Prevalence and Key Radiographic Spinal Malalignment Parameters Associated with the Risk of Pulmonary Function Impairment in Patients Treated Surgically to Correct Adult Spinal Deformity

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Abstract:

Introduction: There is a significant relationship between pulmonary function and degree of spinal deformity, location of apical vertebrae, and coronal imbalance in patients with childhood spinal deformity. By contrast, the pathophysiology, epidemiology, and influence of deformity on respiratory dysfunction in patients with adult spinal deformity (ASD) remain largely unknown. We sought to clarify and compare the prevalence of pulmonary function impairment in patients with ASD with that in patients with lumbar spinal stenosis (LSS), to determine radiographically which spinal malalignment parameters are associated with a risk of respiratory dysfunction, and to determine the association of respiratory dysfunction with corrective surgery.

Methods: We conducted a prospective study of consecutive patients with a diagnosis of ASD or LSS who underwent spinal surgery. We included data from 122 consecutive patients with ASD and 121 consecutive patients with LSS. Parameters were obtained from full-length lateral radiographs taken with the patients standing and in supine and prone positions. We compared respiratory dysfunction between a group of patients with ASD and LSS and determined correlations between respiratory dysfunction and spinopelvic parameters.

Results: Preoperative % forced vital capacity (FVC) of patients with ASD was significantly lower than that of patients with LSS, and the frequency of restrictive ventilatory impairment was significantly higher in those with ASD (15.7%) than those with LSS (7.4%). Thoracolumbar kyphotic curvature (TK) while the patients were in supine position was significantly greater in the group with restrictive ventilatory impairment, and a significant negative correlation was found between %FVC and TK with the patients in supine position. We found no significant improvement of respiratory dysfunction 1 year after surgery.

Conclusions: Spinal deformity is a potential risk factor for restrictive ventilatory impairment in the elderly. We propose that radiographs obtained when patients are in supine position are valuable for evaluating the flexibility of the TK. Rigid TK might be an etiology of restrictive ventilatory impairment in patients with ASD.

Keywords:

adult spinal deformity, pulmonary dysfunction, thoracic kyphosis, surgical spinal correction, supine position

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Introduction

In an aging society, adult spinal deformity (ASD) remains one of the most challenging ailments within the field of spinal disorders because of its great influence on health-related quality of life. Sagittal and coronal spinal malalignments are correlated with low back pain. Therefore, studies have examined the correlation between radiographic spinopelvic parameters and low back pain-related factors evaluated by questionnaires such as the Oswestry Disability Index and Roland-Morris Disability Questionnaire[1-3)]. Moreover, because of contracture of the trunk, involvement of ASD has been found in disorders such as gastroesophageal reflux disease[4-6)].

Substantial attention has been directed towards childhood spinal deformity and its effect on pulmonary function[7-9)].

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Table 1. Preoperative Patient Characteristics.

Variable	ASD (N=122)	LSS (N=121)	
Age at surgery (years)	71.1±7.1	73.2±8.2	NS
Female/male (n)	108/14	104/17	NS
Location of UIV, n (%)			
T3	2 (1.7%)		
T4	9 (7.4%)		
T5	7 (5.7%)		
T6	2 (1.7%)		
T8	7 (5.8%)		
T9	29 (24.0%)		
T10	61 (50.4%)		
T11	3 (2.5%)		
L1	2 (1.7%)		

Interval and ratio values represent the mean±standard deviation.
ASD, adult spinal deformity; LSS, lumbar spinal stenosis; UIV, upper instrumented vertebra; NS, not significant

There is a significant relationship between pulmonary function and degree of spinal deformity, location of apical vertebrae, and coronal imbalance in patients with adolescent idiopathic scoliosis (AIS)[10-12]. Pulmonary function has been recognized as one of the most important postoperative outcomes of surgery to treat AIS[13,14]. By contrast, the pathophysiology, epidemiology, and influence of deformity on pulmonary dysfunction in patients with ASD remain largely unknown.

The aims of present study were to clarify and compare the prevalence of impairment of pulmonary function in patients with ASD with that in patients with lumbar spinal stenosis (LSS); to determine radiographically which spinal malalignment parameters are predominantly associated with a risk for respiratory dysfunction; and to determine the association of respiratory dysfunction with surgery to correct spinal deformity.

Materials and Methods

Patients

After approval by our institutional review board, we conducted a prospective study of consecutive patients with a diagnosis of ASD or LSS who underwent spinal surgery. Patients were considered candidates for thoracolumbar correction if fusion was indicated because of ASD or LSS and if a full course of conservative care had been exhausted. The inclusion criteria were age >60 years and a radiographic diagnosis of ASD defined by at least one of the following parameters: a coronal Cobb angle >30°; a C7 sagittal vertical axis (SVA), which is the distance between the C7 plumb line and the posterosuperior edge of S1, >50 mm; and/or >30° pelvic tilt (PT), which is the orientation of the pelvis with respect to the femurs and the rest of the body. An SVA of <50 mm, lumbar lordosis (LL) of >30°, and Cobb angle of <10° were defined as LSS. In the present study, we included only *de novo* cases of degenerative spinal deformity to study separately secondary degenerative scoliosis superimposed on AIS. Patients were excluded if they had a history of diagnosed AIS; had ankylosing spondylitis, a rounded back because of Parkinson's disease, and a respiratory disease such as asthma or chronic obstructive pulmonary disease; were a smoker; or had not been followed up for at least 1 year.

We included data from 122 consecutive patients with ASD and 121 consecutive patients with LSS who underwent spinal surgery for their disorder between April 2012 and March 2016 performed by two board-certified spinal surgeons at a single institution and followed up for a minimum of 1 year. Basic demographic and surgical data such as age, sex, and area of fusion are noted (Table 1).

Surgical procedure to correct ASD

The patients with ASD had undergone lateral interbody fusion from L1-L2 or L2-L3 to the level of the L4-L5 disc to obtain adequate coronal and sagittal global spinal alignment[13]. Subsequently, the patient had been placed in a prone position to undergo a posterior lumbar interbody fusion at the level of the L5-S disc, and spinal kyphosis was corrected using a cantilever force with S1 screws bilaterally and single or dual iliac screws bilaterally. Allogenic and local autogenous bone grafts were used. Bone morphogenetic protein was not used in any case.

Radiographic measurements

Radiographic data were measured from full-length lateral radiographs obtained preoperatively and at 1 year postoperatively, with the patient freestanding and their fingers placed on their clavicles. The following radiographic parameters were obtained from preoperative and 1 year postoperative images with a lateral view: T5-T12 thoracolumbar kyphotic curvature (TK); T12-S1 LL angles; pelvic incidence; PT; sacral slope; SVA; T1 pelvic angle denotes the angle between the line from the center of the femoral heads to the center of S1 and the line from the femoral head to the center of the T1 vertebra[15]; and global tilt denotes the angle formed by the intersection of two lines, the first drawn from the center of C7 to the center of the sacral endplate and the second drawn from the center of the femoral heads to the center of the sacral endplate[16]. Lordosis was indicated as a negative value, and kyphosis was indicated as a positive value. Preoperative evaluation of flexibility of the thoracolumbar spine was essential to perform the surgery optimally and included an assessment of the necessity of osteotomy and/or range of fusion. Radiographs obtained with the patient in supine and prone positions are reported as effective for evaluating the flexibility of the TK[4,15]. Full-length lateral radiographs were obtained with the patients in supine and prone positions with both arms next to the trunk and without any cushions under the body. TK was measured from images with the patients standing and in prone and supine positions and compared to evaluate the flexibility of the

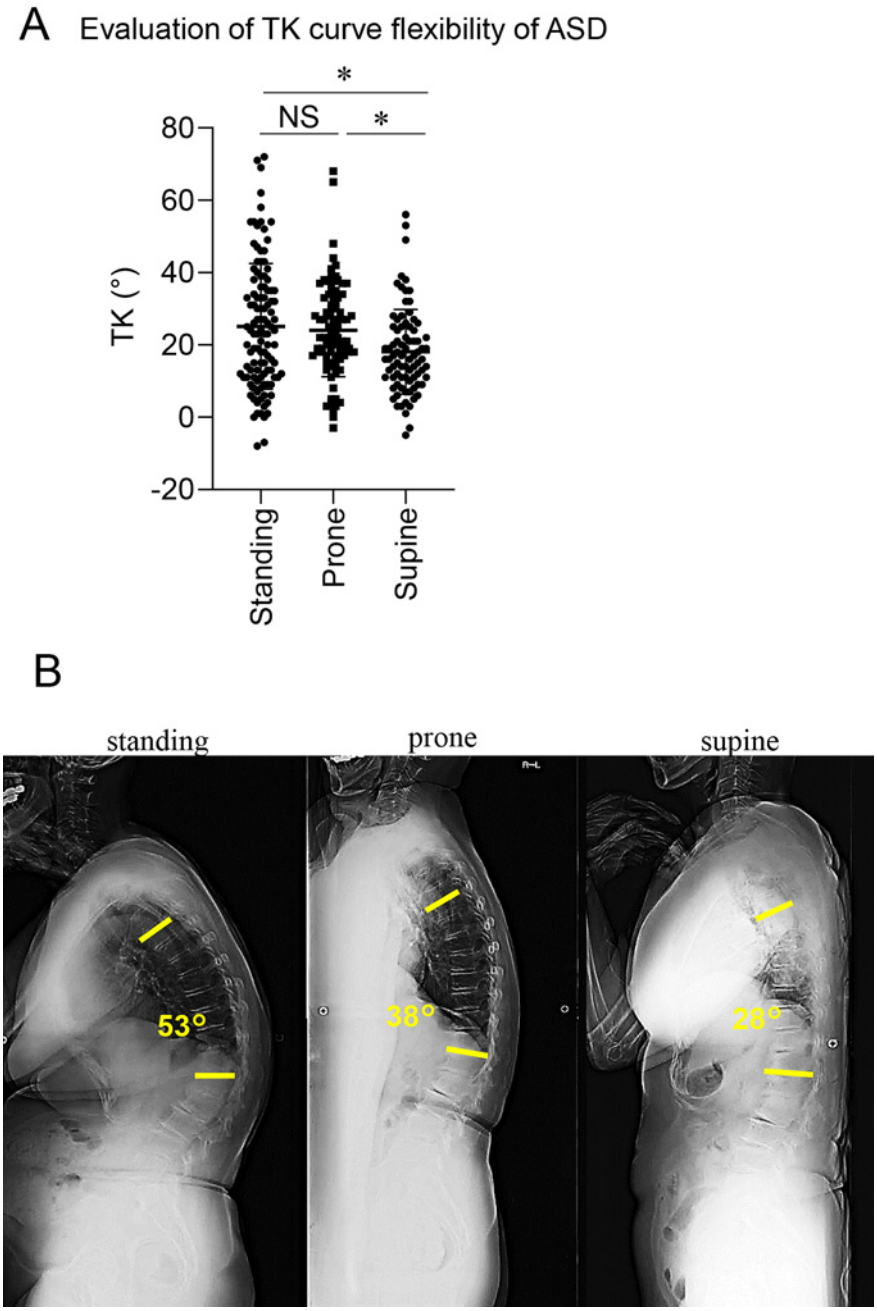

Figure 1. (A) Comparison of TK in patients with ASD while they were standing and in prone and supine positions (*P<0.05; NS, not significant). (B) Representative radiographs obtained with the patients standing and in supine and prone positions.

thoracic spine (Fig. 1). Radiographic parameters were measured by two board-certified spine surgeons (TO, author 2 and HO, author 4) to determine interobserver error. We used the mean values of parameters obtained by their measurements in the following analysis. The intraclass coefficient was 0.880, indicating that the inter-rater reliability was adequate. These authors have >10 years of experience in spinal surgery and are blinded to patient data before the measurements were performed.

Pulmonary function tests

All patients in the study had undergone pulmonary function tests (PFTs) to determine pulmonary volume before and 1 year after surgery. The tests were performed with the patients standing. Each spirometry test was repeated 3 times, and the highest recording was selected. The PFT data are represented as an absolute (best) value for forced expiratory volume in 1 s (FEV1) and forced vital capacity (FVC) as well as percent predictive values normalized to age, weight, and preoperative or postoperative height or arm span. FVC provides an assessment of lung volume, whereas the FEV1 provides an assessment of flow function. Obstructive impairment was defined as %FEV1 <70%, and restrictive impairment was diagnosed if %VC was <80%.

Table 2. Preoperative and Postoperative Spinopelvic Parameters of Patients with Adult Spinal Deformity.

Variable	Preop.	Postop.	*P*
Body height (cm)	150.1±7.7	153.6±7.1	<0.05
PT (°)	37.2±10.1	21.5±9.1	<0.0001
SS (°)	15.2±13.1	28.7±8.3	<0.0001
LL (°)	9.0±21.2	50.0±11.1	<0.0001
PI-LL (°)	42.0±21.1	0.7±13.1	<0.0001
SVA (mm)	124.4±69.2	26.1±39.2	<0.0001
GT (°)	53.2±17.2	22.1±11.3	<0.0001
TPA (°)	41.1±14.4	17.1±10.3	<0.0001
Main Cobb angle (°)	23.1±16.2	10.2±7.2	<0.0001

Interval and ratio values are presented as the mean±standard deviation.
**P*<0.05 or *P*<0.0001 in the comparison with preop.
Preop., preoperative; Postop., postoperative; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis; GT, global tilt; TPA, T1 pelvic angle

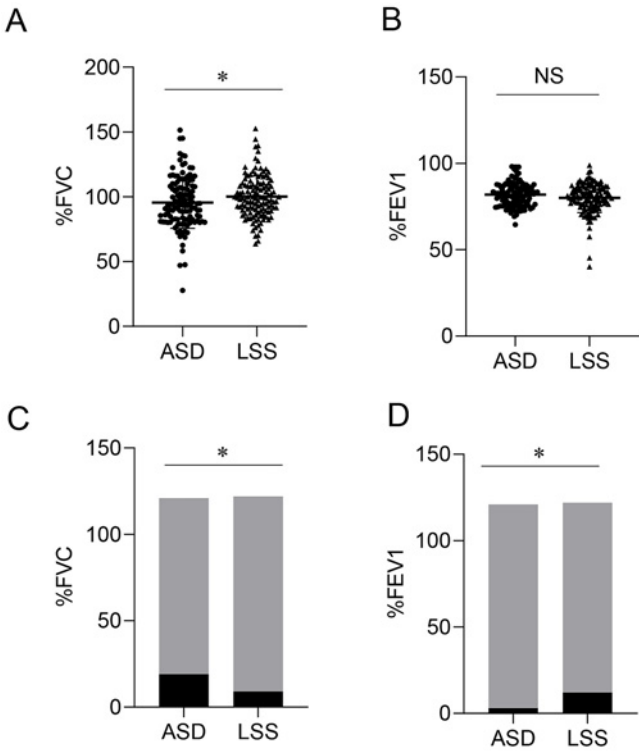

Figure 2. (A) Comparison of %FVC between patients with adult spinal deformity (ASD) and those with lumbar spinal stenosis (LSS) (**P*<0.05; NS, not significant). (B) Comparison of %FEV1 between patients with ASD and those with LSS (**P*<0.05; NS, not significant). (C) Comparison of the frequency of restrictive ventilatory impairment between patients with ASD and those with LSS (**P*<0.05; NS, not significant). (D) Comparison of obstructive ventilatory impairment between patients with ASD and those with LSS (**P*<0.05; NS, not significant).

Statistical analyses

We report means ± standard deviation for continuous variables or number (percentage) for categorical variables. We performed Student's *t* or Fisher's exact test to compare means between the two groups, assuming normal distributions for continuous variables. We illustrated the relationships between TK while the patients were in supine position and preoperative %VC and determined the Pearson correlation coefficients, considering multiple comparisons. We used Prism (version 6.0; GraphPad Software, La Jolla, CA) to calculate summary statistics and perform the *t* tests and R software (version 3.2.3) to calculate ORs and illustrate correlations. Statistical Analysis System software (SAS Institute, Cary, NC) was used to calculate other statistics and *P*-values. A $P < 0.05$ indicates statistical significance.

Results

Patient population

There was no significant difference in age or sex between patients with ASD or LSS (Table 1). Postoperatively, the spinopelvic alignment in patients with ASD improved significantly. The mean preoperative and postoperative alignments are summarized in Table 2. All sagittal spinopelvic parameters were significantly improved postoperatively. The height of patients increased significantly after surgery.

Comparison of respiratory function between patients with ASD and those with LSS

The mean preoperative %FVC value for patients with ASD (95.6% ± 19.8) was significantly less than that for patients with LSS (100% ± 16) (Fig. 2A, B). By contrast, there was no significant difference in mean %FEV1 between the groups. The frequency of restrictive ventilatory impairment was significantly higher in patients with ASD (15.7%) than it was in patients with LSS (7.4%). By contrast, the frequency of obstructive ventilatory impairment in patients with ASD was significantly lower than it was in patients with LSS (Fig. 2C, D). We presumed that the reason for this finding was that indications for surgery for patients with ASD are more strictly selected compared with those for the LSS group in the individual assessment of surgeons because of greater surgical invasion.

Evaluation of TK flexibility in patients with ASD

Fig. 1 shows TK in patients with ASD while they were standing and in prone and supine positions. Mean TK while the patients were in supine position (18.1 ± 11.7°) was significantly lower than it was while they were standing (25.2 ± 17.4°) or in prone position (24 ± 12.8°). This finding indicates that radiographs obtained when the patients are in supine position are valuable for evaluating their TK flexibility.

Comparison of preoperative spinopelvic parameters and TK in supine patients between those with restrictive ventilatory impairment and those without

On the basis of preoperative PFTs, 19 patients with ASD (16%) were classified into a group with restrictive ventila-

Table 3. Comparison of Preoperative Spinopelvic Alignment and TK with the Patient Standing and in Prone or Supine Position between Patients in the Group with Restrictive Ventilatory Impairment and Those in the Group with No Impairment.

	Impairment (N=19)	No Impairment (N=102)	*P*
Standing TK (°)	28.5±18.7	24.5±16.8	NS
Prone TK (°)	29.1±13.6	22.2±11.9	NS
Supine TK (°)	22.8±11.9	16.7±11.4	<0.05*
LL (°)	6.4±19.3	5.4±21.9	NS
PI (°)	52.3±9.5	51.7±11.4	NS
PT (°)	36.1±9.5	37.7±10.9	NS
SS (°)	16.7±10.8	15.0±13.5	NS
PI-LL (°)	45.8±18.4	41.7±22.2	NS
SVA (mm)	144.3±47.6	122.4±72.0	NS
TPA (°)	45.3±11.6	41.2±15.4	NS
GT (°)	55.7±14.0	53.6±19.1	NS

*, statistically significant.

TK, thoracolumbar kyphotic curvature; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; TPA, T1 pelvic angle; GT, global tilt; NS, not significant

tory impairment and 102 were classified into a group without impairment. When the patients were in supine position, TK was significantly larger in the group with impairment (22.8 ± 11.9°) than that in the group without impairment (16.7 ± 11.4°) (Table 3 and Fig. 3A). There was no significant difference in any other parameter between the groups. Additionally, a significant negative correlation was seen between %FVC and TK when the patients were in supine position (Fig. 3B). By contrast, there was a significantly positive correlation between %FVC and change of TK between standing and supine positions (ΔTK).

Pulmonary function following surgery to correct ASD

Preoperatively, mean %FVC was 96% and %FEV1 was 82%; 1 year after surgery, they were 93% and 81%, respectively. One year after surgery, we found no significant improvement in %VC or %FEV1 (Fig. 4).

Discussion

Our present study shows the frequency of restrictive ventilatory impairment was significantly higher in patients with ASD (16%) than it was in those with LSS (7%). Epidemiological studies have found that the prevalence of respiratory dysfunction in the elderly is approximately 10%[16,17]. Together, these findings indicate spinal deformity is a serious risk factor for restrictive ventilatory impairment in the elderly. An association between restrictive thoracic disease such as osteoporosis, spinal hyperkyphosis, or ankylosing spondylitis and increased prevalence of restrictive ventilatory impairment has been recognized[18-24]. However, these previous studies have a number of limitations. First, cohorts were contaminated with cases of persistent AIS. Therefore, here we included only *de novo* cases of degenerative spinal deformity to study separately secondary degenerative scoliosis superimposed on AIS. Second, no control cases were included in the previous studies. Here we included control cases of LSS. Third, the restrictive ventilatory impairment in these patients was considered as reduced spinal mobility but lacked detailed information on global spinal alignment or methods to evaluate spinal mobility. Preoperative evaluation of the flexibility of the curvature of the spine is crucial for selecting an optimal surgical strategy for patients with ASD, and radiographs with the patient in a fulcrum backward-bending position can be used to assess the flexibility of the lumbar spine[4,25]. By contrast, methods to assess the flexibility of the thoracic spine have not yet been established. Here, we showed TK when the patient was in supine position was significantly less than it was when the patient was standing or in prone position. Therefore, we propose that TK when patients are in supine position is valuable for evaluating TK flexibility. A significant correlation was observed between the change of TK between standing and supine positions; TK when the patient was supine was associated with restrictive ventilatory impairment.

The influence of spinal corrective surgery on pulmonary function in patients with ASD is more controversial than it is for patients with AIS. There is a significant decline in pulmonary function 2 years after surgery to correct ASD, but patients with preoperative pulmonary impairment had improved pulmonary function[26]. In the present study, we found no significant improvement of respiratory dysfunction 1 year after surgery. However, %VC improved postoperatively in a few patients who had restrictive ventilatory impairment preoperatively (Fig. 4A).

The present study has some limitations. First, the follow-up period of 1 year might not be long enough to observe improvement of pulmonary functions. Second, height change due to spinal surgery might influence the results of %VC, resulting in an apparent %VC change. Last, the most frequently selected vertebrae for corrective surgery in the present study were the lower thoracic vertebrae (Table 1). Further study is needed to evaluate the effect of spinal corrective surgery for ASD for lung function by studies focusing on cases associated with the upper thoracic spine.

Conclusions

Spinal deformity is a potential risk factor for restrictive ventilatory impairment in the elderly. Radiographs obtained from patients in supine position are valuable for evaluating TK flexibility and show a significant correlation between the TK and restrictive ventilatory impairment.

Conflicts of Interest: The manuscript submitted does not contain information about medical device(s)/drug(s). There were no relevant financial activities outside the submitted work.

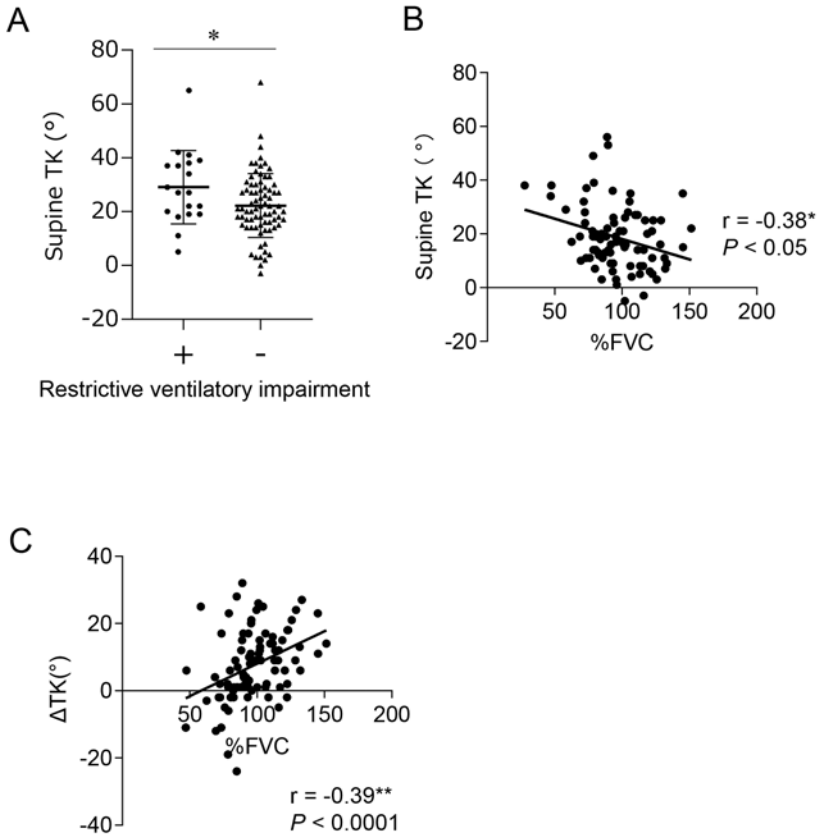

Figure 3. (A) Comparison of TK curves for patients in supine position with restrictive ventilatory impairment and those without impairment (**P*<0.05; NS, not significant). (B) Correlation between TK curves for patients in supine position with ASD and their %FVC. (C) Correlation between the change of TK between standing and supine positions (ΔTK) and their %FVC.

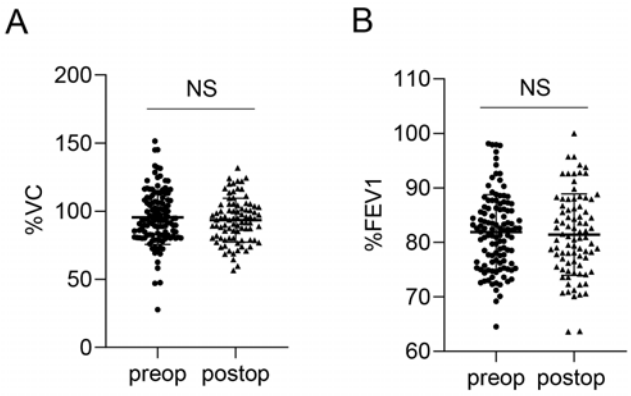

Figure 4. (A) Comparison of preoperative and postoperative %FVC of patients with ASD. (B) Comparison of preoperative and postoperative %FEV1 of patients with ASD.

Ethical Approval: The study was approved by our institutional review board (application No. 1183).

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