Impact of Physical Flexibility Changes on Respiratory Function after Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis Surgery

Hiroki Oba[1], Shota Ikegami[1], Masashi Uehara[1], Terue Hatakenaka[1], Takayuki Kamanaka[1], Yoshinari Miyaoka[1], Daisuke Kurogouchi[1], Takuma Fukuzawa[1], Tetsuhiko Mimura[1], Michihiko Koseki[2] and Jun Takahashi[1]

1) Department of Orthopaedic Surgery, Shinshu University School of Medicine, Matsumoto, Nagano, Japan
2) Faculty of Textile Science and Technology, Shinshu University, Ueda, Nagano, Japan

Abstract:

Introduction: Corrective scoliosis surgery in patients with adolescent idiopathic scoliosis (AIS) increases thoracic volume but does not improve respiratory function (RF). This study evaluates the effect of physical flexibility (PF) improvement after scoliosis surgery on RF.

Methods: This study reviewed the records of 61 consecutive patients with AIS (56 female and 5 male; mean±standard deviation age: 14.8±2.2 years, range: 11-20 years) who had undergone posterior spinal fusion (PSF) of the thoracic curve. PF evaluated as finger-floor distance (FFD) was measured preoperatively and one year after surgery. After dividing the cohort into the PF improvement group and the PF nonimprovement group, RF changes at two years postoperative were statistically compared. Using logistic regression analysis, we evaluated the impact of a PF improvement on % forced vital capacity (%FVC) two years after surgery.

Results: The rate of patients with increased FVC, %FVC, and forced expiratory volume 1.0 second two years after surgery was 79%, 51%, and 80%, respectively. The PF improvement group exhibited a significantly higher gain in %FVC versus the PF nonimprovement group (P=0.043). Moreover, PF improvement significantly prevented a %FVC decrease (odds ratio 8.43, 95% confidence interval 1.92-59.70; P<0.001), with an adjusted odds ratio of 11.86 (P<0.001).

Conclusions: Patients with diminished PF after PSF for AIS may be less likely to achieve postoperative %FVC improvement. As increased postsurgical %FVC had a positive effect on physical function, treatment strategies that focus on maintaining and increasing PF are desirable from an RF viewpoint.

Keywords:

adolescent idiopathic scoliosis, posterior spinal fusion, respiratory function, finger-floor distance, forced vital capacity, forced expiratory volume 1.0 second, Scoliosis Research Society-22r, surgical outcome, pulmonary dysfunction

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Introduction

Chest wall deformity[1-3], suboptimal ventilation-perfusion distribution[4], and airway obstruction[5], contribute to pulmonary dysfunction in patients with adolescent idiopathic scoliosis (AIS)[6]. Suk et al. introduced segmental pedicle screw fixation for AIS in 1995[7], and made it possible to correct coronal, sagittal, and vertebral rotation. Posterior spinal fusion (PSF) did not improve respiratory function (RF) in AIS[6]. Whereas lung volume may increase after PSF, vital capacity does not ameliorate in all patients. To increase postoperative activities of daily living (ADL), surgeons should be aware of the interventional postsurgical factors that influence RF outcomes.

We have observed that while some patients display improved physical flexibility (PF) after surgery for AIS, others have worsened PF[8], which may affect RF. What percentage of patients have improved RF after PSF? Is maintaining body flexibility after PSF important for RF gains and more favorable clinical outcomes? To address these questions, we conducted a retrospective observational cohort study of 61 patients with AIS who had undergone PSF of the thoracic curve.

Corresponding author: Hiroki Oba, oba1@hotmail.co.jp
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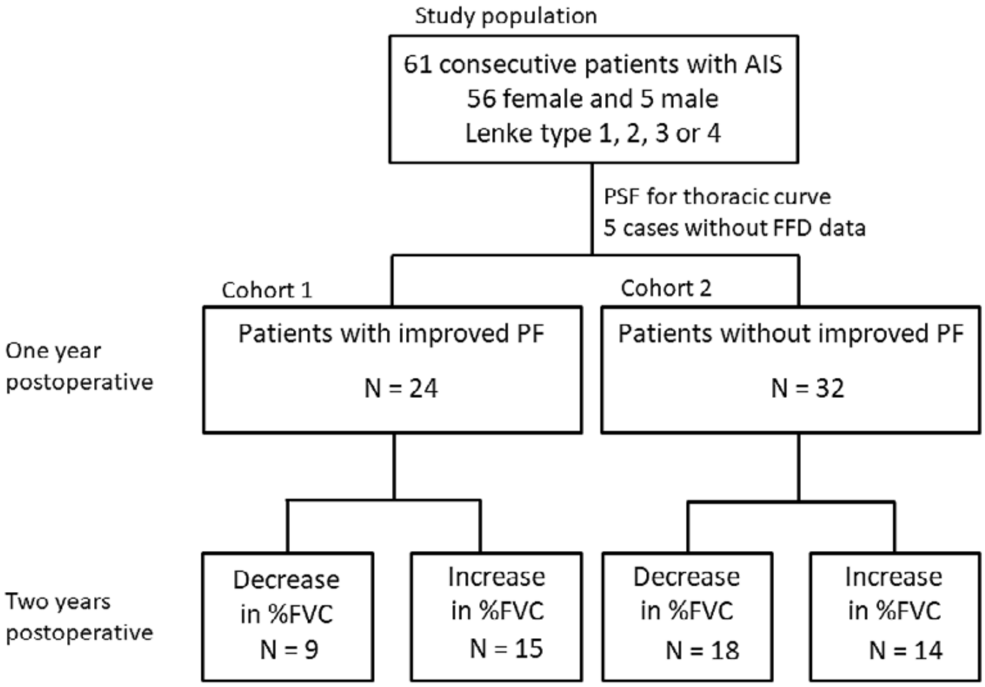

Figure 1. Study design.
Abbreviations: AIS, adolescent idiopathic scoliosis; PSF, posterior spinal fusion; FFD, finger-floor distance; PF, physical flexibility; FVC, forced vital capacity

Materials and Methods

Study design

Retrospective observational cohort study.

Institutional review board approval

The IRB has approved this research of the authors' affiliated institution.

Patients

We retrospectively reviewed the medical records of 61 consecutive patients with AIS (56 female and 5 male; mean ±standard deviation age: 14.8±2.2 years, range: 11-20 years) who underwent PSF of the thoracic curve at our hospital between May 2008 and December 2017 (Fig. 1). The inclusion criteria were: (1) diagnosis of AIS of type 1, 2, 3, or 4 according to the Lenke classification system, (2) receiving one-stage PSF using the rod rotation and direct vertebral rotation technique with an all-pedicle screw construct, and (3) completing a minimum followup period of 2 years. The exclusion criteria were patients with congenital, neuromuscular, syndrome-related, or other types of scoliosis and missing PF results. No patient had a history of bronchial asthma (Table 1).

Surgical procedure

Patients were placed in the prone position into a frame with a 4-point hole under general anesthesia. A vertical incision was made along the back midline. Instrumentation was from the posterior to the vertebral arch and the tip of the transverse process in the surgical range in a standard manner. Pedicle screws were inserted under guidance from preoperative computed tomography navigation. The spinous process and inferior articular process within the fixation area were excised. For rigid curves, Ponte osteotomy was added near the apex. After inserting a cobalt-chromium or titanium alloy rod into the concave side, the scoliotic curve was corrected using the rod rotation technique. We employed a relatively less bent rod on the convex side. The direct vertebral rotation technique corrected rotation. Local bone was transplanted into the facet joint. After inserting a drain under the fascia, the wound was closed in a standard manner.

Patient management after surgery

Most patients were discharged and could return to school 10 days after the surgery. Jogging and riding a bicycle were permitted from 3 months after surgery, noncontact sports from 6 months after surgery, and all exercises, including contact sports, from 1 year postoperative. We normally did not prescribe painkillers or a corset after discharge. Rehabilitation immediately after surgery was not performed apart from walking and daily exercise training until discharge.

Evaluation of RF, PF, and clinical results

A spirometry test was performed pre and two years postoperatively to measure forced vital capacity (FVC) and expiratory volume 1.0 second ($FEV_{1.0}$). %FVC was determined by dividing FVC by predicted FVC calculated using age and height. Finger-floor distance (FFD) was measured pre and 1 year postoperatively as an indicator of PF. At pre and two years postoperative, the angle of trunk rotation (ATR) was

Table 1. Baseline Patient Characteristics (N=61).

Age at surgery (years)	14.8±2.2 (11–20)
Female/Male	56 / 5
Height (cm)	157.8±6.1 (146.6–175.5) [1]
Weight (kg)	47.8±6.3 (35.2–65.0) [1]
Risser sign	
0	6
1	4
2	9
3	6
4	20
5	16
Lenke classification	
1	47
2	12
3	1
4	1
LIV	
T11	9
T12	18
L1	14
L2	10
L3	9
L4	1
MT Cobb angle (°)	55.6±8.1 (40.7–84.1) [1]
Fusion levels (vertebrae)	9.8±2.3 (5–15) [1]
Screw density	1.5±0.2 (1.1-2.0) [1]
Blood loss volume (g)	806.5±547.3 (100–2800) [1]
Operation time (min)	227.6±61.3 (127–408) [1]

[1] Values represent the mean±standard deviation (minimum–maximum).

Abbreviations: LIV, lower instrumented vertebra; MT, main thoracic

determined as an indicator of rotational deformation. Scoliosis Research Society (SRS)-22r questionnaires were completed pre and two years postoperatively to evaluate clinical results. To assess for factors affecting RF, we also recorded height, weight, range of fixation, screw density, bleeding volume, operation time, and history of underarm brace wearing, classical ballet dance, mental disorder, or developmental hip dislocation.

Radiological assessment

Standing long-cassette posteroanterior radiographs were evaluated by spine surgeons (H.O., R.M., and T.H.) before and two years after surgery. The investigators who performed the imaging measurements were unrelated to the surgeries and reviewed the radiographs while blinded to the outcomes. We evaluated the Cobb angle of the upper thoracic (UT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) curves, T12-S1 kyphotic angle, clavicular angle, coronal balance, and sagittal vertical axis.

Statistical analysis

Interval and ratio data were analyzed using Welch's *t*-test, ordinal data were assessed with the Mann-Whitney U test, and nominal data were compared through Fisher's exact test. Logistic regression analysis was performed to evaluate the effect of an FFD improvement one year on the deterioration of vital capacity. Afterward, adjusted odds ratios (ORs) were calculated using tendency scores by inverse probability of treatment weighting (IPTW). All analyses were performed using Prism version 4.0 (Graph Pad Software, La Jolla, CA), the Statistical Package for Social Sciences for Windows version 21.0 (IBM, Chicago, IL), and the statistical package R version 3.2.0 (available at http://www.r-project.org). For all tests, P<0.05 was considered statistically significant.

Results

Overall data

No major surgical events, including massive bleeding and spinal cord injury, were recorded in the cohort. Table 1 summarizes the baseline patient characteristics. No revision surgery was needed, and no patient experienced implant failure, proximal junctional kyphosis, or distal adding-on. The radiographic parameters and ATR before surgery and two years postoperatively are presented in Table 2 and generally showed significant postoperative improvements.

Comparison of RF before surgery and two years postoperative

Between pre and two years postoperative, the overall mean difference for FVC was +206.4 mL (95% confidence interval [CI] 149.4-263.4; P<0.001), that for %FVC was −0.8% (95% CI −3.2-1.6; P=0.507), and that for $FEV_{1.0}$ was +4.1% (95% CI 2.7-5.4; P<0.001) (Fig. 2). Among the 61 patients, the number (percentage) of patients with increased FVC, %FVC, and $FEV_{1.0}$ 2 years after surgery was 48 (79%), 31 (51%), and 49 (80%), respectively.

Change in FFD from before surgery to 1 and 2 years postoperative

Fifty-six patients were measured for FFD preoperatively and one and two years after surgery. The mean±standard error FFD at those time points was 8.8±1.2 cm, 10.9±1.5 cm, and 9.8±1.5 cm, respectively. FFD increased significantly from before surgery to 1 year postoperative (+2.8°, 95% CI 0.4-5.3; P=0.022), and subsequently tended to decrease by 2 years (−1.7°, 95% CI −3.5-0.1; P=0.059) (Fig. 3). We observed that FFD tended to increase as the lowest instrumented vertebra (LIV) moved caudally (one-way ANOVA: F =2.18, P=0.07, R=0.18) (Fig. 4).

Comparison of %FVC in patients with and without FFD improvement

The mean FVC change in the FFD improvement and nonimprovement groups one year postoperative was 247.0±30.6 mL and 198.0±28.5 mL, mean %FVC change was 4.1%±0.6% and −2.2%±1.4%, and mean $FEV_{1.0}$ change was 4.6%±0.6% and 4.0%±0.8%, respectively. The FFD improvement group showed a significantly higher improvement

Table 2. Changes in Radiographic Parameters after PSF (N=61).

Variable	Preoperative	2 years postoperative	P-value
Coronal parameters			
PT Cobb angle (°)	32.4±10.9 (17.3–63.7)	18.7±8.3 (3.0–44.1)	<0.001*
MT Cobb angle (°)	55.5±8.1 (40.7–84.1)	23.9±6.5 (6.4–37.8)	<0.001*
TL/L Cobb angle (°)	38.0±9.1 (18.1–56.4)	17.0±9.3 (1.9–41.1)	<0.001*
MT AVT (mm)	43.3±9.1 (19.9–70.7)	16.0±8.7 (−3.1–38.5)	<0.001*
C7PL (mm)	−2.9±14.5 (−34.7–29.2)	−6.1±10.1 (−28.4–17.6)	0.062
CA (°)	−0.6±2.6 (−7.1–6.2)	2.2±2.1 (−2.8–6.6)	<0.001*
Sagittal parameters			
T5–12 TK (°)	13.3±10.3 (0.6–49.6)	27.3±9.2 (8.5–59.7)	<0.001*
T10–L2 kyphosis (°)	0.6±6.9 (−17.2–14.8)	4.1±8.6 (−18.9–28.2)	0.003*
T12–S1 LL (°)	50.5±11.5 (23.0–74.6)	55.4±10.4 (29.9–78.5)	<0.001*
SVA (cm)	−8.5±22.6 (−53.7–53.7)	−12.9±18.2 (−57.4–32.2)	0.125
Clinical examination			
MT ATR (°)	16.3±6.1 (2.0–30.0)	9.3±3.6 (2.0–20.5)	<0.001*
TL ATR (°)	8.9±4.9 (−5.0–22.5)	4.2±2.6 (−3.5–9.0)	<0.001*

Values represent the mean±standard deviation (minimum–maximum).

* P<0.05 was considered statistically significant.

Abbreviations: PSF, posterior spinal fusion; PT, proximal thoracic; MT, main thoracic; TL/L, thoracolumbar/lumbar; AVT, apical vertebral translation; C7PL, C7 plumb line (deviation to the right defined as a positive value); CA, clavicular angle (raised left shoulder defined as a positive value); TK, thoracic kyphosis; LL, lumbar lordosis; SVA, sagittal vertical axis; ATR, angle of trunk rotation

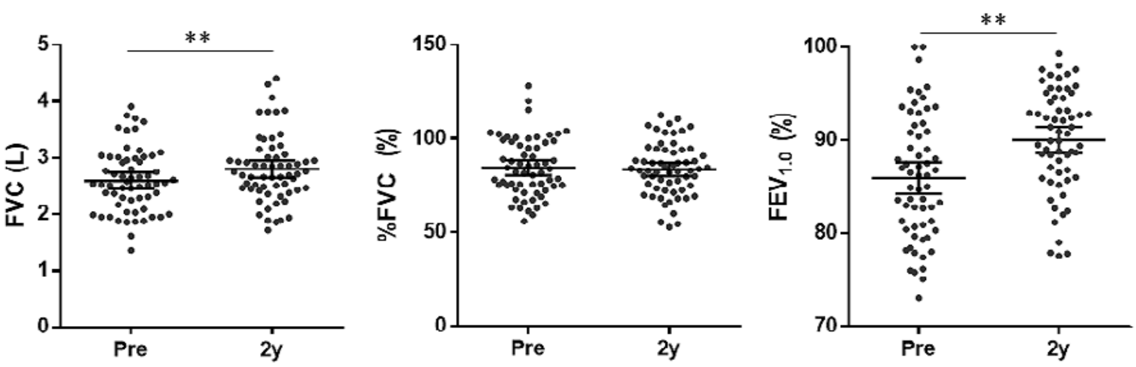

Figure 2. Comparison of respiratory function (RF) before surgery and two years postoperatively.
** P<0.01.

in %FVC one year after surgery versus the FFD nonimprovement group (P=0.043) (Fig. 5). A histogram of FFD improvement and %FVC change one year postoperative revealed that most patients with improved FFD also had ameliorated %FVC (Supplemental Figure).

Impact of PF change on RF after AIS surgery

We defined a decreased FFD value one year after surgery as a PF improvement and evaluated its impact on %FVC amelioration two years after surgery using logistic regression analysis. Improved PF significantly prevented a %FVC decrease (OR 8.43, 95% CI 1.92-59.70; P<0.001) (Table 3). Next, the adjusted OR was calculated with logistic regression analysis using the IPTW method with weighting by the reciprocal of the propensity score using peripheral items (Lenke classification, age, height, weight, range of fixation, screw density, blood loss volume, operation time, UT Cobb angle, MT Cobb angle, TL/L Cobb angle, MT apical vertebral translation, T5-L2 thoracic kyphosis, clavicular angle, coronal balance, MT maximum side bending, TL/L maximum side bending, T10-L2 thoracic kyphosis, T12-S1 lumbar lordosis, sagittal vertical axis, and history of underarm brace wearing, classical ballet dance, mental disorder, or developmental disorder of the hip) that were likely to affect vital capacity and FFD. The c-statistic of the propensity score for this evaluation was 0.905, indicating an adequate explanation rate. The adjusted OR for PF improvement was 11.86 (95% CI 1.73-81.27; P<0.001). Thus, a significantly improved PF one year postoperative independently prevented decreased %FVC.

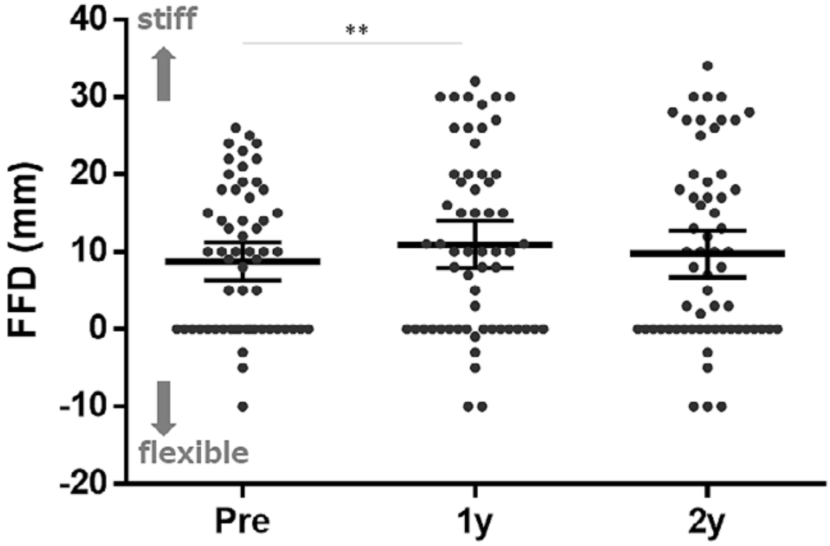

Figure 3. Change of finger-floor distance (FFD) before surgery and one and two years postoperatively.
** P<0.01.

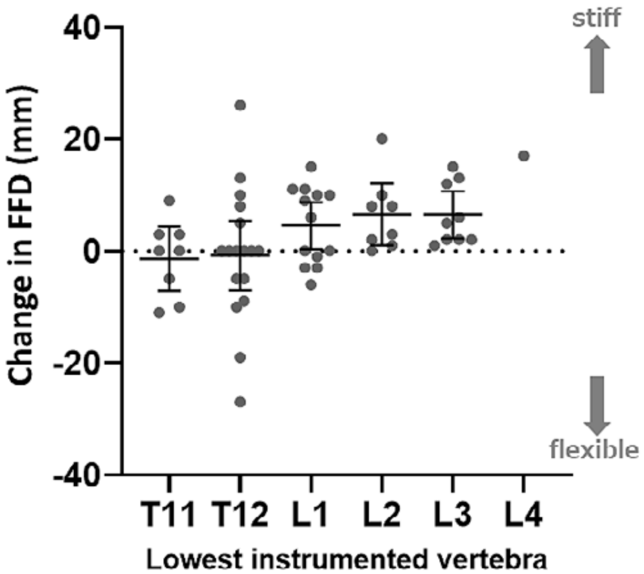

Figure 4. Finger-floor distance (FFD) changes according to the lowest instrumented vertebra.

Comparison of SRS-22r scores between patients with a %FVC decrease or increase

As a subanalysis, we investigated the effect of a %FVC improvement on clinical outcomes. The clinical results of patients with a %FVC decrease (N=31) and those with a %FVC increase (N=30) before and two years after surgery were compared using SRS-22r scores. In the %FVC increase group, the function subscore was significantly improved at 2 years after surgery (0.4 difference, 95% CI 0.2-0.6; P=0.001) and significantly higher than in the %FVC decrease group (0.2 difference, 95% CI −0.1-0.3; P=0.041) (Table 4).

Discussion

The present study revealed several key findings on the impact of PF on RF in AIS patients following PSF. First, although mean $FEV_{1.0}$ and FVC significantly improved two years after surgery, no remarkable gains in %FVC occurred. The rate of patients with increased FVC, % FVC, and $FEV_{1.0}$ after surgery was 79%, 51%, and 80%, respectively. Second, an improvement in FFD one year postoperative significantly prevented a decrease in %FVC two years postoperative. Third, increased postoperative %FVC positively affected physical function according to SRS-22r scores. The above results indicate a clinical benefit of increased PF following surgery for AIS.

Mean $FEV_{1.0}$ and FVC were significantly improved after PSF for AIS, whereas no increase in %FVC was noted. It has been demonstrated that a chest wall deformity can lead to decreased thoracic volume over time[9], and, more importantly, alter the dynamic mechanical properties of inhalation and exhalation to disable energy-efficient respiration[1,6]. In addition, patients with scoliosis often have reduced kyphosis of the thoracic spine. Thoracic kyphosis contributes to securing chest volume. Robert et al. reported that a decrease in thoracic kyphosis correlated significantly to diminished spirometry results in AIS patients[10,11]. In recent years, the use of pedicle screws enabled three-dimensional surgical correction[12], which increases postoperative rib cage volume[13]. Although we observed a significant increase in thoracic kyphosis and decreases in Cobb angle and ATR, there was no improvement in %FVC. Similarly, in their meta-analysis, Kato et al. detected no significant gains in %FVC after surgery in patients with scoliosis[6]. However, 52% of our patients ultimately displayed an improvement in %FVC. Unlike in Kato's report[6], $FEV_{1.0}$ was higher in 80% of patients and increased significantly over preoperative levels.

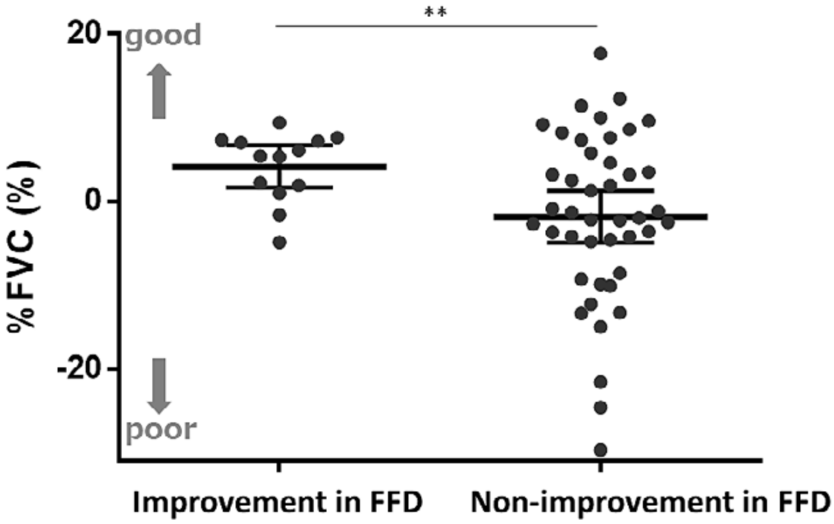

Figure 5. Comparison of forced vital capacity (FVC) in patients with and without finger-floor distance (FFD) improvement.
** P<0.01.

Table 3. Impact of a Physical Flexibility Increase on %FVC Improvement Two Years Postoperatively.

	OR	(95% CI)	P-value
Improvement of PF at 1 y	8.43	(1.92–59.70)	0.01*
Improvement of PF at 1 y (adjusted)	11.86	(1.73–81.27)	0.01*

* P<0.05 was considered statistically significant.
Abbreviations: FVC, forced vital capacity; PF, physical flexibility; 1 y, one year postoperative; OR, odds ratio; CI, confidence interval
Data were calculated by logistic regression analysis after adjustment using the inverse probability of treatment weighting method for Lenke classification, age, height, weight, range of fixation, screw density, blood loss volume, operation time, PT Cobb angle, MT Cobb angle, TL/L Cobb angle, MT AVT, CA, C7PL, MT maximum side bending, TL/L maximum side bending, T10-L2 TK, T12-S1 LL, SVA, and history of underarm brace wearing, classical ballet dance, mental disorder, or developmental dislocation of the hip.
Abbreviations: PT, proximal thoracic; MT, main thoracic; TL/L, thoracolumbar/lumbar; AVT, apical vertebral translation; TK, thoracic kyphosis; LL, lumbar lordosis; SVA, sagittal vertical axis; C7PL, C7 plumb line (deviation to the right defined as a positive value); CA, clavicular angle (raised left shoulder defined as a positive value)

An improvement in FFD one year postoperative significantly prevented a decrease in %FVC two years postoperative. Since patients with AIS reportedly have limitations in lumbar spine range of motion from their scoliotic curve before surgery[14], range of motion is not always reduced by correction. Strikingly, roughly a quarter of the cases in our study showed a reduction in FFD one year after surgery, and almost all of them achieved an improvement in %FVC (Supplemental Figure). Since we considered confounding factors such as surgical scope, surgical invasion, and residual curve impaired PF, we employed propensity scores that included all suspected outcome involvement. Those results confirmed PF as an independent predictor of %FVC improvement. It was also possible that decreased PF could reduce vital capacity due to enlargement of the rib cage and severe rib movement restriction. In studies of ankylosing spondylitis, lower spinal mobility correlated significantly with decreased vital capacity[15,16]. The abdominal muscles are necessary to breathe under restricted thoracic movement. PF is required to utilize the muscles that assist breathing. The above factors indicate that the main factor influencing an increase in postoperative RF is the maintenance of postoperative flexibility. Alternatively, it may simply be that the amount of activity itself after surgery is reflected in PF.

We observed that FFD increased as the LIV moved caudally (Fig. 4), consistent with previous reports[8,17]. However, we believe that not only LIV level but also postoperative lifestyle influence FFD value changes during the first year after surgery. The fact that FFD increased in the first postoperative year before decreasing slightly in the ensuing year suggested that perioperative exercise restrictions may have impacted FFD (Fig. 3). Vishal et al. investigated the timing of physical activity after scoliosis surgery and reported that only 60% (54/90) of patients could bow three months post-

Table 4. SRS-22r Scores for the %FVC Decrease Group and %FVC Increase Group (N=61).

Variable	%FVC decrease (N=30)	%FVC increase (N=31)	P-value
Preoperative			
Pain	4.36±0.08	4.36±0.07	0.977
Self-image	2.63±0.09	2.78±0.09	0.253
Function	4.66±0.07	4.48±0.07	0.111
Mental health	3.88±0.13	4.16±0.11	0.121
Two years postoperative			
Pain	4.52±0.08	4.62±0.06	0.370
Self-image	3.96±0.15	3.85±0.10	0.555
Function	4.62±0.07	4.79±0.04	0.041*
Mental health	4.30±0.13	4.16±0.11	0.224
Satisfaction	4.03±0.17	4.08±0.09	0.817
Subtotal	4.35±0.09	4.44±0.04	0.408
Change			
Pain	0.16±0.07	0.27±0.09	0.366
Self-image	1.33±0.18	1.07±0.13	0.255
Function	−0.04±0.07	0.31±0.06	0.001*
Mental health	0.42±0.14	0.34±0.11	0.682

Values represent the mean±standard error.

* P<0.05 was considered statistically significant.

Abbreviations: SRS-22r, Scoliosis Research Society-22r; FVC, forced vital capacity

operative[18]. Lehman et al. conducted a questionnaire survey of scoliosis surgeons regarding the timing of returning to movement after AIS surgery to reveal that most operators allowed running after three months, noncontact and contact sports after six months, and collision sports 12 months after surgery. Meanwhile, almost no mechanical problems due to a return to exercise were reported[19]. If patients engage in limited trunk movement during the year after AIS surgery due to misunderstandings on allowable exercise intensity, their FFD may increase. It is important to explain a timely return to exercise to patients since excessive rest during the first year after surgery may adversely affect respiratory capacity after that.

Lastly, increased postoperative %FVC positively affected physical function and suggested that a decrease in vital capacity after surgery could lead to diminished ADL. Uehara et al. evaluated the changes in FFD in 66 AIS patients after lumbar surgery and witnessed significant FFD restriction as the LIV were moved inferiorly, although clinical results appeared unaffected by limited FFD[8]. Fabricant et al. reported that unless the fixed distal end reached L4, the athletics reversion rate did not decrease significantly, regardless of the LIV[20]. In the present study, there was 1 case in which the LIV reached L4, but the patient's postoperative function score improved. For these reasons, we suspect that a reduction in vital capacity is an important factor leading to decreased ADL. A necessary rest period should be prescribed if the surgeon has doubts regarding patient safety. Otherwise, early exercise and flexibility training may be encouraged if firm surgical fixation is confirmed to maximize vital capacity and ADL.

This study was limited by the absence of a control group and a retrospective design. A larger prospective validation study is necessary to support our hypotheses. Another limitation was the short followup period of 2 years after surgery. Burt et al. reported almost no change in RF from 2 to 5 years postsurgically in AIS patients who underwent posterior surgery[21]. Therefore, we presume that the effects of FFD one year postoperative on results two years postoperative may be extended to a long-term RF prognosis. However, a longer followup is needed to confirm this. A third limitation was that vital capacity was not corrected by arm span[22]. We measured %FVC values by adjusting for height before and after the operation. Each patient's height elongation was several centimeters preoperatively to immediately after surgery. Thus, the height-corrected improvement in %FVC may have been underestimated. Finally, only FFD was evaluated as a flexibility assessment. Multiple measurement parameters will be needed to elucidate the relationship between flexibility and RF comprehensively.

Conclusion

Following PSF for AIS, patients who lose PF may be less likely to achieve gains in postoperative %FVC. Increased %FVC might have a positive effect on postoperative physical function. Therefore, treatment strategies to maintain and improve PF after AIS surgery are advised to maximize RF and ADL. It may also be important not to recommend excessive rest to postoperative patients, instead giving them clear permission to return to exercise at the earliest appropriate time.

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

Ethical Approval: Approval code 4678, Shinshu University School of Medicine

Informed Consent: Informed consent was obtained by all participants in this study.

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