OPEN

Is There a Correlation Between Cobb Angle and Pulmonary Function Tests at 2-year Follow-up in Patients With Severe Spinal Deformity Treated by Posterior Vertebral Column Resection?

Zhaoquan Zhang, MD, Zhibo Song, MD, Xiaochen Yang, MD, Tao Li, MD, Ni Bi, MD, and Yingsong Wang, MD

Study design: A retrospective study.

Objective: The aim was to evaluate the relationships of Cobb angle and pulmonary function tests (PFTs) changes in severe spinal deformity and underwent posterior vertebral column resection (PVCR).

Summary of Background Data: No previous study focused on the correlation of deformity correction and PFTs changes in patients with cobb angle > 90 degrees.

Methods: PFTs values [forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and percent-predicted values FVC%, FEV1%] were evaluated preoperative and at 2 years after PVCR. FVC% <80% were defined as restrictive ventilation dysfunction (RVD), the severity of RVD were divided into mild (FEV1% ≥70%), moderate (70% > FEV1% ≥50%) and severe (FEV1% <50%). The relationships among PFTs values improvements and all possible impact factors (mainly correction cobb angle) collected in this study were analyzed. PFTs data were compared among the 3 RVD subgroups (mild vs. moderate vs. severe) and between residual > 30 versus <30 degrees.

Results: A total of 53 cases (28 male/25 female, mean ages 18.9 Y) underwent PVCR in one center from 2004 to 2016 were enrolled cobb angle. When 2 years after PVCR, average PFTs values showed significant improvements. PFTs values changes showed no correlation with correction rate and correction angle. The only significant impact factor in this study for FVC, FVC%, FEV1 improvements was preoperative FVC% and the only impact factor for FEV1% improvement was preoperative FEV1%, the relationships were negative. In accordance with the regression analysis, PFTs values improvements among the 3 RVD subgroups from high to low was severe > moderate > mild. However, patients with residual cobb angle <30 degrees had less PFTs values improvements than patients with residual cobb angle > 30 degrees.

Conclusions: Two years after PVCR, PFTs values were significantly improved. There is no linear correlation between cobb angle change and PFTs values improvements. Lower preoperative FVC% and FEV1% indicate more PFTs values improvements at 2 years post-PVCR.

Level of Evidence: Level III.

Key Words: spinal deformity, pulmonary function, cobb angle, restrictive ventilation dysfunction, pulmonary function tests, posterior vertebral column resection

(*Clin Spine Surg* 2022;35:E483–E489)

Spinal deformity leads to the distortion of thorax with a multifactorial decrease in lung volumes, displaces the intrathoracic organs, impedes on the movement of ribs and affects the mechanics of the respiratory muscles then eventually results in extrinsic restrictive ventilation dysfunction (RVD).[1–3] Patients with much severe thoracic scoliotic/kyphotic curves may suffer from worse RVD, clinically manifested as shallow fast breathing.[3,4] With the aggravation of lung function impairment, some patients will lose the ability to participate in daily life. One of the most important treatment goals of such cases was to improve physical performance and pulmonary function (PF). To cure such cases, surgical treatment may be the best choice.

However, whether the surgical treatment improves the postoperative PF still controversial, even for the adolescent idiopathic scoliosis (AIS) patients who com-

Received for publication September 14, 2021; accepted November 11, 2021.
From the Department of Orthopaedics of Second Affiliated Hospital of Kunming Medical University, Kunming, China.
All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.
This work was supported by National Natural Science Foundation of China.
The authors declare no conflict of interest.
Reprints: Yingsong Wang, MD, Department of Orthopaedics of Second Affiliated Hospital of Kunming Medical University, Kunming 650101, China (e-mail: ynwys@163.com).

monly showed preoperative mild to moderate RVD. The controversy mainly existed in the following aspects, whether different surgical approach had variant effect on the postoperative PF,[5] whether chest wall violation especially thoracoplasty had adverse effect on the postoperative PF[5,6] and whether postoperative thoracic volume changed after correction surgery.[7–10] And those problems were also noticed in patients with severe spinal deformity.[11–14] Different from AIS patients, patients with severe rigid spinal deformity (SRSD) usually had more severe and more complex PF deficits.[3,15–17] The treatment of patients with SRSD is a great challenge, not only because of the severe pulmonary dysfunction and malnutrition may preclude surgery, but also because of the required surgical approach is extremely high technical.

Three-column osteotomy is often needed for the surgical treatment of SRSD patients. Vertebral column resection for deformity correction was first described in 1922 by MacLennan.[18] In 1987, Bradford performed both anterior and posterior vertebral column resection (PVCR) with spinal shortening and posterior instrumentation and fusion with fixed coronal decompensation in 16 patients with fixed multiplanar deformities.[19] Since 2002, vertebral column resection has been made safer and can be performed from a posterior-only approach, thereby obviating the need for a separate anterior procedure.[20]

We have been using PVCR to treat SRSD patients since 2004 and we treated the postoperative PF as one of the important indexes to evaluate the efficacy of PVCR. However, only a few studies reported the postoperative PF of SRSD patients treated by PVCR.[13,14,21] To our acknowledgment, no previous study reported the relationships between the cobb angle change and the postoperative medium-term pulmonary function tests (PFTs) values changes in SRSD patients treated by PVCR. Since there was some research reported that the preoperative PFTs values correlated to the cobb angle in both patients with AIS and severe scoliosis,[3,22,23] we hypothesis there is relation between the cobb angle change and postoperative PFTs values improvements.

We retrospectively analyzed preoperative and 2-year follow-up PFTs data of 53 patients treated by PVCR whose major curves > 90 degrees. The main objective of this study was to evaluate the relationships between correction angle and PFTs values changes in patients with severe rigid spinal deformity treated by PVCR for better understanding of the PF of the such patients and guiding clinical decision making.

MATERIALS AND METHODS

The retrospective analysis enrolled consecutive cases with SRSD who underwent one-stage PVCR reported by Xie et al[24] in 1 single institution from 2004 to 2016 (Fig. 1). Inclusion criteria were (1) Routine radiographs of standing full-length spine and lung function measurements were completed preoperative and at postoperative 2-year follow-up; (2) main curvature > 90 degrees with flexibility <20%. Exclusion criteria were (1) patients with chronic cardiopulmonary diseases; (2) history of chest surgery, spine surgery or smoking; (3) neuromuscular or syndromic scoliosis. Approval was obtained from the institutional review board. All patients provided written informed consent for the operation and the related study.

Data Collection

Demographic data including age, sex, and surgical data including operation duration, blood loss, number of ribs resected, whether thoracoplasty was performed and plural rupture were reviewed in all patients.

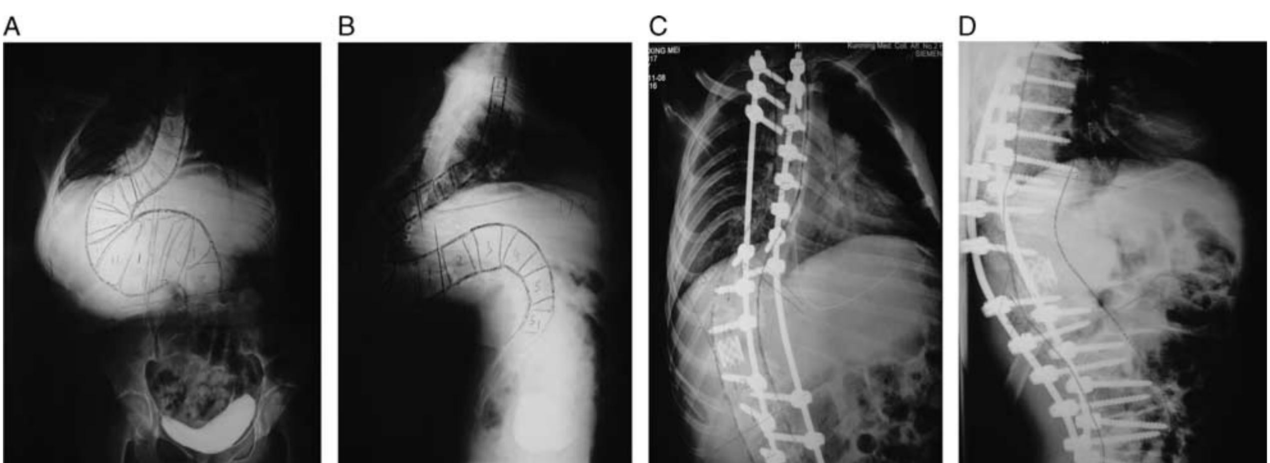

FIGURE 1. A 17 years old female severe rigid spinal deformity patient with preoperative scoliosis of 157 degrees (A) and kyphosis of 178 degrees (B) showed preoperative severe restrictive ventilation dysfunction [forced vital capacity (FVC) = 1.43 L, forced expiratory volume in 1 s (FEV1) = 1.46 L, FVC% = 51%, FEV1% = 46%], and the apex vertebra located at T10 level at both coronal and sagittal plane. At 2-year follow-up after posterior vertebral column resection at T10 level, the scoliosis was corrected to 62 degrees (C), the kyphosis was corrected to 57 degrees (D), and the pulmonary function tests were improved to FVC = 3.55 L, FEV1 = 3.10 L, FVC% = 76.1%, FEV1% = 80.6%.

Radiographical Measurements

Using standing anterior-posterior and lateral full-length spinal radiography images for measurements of coronal and sagittal main curvatures which were extracted as cobb angle before surgery and at postoperative 2-year follow-up, apex location of main curvature were collected, flexibility was obtained from bending images. Two clinicians performed longitudinal traction under radiation protection to obtain radiographs in supine position. Then we used those radiographs to assess the spinal flexibility. Flexibility = (cobb angle in standing position–cobb angle in supine postion)/cobb angle in standing position%. Correction angle = preoperative cobb angle−final follow-up cobb angle, correction rate = correction angle/preoperative cobb angle.

PFTs

Patients underwent PFTs before surgery and at regular 2-year follow-up. Forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1) and percent-predicted values (FVC%, FEV1%) were used. All PFTs used in this study were measured before administration of bronchodilators. Spirometry was repeated 3 times at each evaluation in the same center, the highest value was taken. Arm span was used instead of height to calculate age-based predicted normal values.[14] FVC% <80% were defined as RVD, the severity of RVD were divided into mild (FEV1% ≥ 70%), moderate (70% > FEV1% ≥ 50%), and severe (FEV1% < 50%).[25,26]

Correlation and Subgroup Analysis

Correlation Analysis

Step 1: correlation analysis were performed among PFTs values improvements and all possible impact factors including demographic data, surgical data, radiographic parameters, and preoperative PFTs values. Pearson correlation test were used for continuous numerical variables and spearman correlation test were used for categorical variables. The variables had significant linear relationships with PFTs parameters improvements were filtered out.

Step 2: multiple linear regression analysis (stepwise method) was used for analysis between the variables filtered out in step 1 and PFTs values improvements.

Subgroup Analysis

Paired *t* test was used to analyze repeated measurement data (cobb angle and PFTs parameters of preoperative VS. 2-year follow-up). Analysis of variance was used for PFTs data comparison among the 3 RVD subgroups (mild vs. moderate vs. severe). Nonparametric test was used for PFTs data comparison between residual > 30 degrees versus <30 degrees.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences 22.0 (SPSS). Statistical significance was defined as $P < 0.05$.

RESULTS

PFTs Parameters Showed Improvements at 2 Years Follow-up After PVCR

The basic characteristics of the 53 cases with a mean age of 18.9 (10–43) years old were collected in this study, 52.83% (28/53) patients were male. The main curvature was significantly ($P < 0.05$) corrected from preoperative mean 118.7 degrees (91–175 degrees) to 43.2 degrees (18–78 degrees), the mean correction angle was 75.5 degrees (42–143 degrees), and the correction rate was 63.42% (35.29%–83.53%). The mean flexibility of main curvature was 8.87% (0–20). The mean blood loss was 3549 (1000–12 450) ml and the mean operation duration was 600 (310–900) min. 92.5% (49/53) patients underwent thoracopalsty and 54.7% (29/53) patients experienced plural rupture. The average posterior instrumentation levels were 14.55 (10–17), with the highest upper instrumented vertebra at T1 and the lowest instrumented vertebra at S1. Eighteen patients with > 90 degrees kyphosis, > 90 degrees kyphosis showed no significant correlation to the preoperative PFTs values (Table 1).

Respiratory impairments were restrictive (FVC = 1.59 L, FVC% = 49.25%; FEV_1 = 1.44 L, FEV_1% = 52.51%).

TABLE 1. The Linear Relationship Among PFTs Values Improvements and Impact Factors (r/r_s)

Explanatory Variables	FVC-im	FVC%-im	FEV1-im	FEV1%-im	With > 90 Degrees Kyphosis
Preop-FVC	−0.335*	−0.338*	−0.246	−0.373**	0.150
Preop-FVC%	−0.385**	−0.470**	−0.294*	−0.423**	0.197
Preop-FEV1	−0.285*	−0.281*	−0.215	−0.354**	0.141
Preop-FEV1%	−0.375**	−0.436**	−0.275*	−0.478**	0.142
flexibility	−0.255	−0.266	−0.208	−0.317*	0.050
Blood loss	0.325*	0.194	0.211	0.096	0.173
Correction angle	0.169	0.121	0.235	−0.113	−0.257
Correction rate	−0.01	−0.073	0.041	−0.105	0.005
With > 90 degrees kyphosis	−0.132	−0.213	0.010	−0.003	—

All possible impact factors were analyzed for the correlation with the PFTs values improvements, the factors showed significant relationships with any PFTs values improvements were listed. Correction angle and correction rate are specifically listed, although there is no linear relationship.

Im represents for improvement.

FEV1 indicates forced expiratory volume in 1 second; FVC, forced vital capacity; im, improvement; PFT, pulmonary function test.

*Significantly correlated at the 0.05 level (2-sided).

**Significantly correlated at the 0.01 level (2-sided).

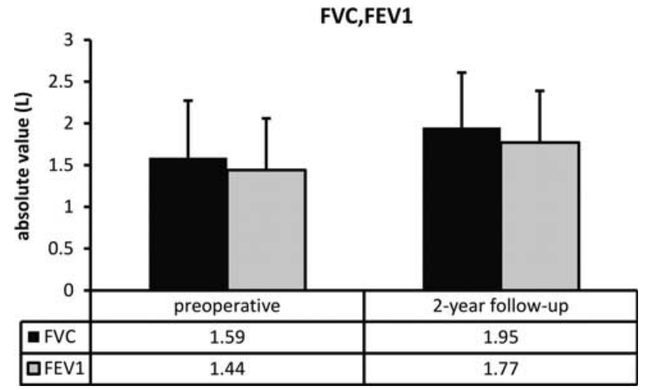

FIGURE 2. Forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1) were significantly improved at 2 years follow-up.

When 2 years after PVCR, PFTs values were significantly ($P<0.05$) improved (Figs. 2, 3). 94.34% of patients showed preoperative RVD (FVC% <80%), among which, the proportion of patients with mild, moderate and severe RVD was 16.98% (9/53), 28.3% (15/53), and 49% (26/53), respectively, patients with FVC % >80% were included in the mild group in this study.

More Preoperative FVC%, FEV1% Reduction, More Postoperative PFTs Values Improvements

We analyzed the linear relationships between PFTs values improvements with all possible impact factors collected in this study, and the factors showed significant relationships with any PFTs values improvements were listed in Table 1. Age, cobb angle, apex location, >90 degrees kyphosis, correction angle, correction rate, operation duration, thoracoplasty, pleural rupture, and number of ribs resected showed no significant linear correlation to the PFTs parameters improvements.

The regression analysis then indicated that the only significant impact factor for FVC, FVC%, FEV1 improvements was preoperative FVC% and the only impact factor for FEV1% improvement was preoperative FEV1% (Table 2).

TABLE 2. Multiple Regression Analysis (Stepwise Method) for Postoperative PFTs Parameters Improvements (n = 53)

PFTs-im	Explanatory Variable	β Coefficient	P*	R^2
FVC-im	Preoperative FVC%	−0.008	0.004*	0.148
FEV1-im	Preoperative FVC%	−0.004	0.033*	0.086
FVC%-im	Preoperative FVC%	−0.269	0.000*	0.221
FEV1%-im	Preoperative FEV1%	−0.410	0.000*	0.229

The regression analysis included all the possible impact factors in Table 1, only the factors included in the regression equation are shown above, and other factors excluded in the establishment of the regression equation were not shown.

FEV1 indicates forced expiratory volume in 1 second; FVC, forced vital capacity; im, improvement PFT, PFT, pulmonary function test.

$*P<0.05$.

The β coefficient for all the PFTs values improvements were minus, this was in accordance with the results of linear relationships analysis. So we concluded the PFTs values improvements were negatively affected by the preoperative FVC% and FEV1%, which means the smaller the preoperative FVC%, FEV1% values were, the more improvements of the postoperative PFTs values were achieved.

PFTs Values Improvements Were Different Among the Mild, Moderate, and Severe RVD Groups

At postoperative 2-year follow-up, FVC, FEV1 values were all significantly ($P<0.05$) increased in all the 3 RVD subgroups and FVC%, FEV1% values were significantly ($P<0.05$) increased in the moderate and severe RVD groups while the FVC% slightly ($P>0.05$) increased and FEV1% slightly ($P>0.05$) decreased in the mild RVD group (Figs. 4, 5).

Even though the order of PFTs values improvements among the 3 subgroups from high to low was severe > moderate > mild (Table 3), the order of PFTs values at 2-year follow-up among the 3 groups from high to low still was mild > moderate > severe just like order of the preoperative PFTs values (Figs. 4, 5). The results also confirmed the results of regression analysis that patients

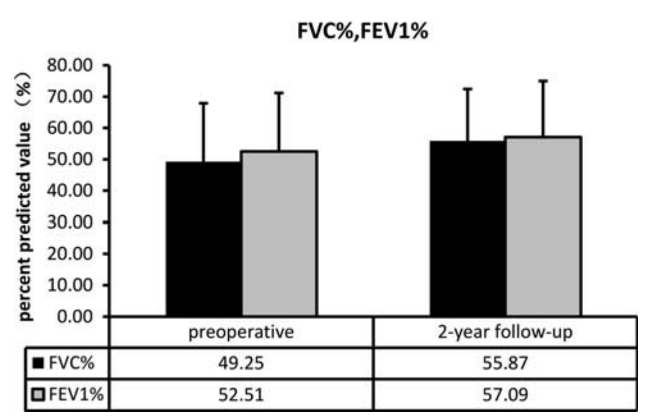

FIGURE 3. Forced vital capacity (FVC)%, forced expiratory volume in 1 second (FEV1%) were significantly improved at 2 years follow-up.

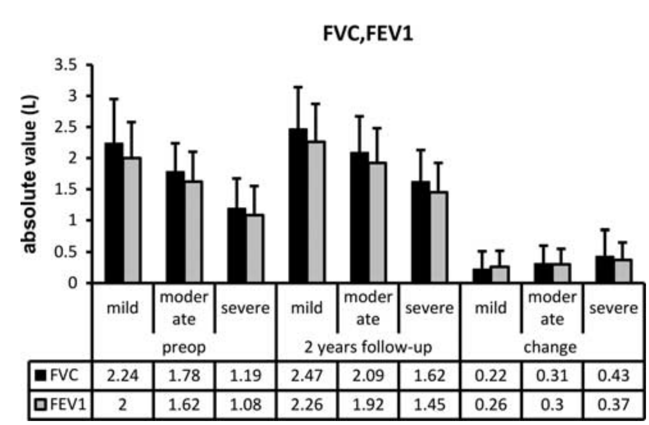

FIGURE 4. Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1) among the 3 restrictive ventilation dysfunction subgroups.

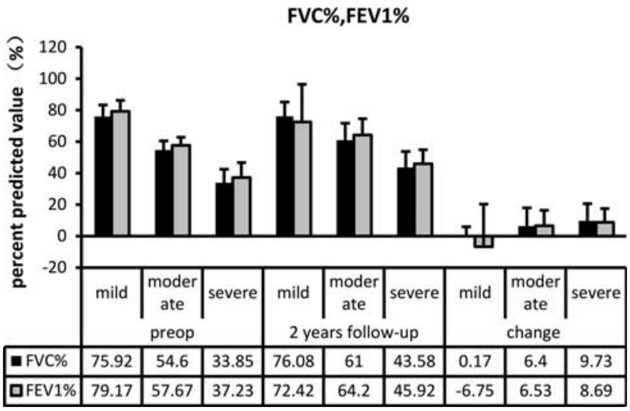

FIGURE 5. Forced vital capacity (FVC)%, forced expiratory volume in 1 second (FEV1%) among the 3 restrictive ventilation dysfunction subgroups.

with more preoperative PFTs reduction commonly showed more PFTs values improvements.

More Correction Angle Did Not Necessarily Show More Benefits for PF

Patients with residual cobb angle <30 degrees had significantly less FVC, FEV1 values improvements and insignificantly less FVC%, FEV1% values improvements than patients with residual cobb angle >30 degrees (Table 4). Combined with the results that correction angle and correction rate do not simply relate to PFTs improvements, we concluded that correction angle was not the more the better for the PF recovery, it should be prudently chosen for the best results.

Complications

Pulmonary complications occurred in 5 (9.3%) patients. Three with postop lungs infection, 1 with respiratory failure, 1 with pulmonary embolism, no body died. Three happened in preoperative severe RVD group, each group of mild and moderate RVD had 1 patient with lungs infection. All patients with complications were recovered at 2-year follow-up. Five patients were all underwent thoracoplasty, among which 4 patients endured plural rupture. We concluded patients with preoperative severe RVD and underwent chest wall violation were most likely to suffer from postop pulmonary complications.

Nonpulmonary complications were observed in 6 (11.3%) patients, including implant failure in 2 patients, superficial wound infection in 3 patients and lower limb numbness in 1 patients, no permanent neurological deficit was observed.

TABLE 3. PFTs Parameters Improvements Among the Subgroups According to Preoperative RVD Grade

PFTs-im	Mild RVD (n = 12)	Moderate RVD (n = 15)	Severe RVD (n = 26)
FVC-im	0.22	0.31	0.43
FEV1-im	0.26	0.3	0.37
FVC%-im	0.17	6.4	9.73*
FEV1%-im	−6.75	6.53	8.69*

*$P<0.0167$ (Bonferroni method adjusted) when compared with mild group and △ indicates $P<0.0167$ (Bonferroni method adjusted) when compared with moderate group, and im represents for improvement.

FEV1 indicates forced expiratory volume in 1 second; FVC, forced vital capacity; im, improvement;, PFT, pulmonary function test; RVD, restrictive ventilation dysfunction.

TABLE 4. PFTs Improvements Between Patients With Residual Cobb Angle <30 Degrees and >30 Degrees

PFTs-im	<30 Degrees (n = 9)	>30 Degrees (n = 44)	*P*
FVC-im	0.13	0.39	**0.014**
FEV1-im	0.14	0.37	**0.007**
FVC%-im	2.11	7.55	0.111
FEV1%-im	2.33	5.05	0.176

Bold values indicates statistical significance ($P<0.05$).

FEV1 indicates forced expiratory volume in 1 second; FVC, forced vital capacity; im, improvement; PFT, pulmonary function test.

DISCUSSION

PVCR was highly recognized as the most powerful surgical method to treat SRSD patients (main curvature >90 degrees and flexibility <20%[27]). We conducted this study mainly to explore the relationship between the relationship between PFTs values improvements and correction angle. We found the PVCR commonly improved the PFTs values at 2 years follow-up in patients with severe spinal deformity, and the PFTs values improvements related to the severity of preoperative RVD. However, the PFTs values improvements showed no simple linear relationship with deformity correction. And additional >90 degrees kyphosis showed no linear relationship with preoperative PFTs values and PFTs values improvements.

Spinal Deformity and Lung Function

Normal thorax depends on 2 characteristics: a large and stable volume and the ability to change volume with respiratory movement. Spinal deformity causes thorax distortion. Thorax distortion is a complex 3-dimensional deformity includes the spine, the ribs, and the sternum, which leads to the restriction of the convex hemithorax volume and restriction of the motion of the involved ribs.[28,29] Then both primary respiration through lung expansion activated by the diaphragm and secondary breathing through upward excursion of the ribs enabled by the secondary muscles of respiration were all influenced.[28] So patients with spinal deformity commonly presented with extrinsic RVD with decreased total lung capacity.[1,2,14]

Forced vital capacity (FVC) provides a proper assessment of pulmonary volume, and forced expiratory volume (FEV1) in 1 second provides a proper assessment of pulmonary expiratory flow. Percent-predicted values (FVC%/ FEV1%) were generated to normalize for age, sex, weight, and height, in order to compensate for changes in PF that occur with growth during the adolescent period. FVC, FEV1 absolute and percent-predicted values were proportionally decreased with total lung capacity, provided a simple but adequate assessment of RVD in patients with spinal deformity.[9,28,30] In this study, 94.34% patients showed preoperative RVD and the proportion of moderate, severe RVD were 28.30%, 49.06% respectively, indicated SRSD patients usually had more severe RVD.[4]

The Effect of PVCR on the PF Recovery

Spinal deformity is commonly the initial factors of lung function impairment in such patients, so deformity correction is crucial for the improvement of lung function. In this study, the PFTs values of the 53 patients showed significant improvement at 2 years after PVCR. Before this study, only a few literatures reported the improvement of lung function after PVCR. Fujii et al[13] reported the PF of one patient with 91 degrees scoliosis improved after PVCR. Except our previous reports, the only case series were reported by Bumpass et al.[14] They reported improvements in lung function when patients below 18 years of age, but adults even experienced a slight decline in PFTs values.[14] Our average correction angle was 75.3 degrees, while the cases in the study of Bumpass and colleagues only got correction angle <50 degrees, the difference in correction angle may be responsible for the PFTs difference in our reported results.

PFTs Values Change Showed no Simple Linear Relationship With Correction Angle

However, our results showed there were not simple linear relationships between PFTs values changes and correction angle. Our results consent to the study of Ling et al,[31] their study proved the lung ventilation and perfusion function deviation did not correlated with cobb angle, but the ventilation function strongly correlated to the perfusion function ($r = 0.753$) in patients with severe and rigid scoliosis. As a multifactorial procure, the relationship between cobb angle and PFTs values may be covered up by other factors, such as apex location, lungs' blood perfusion and flexibility,[13,22,23,32] especially in patients with SRSD who experienced more complicated pulmonary deficits.[13,31] So we believe that cobb angle, as a 2-dimensional parameter which was used for the evaluation of the severity of spinal deformity, had limited values for the prediction of PF prognosis. The study by Newton et al[33] showed the relationships between preoperative PF deficits and cobb angle in patients with AIS may also prove our results. This may help to explain why simple linear relationship between PFTs values change and correction angle cannot be established, so as the relationship between additional >90 degrees kyphosis and PFTs values improvements. Similarly, a current report showed kyphosis restoration did not directly improve the PF.[8]

The Severity of Preoperative RVD May be a Predicator for the Postoperative PF Prognosis

Byun et al[34] studied the PF of 35 AIS patients with main thoracic curve underwent posterior spinal fusion and reported that patients with severe preoperative respiratory impairment showed greater PF improvement after surgery than patients with nonsevere respiratory impairment when follow-up duration >10 years. Consent to the study of Byun and colleagues, our results ascertained patents with varying degrees of preoperative RVD had different prognosis of lung function, patients with more severe preoperative RVD showed more PFTs values improvements.

In this study, patients with preoperative severe RVD had greatest PFTs values improvements, even so, the lung function of such cases at 2-year post-PVCR was still the worst. So even though we are optimistic about the continuous lung function improvement with the increase of follow-up time especially for patients who have the greatest potential for lung and thoracic cage growth after spinal deformity correction[14] based on the long-term follow-up results of AIS patients,[5,34] we still have to be more cautious about the possible adverse effect on the postoperative PF deriving from the anterior approach[5,20] and so was the thoracoplasty.[12] Conversely, the lung function of patients with preoperative mild RVD was still at a high-level despite a certain degree of decrease after PVCR. So we suggest early intervention when lung function was less impaired may have a better prognosis.

Residual Cobb Angle and the PFTs Values Improvements

Too much deformity correction may be not necessary for the postoperative PF improvements, proper deformity correction strategy should be prudently chosen.[35] Our subgroup analysis showed that patients with residual cobb angle >30 degrees had greater PFTs values improvements than patients with residual cobb angle <30 degrees, indicated too much correction angle may to some extent reverse the benefits of deformity correction on PF. Despite the PF recovery, too much deformity correction may have adverse effect on the blood flow of spinal cord then cause a secondary spinal cord injury during the surgery.[36] So even though PVCR could achieve high correction rate, too much correction was not always necessary. But we need to stress here that because of the small sample size, we did not make the residual cobb angle of 30 degrees as the discriminator, we just speculated that too much correction angle may not be the best choice.[35]

This study had few limitations. The selection bias may affect the results among the subgroups because of the small sample size. Because of the lack of CT data in some cases included in this study, important imaging parameters such as rotation degree of apex vertebra and thoracic volume were not included in this study. Future studies should expand the sample size, include more complete imaging parameters and increase the duration of follow-up.

CONCLUSIONS

The relationships between PFTs parameters and correction angle in patients with severe rigid spinal deformity are complicated and nonlinear. Our results and analysis also provided some new valuable references for decision making of spine surgeons. We found that for patients with preoperative moderate to severe RVD, the

PF should be a main concern in the decision making, but for patients with preoperative mild RVD, the PF could be less concerned. Too much correction is not always necessary for PF recovery.

ACKNOWLEDGMENTS

The author wish to acknowledge the Jingming Xie, MD; Zhi Zhao, MD for their assistance in the statistical analysis and critical revision of the manuscript for important intellectual content of this study.

REFERENCES

1. Tsiligiannis T, Grivas T. Pulmonary function in children with idiopathic scoliosis. *Scoliosis*. 2012;7:7.
2. Yaszay B, Bastrom TP, Bartley CE, et al. The effects of the three-dimensional deformity of adolescent idiopathic scoliosis on pulmonary function. *Eur Spine J*. 2017;26:1658–1664.
3. Lao L, Weng X, Qiu G, et al. The role of preoperative pulmonary function tests in the surgical treatment of extremely severe scoliosis. *J Orthop Surg*. 2013;8:32.
4. Zhang BB, Zhang T, Tao HR, et al. Neurological complications of thoracic posterior vertebral column resection for severe congenital spinal deformities. *Eur Spine J*. 2017;26:1871–1877.
5. Gitelman Y, Lenke LG, Bridwell KH, et al. Pulmonary function in adolescent idiopathic scoliosis relative to the surgical procedure: a 10-year follow-up analysis. *Spine*. 2011;36:1665–1672.
6. Lee ACH, Feger MA, Singla A, et al. Effect of surgical approach on pulmonary function in adolescent idiopathic scoliosis patients: a systemic review and meta-analysis. *Spine*. 2016;41:E1343–E55.
7. Sarwahi V, Sugarman EP, Wollowick AL, et al. Scoliosis surgery in patients with adolescent idiopathic scoliosis does not alter lung volume: a 3-dimensional computed tomography-based study. *Spine*. 2014;39:E399–E405.
8. Buckland AJ, Woo D, Vasquez-Montes D, et al. The relationship between 3-dimensional spinal alignment, thoracic volume, and pulmonary function in surgical correction of adolescent idiopathic scoliosis: a 5-year follow-up study. *Spine*. 2020;45:983–992.
9. Ledonio CG, Rosenstein BE, Johnston CE, et al. Pulmonary function tests correlated with thoracic volumes in adolescent idiopathic scoliosis. *J Orthop Res*. 2017;35:175–182.
10. Wozniczka JK, Ledonio CGT, Polly DW Jr, et al. Adolescent idiopathic scoliosis thoracic volume modeling: the effect of surgical correction. *J Pediatr Orthop*. 2017;37:e512–e518.
11. Sucato DJ, Erken YH, Davis S, et al. Prone thoracoscopic release does not adversely affect pulmonary function when added to a posterior spinal fusion for severe spine deformity. *Spine*. 2009;34:771–778.
12. Koller H, Schulte TL, Bullmann V, et al. The influence of isolated thoracoplasty on the evolution of pulmonary function after treatment of severe thoracic scoliosis. *Eur Spine J*. 2017;26:1765–1774.
13. Fujii T, Watanabe K, Toyama Y, et al. Pulmonary function recovery demonstrated by ventilation-perfusion scan after posterior vertebral column resection for severe adolescent idiopathic scoliosis: a case report. *Spine*. 2014;39:E1190–E1194.
14. Bumpass DB, Lenke LG, Bridwell KH, et al. Pulmonary function improvement after vertebral column resection for severe spinal deformity. *Spine*. 2014;39:587–595.
15. Wang H, Zheng Z, Liu H, et al. Radiological factors influencing pulmonary function test in severe spinal deformity. *Zhonghua Yi Xue Za Zhi*. 2015;95:3012–3016.
16. Sucato DJ. Management of severe spinal deformity: scoliosis and kyphosis. *Spine*. 2010;35:2186–2192.
17. Chen J, Sui WY, Yang JF, et al. The radiographic, pulmonary, and clinical outcomes of patients with severe rigid spinal deformities treated via halo-pelvic traction. *BMC Musculoskelet Disord*. 2021;22:106.
18. MacLennan A. Scoliosis. *Br Med J*. 1922;2:864–866.
19. Bradford DS. Vertebral column resection. *Orthop Trans*. 1987;11: 502.
20. Suk S-I, Kim J-H, Kim W-J, et al. Posterior vertebral column resection for severe spinal deformities. *Spine*. 2002;27:2374–2382.
21. Xie J-M, Bi N, Wang Y-S, et al. The effect of PVCR on pulmonary function improvement in severe rigid spinal deformity patients with respiratory dysfunction. *Spine J*. 2012;12(suppl 9):S40–S40.
22. Wang Y, Yang F, Wang D, et al. Correlation analysis between the pulmonary function test and the radiological parameters of the main right thoracic curve in adolescent idiopathic scoliosis. *J Orthop Surg Res*. 2019;14:443.
23. Johari J, Sharifudin MA, Ab Rahman A, et al. Relationship between pulmonary function and degree of spinal deformity, location of apical vertebrae and age among adolescent idiopathic scoliosis patients. *Singapore Med J*. 2016;57:33–38.
24. Xie J-M, Wang Y-S, Zhao Z, et al. Posterior vertebral column resection for correction of rigid spinal deformity curves more than 100 degrees. *J Neurosurg Spine*. 2012;17:540–551.
25. Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *Eur Respir J*. 2005;26:948–968.
26. Jr A, Bleecker ER, Epler GR. Evaluation of impairment/disability secondary to respiratory disorders. *Am Rev Respir Dis*. 1986;133: 1205–1209.
27. Xie JM, Chen ZQ, Shen JX, et al. Expert consensus for PVCR in severe, rigid and angular spinal deformity treatment: The Kunming consensus. *J Orthop Surg*. 2017;25:2309499017713939.
28. Campbell RM Jr, Smith M, Mayes TC, et al. The characteristics of thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis. *J Bone Joint Surg Am*. 2003;85:399–408.
29. Redding G, Song K, Inscore S, et al. Lung function asymmetry in children with congenital and infantile scoliosis. *Spine J*. 2008;8: 639–644.
30. Lee P-C, Ledonio C, Larson AN, et al. Thoracic volumes correlated with pulmonary function tests in adult scoliosis patients following different treatments in adolescence. *J Med Device*. 2018:13.
31. Ling XT, Guo L, Li YH, et al. Ventilation/perfusion SPECT/CT in patients with severe and rigid scoliosis: an evaluation by relationship to spinal deformity and lung function. *Clin Neurol Neurosurg*. 2019;176:97–102.
32. Ohashi M, Watanabe K, Hirano T, et al. Flexibility of the thoracic curve and three-dimensional thoracic kyphosis can predict pulmonary function in nonoperatively treated adult patients with adolescent idiopathic scoliosis. *J Orthop Sci*. 2020;25:551–556.
33. Newton PO, Faro FD, Gollogly S, et al. Results of preoperative pulmonary function testing of adolescents with idiopathic scoliosis. A study of six hundred and thirty-one patients. *J Bone Joint Surg Am*. 2005;87:1937–1946.
34. Byun YM, Iida T, Yamada K, et al. Long-term pulmonary function after posterior spinal fusion in main thoracic adolescent idiopathic scoliosis. *PLoS One*. 2020;15:e0235123.
35. Winter RB, Lonstein JE, Denis F. how much correction is enough? *Spine*. 2007;32:2641–2643.
36. Li T, Zhao Z, Wang YS, et al. A preliminary study of spinal cord blood flow during PVCR with spinal column shortening: a prospective clinic study in severe rigid scoliokyphosis patients. *Medicine*. 2020;99: e21579.

