], Yawara Eguchi[3)], Kazuki Fujimoto[3)5)], Hiroshi Takahashi[6)], Seiji Ohtori[3)] and Hisateru Niki[1)]

1) Department of Orthopaedic Surgery, St. Marianna University School of Medicine, Kawasaki, Japan
2) Department of Orthopedic Surgery, Seirei Sakura Citizen Hospital, Sakura, Japan
3) Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University, Chiba, Japan
4) Department of Orthopaedic Surgery, Kitasato University School of Medicine, Sagamihara, Japan
5) Department of Orthopaedic Surgery, Konodai Hospital, National Center for Global Health and Medicine, Ichikawa, Japan
6) Department of Orthopaedic Surgery, Faculty of Medicine, University of Tsukuba, Tsukuba, Japan

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Abstract:

Introduction: The purpose of the present study was to determine, in a mid-term follow-up 5 years or more after surgery, the forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), and expiratory flow in patients with adolescent idiopathic scoliosis (AIS) who underwent posterior spinal fusion (PSF) with or without thoracoplasty.

Methods: The subjects were 134 patients with AIS who underwent PSF between 2004 and 2013. Forty-five patients agreed to participate in the study. We divided the patients into two groups as follows: 24 patients who underwent PSF with thoracoplasty from 2004 to 2010 in the TP group and 21 patients who underwent PSF without thoracoplasty from 2011 to 2013 in the non-TP group. We evaluated whole spine X-ray imaging and pulmonary function tests (PFTs) in these patients. PFTs measured FVC, 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).

Results: The main thoracic curves were 53.6 ± 10.1° before surgery, 19.8 ± 7.6° 1 week after surgery, 22.3 ± 8.3° 2 years after surgery, and 23.3 ± 7.6° at the most recent observation. Compared with preoperative values, FVC, FEV1, and % FEV1 were improved significantly at the most recent observation. No significant difference was observed between % FVC before surgery and at the most recent observation. Compared with preoperative values, PEF, V50, and V25 were improved significantly at the most recent observation. V50/V25 did not change significantly. The changes in PFT values in the TP group and the non-TP group were compared. No significant differences were observed in FVC, % FVC, FEV1, % FEV1, PEF, V50, or V25.

Conclusions: Regardless of whether thoracoplasty was performed or not, FVC, FEV1, and expiratory flow were improved 5 years or later after PSF.

Keywords:

adolescent idiopathic scoliosis, pulmonary function, expiratory flow, thoracoplasty

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Introduction

Because adolescent idiopathic scoliosis (AIS) develops after the age of 10 years, and its etiology has not yet been elucidated, long-term observation is required[1,2]. Allowing large deformities in AIS to remain can lead to poor quality

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Corresponding author: Tsutomu Akazawa, cds00350@par.odn.ne.jp
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of life, back pain, and reduced respiratory function[3,4]. Reduced respiratory function is associated with thoracic curves and thoracic cage deformities[5].

Several studies have analyzed the effects of a surgical approach on postoperative pulmonary function in AIS[6,7] and showed various results[8]. The pulmonary function was improved, unaffected, and impaired after posterior spinal fusion (PSF) in patients with AIS without thoracotomy or thoracoplasty. Similarly, PSF with thoracoplasty was improved, had no effect, or caused deleterious effects on the pulmonary function. It has been controversial whether thoracoplasty affects the pulmonary function in AIS patients.

Most studies have described forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1) in patients with AIS. In addition to FVC and FEV1, forced expiratory flow is an indicator of the pulmonary function. The maximum expiratory flow rate is the maximum value of the strength (speed) of breath when one exhales with full power, and it reflects the status of the bronchi. One study found that FVC did not improve, whereas FEV1 and expiratory flow were improved, after PSF with thoracoplasty[9]. However, since this study did not compare PSF with and without thoracoplasty, it is unclear whether the improvements of FEV1 and expiratory flow were due to the effect of thoracoplasty or the effect of PSF alone.

The purpose of the present study was to determine, in a mid-term follow-up 5 years or later after surgery, the FVC, FEV1, and expiratory flow in patients with AIS who underwent PSF with or without thoracoplasty. We hypothesized that the patients who underwent PSF with thoracoplasty would have lower pulmonary function than those without thoracoplasty.

Materials and Methods

1. *Subjects*

Our institutional review board approved the present study. The subjects were 134 patients with AIS who underwent PSF between 2004 and 2013. Inclusion criteria were (1) age of 10-19 years at surgery and (2) minimum 5-year follow-up. Exclusion criteria were (1) diagnosis other than AIS; (2) history of pulmonary diseases such as pneumonia, bronchial asthma, chronic bronchitis, emphysema, and diffuse panbronchiolitis; (3) reoperation; or (4) lumbar spinal fusion surgery alone. Ultimately, 45 patients (41 female and 4 male) met criteria and agreed to participate in this research. The average age at surgery was 15.4 years (range: 12 to 19 years); the average age at follow-up was 22.9 years (range: 18 to 28 years); and the average postoperative observation period was 7.2 years (range: 5 to 11 years). Lenke type was 1 in 24 patients, 2 in 12, 3 in 1, and 6 in 8. The upper instrumented vertebrae were T1 in 2 patients, T2 in 2, T3 in 4, T4 in 19, T5 in 14, T6 in 3, and T9 in 1. The lower instrumented vertebrae were T11 in 1 patient, T12 in 6, L1 in 15, L2 in 7, L3 in 12, and L4 in 4. We included 24 patients who underwent PSF with thoracoplasty from 2004 to 2010 in the TP group and 21 patients who underwent PSF without thoracoplasty from 2011 to 2013 in the non-TP group. We evaluated whole spine X-ray imaging and pulmonary function tests (PFTs) in these patients.

2. *Measurements*

Whole spine X-ray images were obtained frontally and laterally with the patient upright. We evaluated images obtained before the operation, 1 week after the operation, 2 years after the operation, and at the most recent observation (5 years or later after the operation). In the frontal view, we measured the proximal thoracic (PT) curve, main thoracic (MT) curve, and lumbar (L) curve. In the lateral view, we measured the thoracic kyphosis angle (TK: T5-T12 angle) and the lumbar lordosis angle (LL: L1-S1 angle).

PFTs measured FVC, 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). We evaluated PFTs performed before surgery and at the most recent observation. The PFTs were performed with the patient sitting and repeated three times. The best value was selected. To account for height loss due to scoliosis, the following formula was used: ΔH (mm) = $0.6 \times X + 2.6$, where $X = \Sigma$ (Cobb angle $-30°$)[10]. The predicted FVC was calculated from the corrected height at the time of measurement, sex, and age, and % FVC was calculated. To predict FVC, the formula of Baldwin et al.[11] was used for patients aged 18 years or older: predicted FVC (L) for men = $(27.63 - 0.112 \times \text{age}) \times$ corrected height (cm)/1,000, and predicted FVC (L) for women = $(21.78 - 0.101 \times \text{age}) \times$ corrected height (cm) / 1,000. For children aged <18 years, the formula of Nishima et al.[12] was used: predicted FVC (L) for boys = $0.0481 \times$ corrected height (cm) - 4.240, and predicted FVC (L) for girls = $0.0410 \times$ corrected height (cm) - 3.480. The predicted FEV1 was obtained from the corrected height at the time of measurement, sex, and age, and % FEV1 was calculated. To predict FEV1, the formula of Berglund et al.[13] was used: predicted FEV1 (L) for male patients = $0.0344 \times$ corrected height (cm) - $0.033 \times$ age - 1.00, and predicted FEV1.0 (L) for female patients = $0.0267 \times$ corrected height (cm) - $0.027 \times$ age - 0.54. The Gaensler equation was used to determine the proportion of air expelled in 1 s = FEV1 / FVC × 100.

For sub-analysis, thoracic cage deformities were evaluated using CT. We were able to evaluate 30 patients who underwent CT imaging preoperatively and at the most recent observation. Axial CT images were obtained of the apex of the main thoracic curve. For apex vertebra rotation, the rotation angle to the sagittal plane (RA sag) was measured according to the method developed by Aaro et al.[14]. For the rib hump, the rib hump index was measured according to the method developed by Aaro et al.[14].

3. *Surgical procedures*

In the TP group, pedicle screws, hooks, and sublaminar wiring using polymer polyethylene tape were used as anchors, and the curves were corrected by rod rotation. After correcting scoliosis, thoracoplasty was performed according to the method reported by Yang et al.[15]. A midline skin incision was performed on the remaining rib hump. In three convex ribs near the apex of the thoracic vertebra, the most prominent rib (3 cm long) was resected from a site 3 to 4 cm from the transverse rib joint (Fig. 1). In the non-TP group, pedicle screw fixation without thoracoplasty was performed. Pedicle screws were used mainly as anchors, and the curves were corrected by rod rotation. No thoracic cage destruction, such as rib resection or anterior release, was performed.

4. *Statistical analyses*

Statistical analyses were performed using IBM SPSS Statistics (version 26; IBM Corp., Armonk, NY, USA). Values were expressed as mean ± standard deviation. For comparisons between two groups, we used a paired t test or an unpaired t test. A Pearson correlation coefficient was used to determine correlations between two values. The level of significance was set at $p < 5\%$.

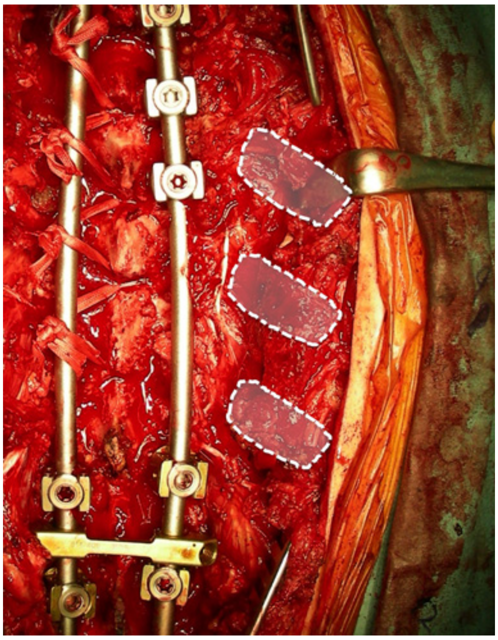

Figure 1. Thoracoplasty was performed after scoliosis correction. A midline skin incision was performed on the remaining rib hump. In three convex ribs near the apex of the thoracic vertebra, the most prominent rib was resected (areas surrounded by white dotted line).

Results

1. *X-ray imaging measurements*

The MT curves were 53.6° ± 10.1° before surgery, 19.8° ± 7.6° 1 week after surgery, 22.3° ± 8.3° 2 years after surgery, and 23.3° ± 7.6° at the most recent observation. Compared with preoperative values, the MT curves were corrected significantly 1 week after surgery, 2 years after surgery, and at the most recent observation. The PT curves were 29.4° ± 9.3° before surgery, 18.6° ± 7.8° 1 week after surgery, 18.1° ± 7.3° 2 years after surgery, and 18.5° ± 7.0° at the most recent observation. Compared with preoperative values, the PT curves were corrected significantly 1 week after surgery, 2 years after surgery, and at the most recent observation. The L curves were 36.7° ± 13.3° before surgery, 13.9° ± 7.0° 1 week after surgery, 15.5° ± 7.4° 2 years after surgery, and 15.3° ± 7.3° at the most recent observation. Compared with preoperative values, the L curves were corrected significantly 1 week after surgery, 2 years after surgery, and at the most recent observation. Compared with preoperative values, the TKs were 15.7° ± 10.3° before surgery, 15.7° ± 6.6° 1 week after surgery, 19.4° ± 7.8° 2 years after surgery, and 20.9° ± 8.0° at the most recent observation. Compared with preoperative values, the LL was 48.7° ± 12.8° before surgery, 42.5° ± 11.3° 1 week after surgery, 50.2° ± 9.1° 2 years after surgery, and 52.8° ± 10.2° at the most recent observation.

2. *Pulmonary function test measurements*

Compared with preoperative values, FVC was improved significantly at the most recent observation (2.39 ± 0.62 L before surgery, 2.54 ± 0.57 L at the most recent observation, $p = 0.026$). No significant difference was observed between % FVC before surgery and at the most recent observation (78.3% ± 18.5% before surgery, 81.4% ± 17.8% at the most recent observation, $p = 0.123$). FEV1 (2.05 ± 0.55 L before surgery, 2.21 ± 0.51 L at the most recent observation, $p = 0.009$) and % FEV1 (62.3% ± 16.2% before surgery, 71.0% ± 15.5% at the most recent observation, $p < 0.001$) were improved significantly. FEV/FVC (84.1% ± 15.0% before surgery, 85.2% ± 14.6% at the most recent observation, $p = 0.724$) did not change significantly (Table 1). Compared with preoperative values, PEF (4.06 ± 1.51 L before surgery, 4.96 ± 1.72 L at the most recent observation, $p < 0.001$), V 50 (2.68 ± 1.02 L before surgery, 3.04 ± 1.08 L at the most recent observation, $p = 0.003$), and V25 (1.24 ± 0.58 L before surgery, 1.43 ± 0.64 L at the most recent observation, $p = 0.023$) were improved significantly at the most recent observation. V50/V25 (2.37 ± 0.83 before surgery, 2.25 ± 0.56 at the most recent observation, $p = 0.397$) did not change significantly (Table 2).

The changes in PFT values between the TP group and the non-TP group were compared. No significant differences were observed in FVC ($p = 0.521$), % FVC ($p = 0.521$), FEV1 ($p = 0.814$), % FEV1 ($p = 0.853$), and FEV1/FVC ($p = 0.457$) (Table 3). No significant differences were observed in PEF ($p = 0.347$), V50 ($p = 0.661$) and V25 ($p = 0.718$) (Table 4).

Table 1. Comparison of FVC and FEV1 between Preoperative and the Most Recent Observation.

	Preoperative	Most recent observation	p value
FVC (L)	2.39±0.62	2.54±0.57	0.026*
%FVC (%)	78.3±18.5	81.4±17.8	0.123
FEV1 (L)	2.05±0.55	2.21±0.51	0.009*
%FEV1 (%)	62.3±16.2	71.0±15.5	<0.001*
FEV1/FVC (%)	84.1±15.0	85.2±14.6	0.724

Values are mean±standard deviation. * indicates significant difference.
FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s

Table 2. Comparison of Expiratory Flows between Preoperative and the Most Recent Observation.

	Preoperative	Most recent observation	p value
PEF (L/sec)	4.06±1.51	4.96±1.72	<0.001*
V50 (L/sec)	2.68±1.02	3.04±1.08	0.003*
V25 (L/sec)	1.24±0.58	1.43±0.64	0.023*
V50/V25	2.37±0.83	2.25±0.56	0.397

Values are mean±standard deviation. * indicates significant difference.
PEF: peak expiratory flow; V50: maximum expiratory flow at 50% of forced vital capacity; V25: maximum expiratory flow at 25% of forced vital capacity; V50/V25: ratio of V50 to V25

Table 3. Comparison of FVC and FEV1 Changes between the TP Group and the Non-TP Group.

	TP group	Non-TP group	p value
FVC (L)			
Preoperative	2.27±0.64	2.52±0.57	
Most recent observation	2.38±0.50	2.72±0.60	
Change	0.11±0.46	0.20±0.44	0.521
%FVC (%)			
Preoperative	74.5±18.6	82.7±17.7	
Most recent observation	76.4±16.4	87.2±17.9	
Change	1.9±12.0	4.5±15.0	0.521
FEV1 (L)			
Preoperative	1.88±0.52	2.25±0.52	
Most recent observation	2.05±0.42	2.40±0.55	
Change	0.17±0.40	0.15±0.40	0.814
%FEV1 (%)			
Preoperative	57.1±16.0	68.2±14.7	
Final	66.2±13.9	76.6±15.7	
Change	9.1±11.7	8.4±12.1	0.853
FEV1/FVC (%)			
Preoperative	83.0±7.9	85.2±20.5	
Most recent observation	86.4±7.3	83.8±20.1	
Change	3.34±6.53	–1.4±30.6	0.457

Values are mean±standard deviation. Minus values indicate decreasing.
FVC: forced vital capacity; FEV1: forced expiratory volume in 1 s

Table 4. Comparison of Expiratory Flow Changes between the TP Group and the Non-TP Group.

	TP group	Non-TP group	p value
PEF (L/sec)			
Preoperative	3.67±1.51	4.51±1.42	
Most recent observation	4.38±1.18	5.63±2.01	
Change	0.71±1.49	1.12±1.40	0.347
V50 (L/sec)			
Preoperative	2.30±0.93	3.10±0.96	
Most recent observation	2.62±0.71	3.52±1.22	
Change	0.32±0.74	0.42±0.83	0.661
V25 (L/sec)			
Preoperative	1.01±0.50	1.50±0.57	
Most recent observation	1.23±0.44	1.66±0.77	
Change	0.22±0.45	0.16±0.67	0.718
V50/V25			
Preoperative	2.50±0.92	2.22±0.69	
Most recent observation	2.22±0.45	2.29±0.68	
Change	–0.28±0.75	0.08±1.00	0.184

Values are mean±standard deviation. Minus values indicate decreasing.
PEF: peak expiratory flow; V50: maximum expiratory flow at 50% of forced vital capacity; V25: maximum expiratory flow at 25% of forced vital capacity; V50/V25: ratio of V50 to V25

3. *Correlations between PFTs and X-ray imaging measurements*

The preoperative MT curve had weak negative correlations with the preoperative FVC (r = –0.311, p = 0.037), % FVC (r = –0.353, p = 0.017), FEV1 (r = –0.352, p = 0.018), %FEV1 (r = –0.382, p = 0.010), PEF (r = –0.198, p = 0.192), V50 (r = –0.290, p = 0.053), and V25 (r = –0.384, p = 0.009). The preoperative TK had positive correlations with the preoperative FVC (r = 0.253, p = 0.093), % FVC (r = 0.318, p = 0.033), FEV1 (r = 0.285, p = 0.058), % FEV1 (r = 0.307, p = 0.040), PEF (r = 0.253, p = 0.094), V50 (r = 0.224, p = 0.138), and V25 (r = 0.226, p = 0.136).

The changes of % FVC had a weak positive correlation with the correction rate of the MT curve of the most recent observation (r = 0.284, p = 0.058). There was no significant correlation between the changes of FVC (r = 0.189, p = 0.213), FEV1 (r = 0.085, p = 0.578), % FEV1 (r = 0.133, p = 0.385), PEF (r = –0.002, p = 0.987), V50 (r = 0.063, p = 0.680), or V25 (r = 0.029, p = 0.850) and the correction rate of the MT curve of the most recent observation.

There was no significant correlation between the changes of FVC (r = 0.044, p = 0.772), % FVC (r = –0.047, p = 0.761), FEV1 (r = 0.136, p = 0.374), % FEV1 (r = 0.069, p = 0.651), PEF (r = 0.180, p = 0.236), V50 (r = 0.087, p = 0.568), or V25 (r = 0.154, p = 0.313) and the MT curve of the most recent observation. There was no significant correlation between the changes of FVC (r = 0.188, p = 0.217), % FVC (r = 0.131, p = 0.390), FEV1 (r = 0.175, p = 0.249), % FEV1 (r = 0.205, p = 0.178), PEF (r = 0.080, p = 0.600), V50 (r = 0.144, p = 0.344), or V25 (r = 0.221, p = 0.145) and TK of the most recent observation.

In summary, the correlation between PFT values and X-ray parameters indicate that patients with the larger preoperative MT curve and the smaller preoperative TK have lower pulmonary functions. If the postoperative MT curve correction rate was high at the most recent observation, the

% FVC tended to improve.

4. *Thoracic cage deformity assessment*

In the thoracic deformity on CT assessment, the RA sag had weak negative correlations with FVC (r = –0.271, p = 0.147), % FVC (r = –0.352, p = 0.057), FEV1 (r = –0.274, p = 0.143), and % FEV1 (–0.343, p = 0.064) at the most recent observation. There was no significant correlation between the rib hump index and FVC (r = –0.089, p = 0.640), % FVC (r = –0.191, p = 0.312), FEV1 (r = –0.072, p = 0.705), and % FEV1 (r = -0.172, p = 0.365) at the most recent observation. In the TP group, there were no significant changes of RA sag (16.2° ± 6.0°, before surgery, 18°.9 ± 7.1° at the most recent observation, p = 0.076) and the rib hump index (0.37 ± 0.19 before surgery, 0.39 ± 0.32 at the most recent observation, p = 0.739). In the non-TP group, there were no significant changes of RA sag (9.5° ± 3.5° before surgery, 9.5° ± 4.7° at the most recent observation, p = 0.999) and the rib hump index (0.12 ± 0.15 before surgery, 0.23 ± 0.52 at the most recent observation, p = 0.455).

5. *Comparison between participants and nonparticipants*

We compared the demographics of the 45 participants enrolled in this study with 89 nonparticipants. There were no significant differences in age at surgery (participants, 15.4 ± 2.0 years; nonparticipants, 15.4 ± 1.9 years; p = 0.989), body mass index (participants, 18.7 ± 2.5; nonparticipants, 19.1 ± 2.5; p = 0.461), preoperative FVC (participants, 2.39 ± 0.62 L; nonparticipants, 2.53 ± 0.54 L; p = 0.275), preoperative FEV1 (participants, 2.05 ± 0.55 L; nonparticipants, 2.14 ± 0.48 L; p = 0.429), the preoperative MT curve (participants, 53.6° ± 10.1°; nonparticipants, 53.8° ± 11.8°; p = 0.927), and preoperative TK (participants, 15.7° ± 10.3°; nonparticipants, 14.2° ± 12.3°; p = 0.532). The proportion of female participants and nonparticipants was not significantly different between the groups (participants, 88.9% female; nonparticipants, 87.6% female; p = 0.833).

Discussion

Thoracoplasty is a classical method of improving rib humps[16]. Kim et al.[7] reported postoperative respiratory deterioration in patients undergoing PSF with thoracoplasty. Thoracoplasty has also been reported as a risk factor for postoperative respiratory complications[17]. By contrast, Hod-Feins et al.[18] reported that thoracoplasty did not correlate with a high incidence of postoperative pulmonary complications, even in neuromuscular scoliosis, and should be used whenever necessary. Suk et al. noted that thoracoplasty could provide better clinical results without compromising lung function in segmental pedicle screw fixation to treat AIS[19]. In our study, with or without thoracoplasty, mid-term improvements in FVC, FEV1, and expiratory flow were observed after PSF.

There are only a few reports of the respiratory function of patients observed longer than 10 years after AIS surgery. Gitelman et al.[20] compared patients who underwent PSF without chest cage disruption with patients who underwent surgery with some form of chest cage disruption (anterior spinal fusion, anteroposterior spinal fusion, or PSF with thoracoplasty). They found that % FVC and % FEV1 decreased in the patients with some form of chest cage disruption, whereas the values did not change significantly in the patients without chest cage disruption. Pehrsson et al.[21] reported that VC increased from 3.1 L to 3.6 L and % VC increased from 67% to 84% in patients at an average of 23 years after Harrington instrumentation. The published long-term follow-up studies suggested that posterior-only surgery improved the pulmonary function, whereas chest cage disruption such as thoracoplasty led to deterioration of the pulmonary function. Although the pulmonary function improved regardless of thoracoplasty in the present study, this needs to be followed up over a longer period of 10 years to draw a comparable conclusion.

There are few reports of the expiratory flow of patients with scoliosis. In patients with AIS who underwent PSF with thoracoplasty, expiratory flow was improved despite a lack of improvement in FVC[9]. Yagci et al. reported that patients with AIS had worsened PEF after wearing a brace[22]. Reduced PEF might be due to weakness in respiratory muscles in patients with neuromuscular disease[23,24]. Because PEF was improved with or without thoracoplasty in the present study, we assumed that the improvement of PEF might be the effect of PSF.

There are several limitations to the present study. Because PFTs were not performed after administration of bronchodilators, it is not possible to determine whether the pattern of obstruction was reversible. This was a retrospective study, and no conclusions regarding causation can be made. Follow-up rates were low (33.6%), and future follow-up of patients who refused to participate in this survey is warranted. However, we considered that the present study group was representative of the whole group of patients because there were no significant differences in the demographics between participants and nonparticipants. The % FEV1 in this study was low compared to those in previous reports. We assumed that this was due to the use of corrected height values that take into account the scoliosis curve. Although sports activities or pulmonary rehabilitation was likely to influence the pulmonary function, we did not evaluate sports activities or pulmonary rehabilitation. We will evaluate sports activities or pulmonary rehabilitation in the future.

Conclusions

Regardless of whether thoracoplasty was performed or not, FVC, FEV1, and expiratory flow were improved 5 years or later after PSF. Thoracoplasty had no adverse effect on the pulmonary function, and PSF itself improved the pulmonary function in the mid-term follow-up.

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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.

Ethical Approval: No. 30-018, Institutional review board of Seirei Sakura Citizen Hospital.

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