

Pulmonary Function After Thoracoplasty in the Surgical Treatment of Adolescent Idiopathic Scoliosis

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Study Design: Retrospective case series review.

Objective: To compare two similar groups of adolescents surgically treated for their spinal deformity either by posterior segmental fusion alone (PSF) or by posterior spinal fusion and thoracoplasty (PSF + T); attention was focused on the long-term effects of thoracoplasty on pulmonary function in the surgical treatment of adolescent idiopathic scoliosis.

Summary of Background Data: Posterior spinal arthrodesis with thoracoplasty and an open anterior approach, with respect to a posterior only fusion have been found to have a deleterious effect on pulmonary function for as long as five years postoperatively after surgical treatment of adolescent idiopathic scoliosis.

Methods: A group of 40 consecutive adolescent patients, surgically treated between 1998 and 2001 by posterior spinal fusion and thoracoplasty, was compared with a similar cohort of 40 adolescents treated in the same period by posterior segmental fusion alone. Pedicle screw instrumentation alone and a minimum five-year follow-up were requested as inclusion criteria. Both a radiographic analysis and a chart review was performed, evaluating the pulmonary function tests (PFTs), the SRS-30 score questionnaire and the Lenke classification system. A radiographic Rib Hump (RH) assessment was also performed.

Results: The entire series was reviewed at an average clinical follow-up of 8.3 years. There were no statistically significant differences between the two groups in terms of gender, age (PSF + T: 16.3y vs. PSF: 15.2y), Lenke curve type classification and preoperative Cobb's main thoracic (MT) curve magnitude (PSF + T: 66° vs. PSF: 63°), whereas both final MT percent correction (PSF + T: 53.03% vs. PSF: 51.35%; $P < 0.03$), RH absolute correction (PSF + T: -2.1 cm vs. PSF: -1.05;

$P < 0.01$) and RH overall percent correction (PSF + T: 55.4% vs. PSF: 35.4%; $P < 0.0001$) were greater in the thoracoplasty group. No statistical differences were observed between the two groups in PFTs both pre-operatively and at last follow-up. Nevertheless, comparing preoperative to final PFT'S within each group, only in the PSF group both forced vital capacity and forced expiratory volume in one second showed a statistically significant improvement at final evaluation. At last follow-up visit, the SRS-30 scores did not show any statistical difference between the two groups (total score PSF + T: 4.1 vs. PSF: 4.3).

Conclusions: Our findings suggest that thoracoplasty did not adversely affect long-term PFTs in AIS patients treated by posterior spinal fusion alone using pedicle screws instrumentation, as already highlighted by previous reports. A trend towards better coronal plane correction and rib hump improvement was seen, although not clearly reported in a self-assessment disease-specific questionnaire.

Key Words: adolescent idiopathic scoliosis, posterior instrumented fusion, thoracoplasty, pedicle screw instrumentation, pulmonary function

(*J Spinal Disord Tech* 2010;23:e63–e69)

The primary goal of the surgical treatment in adolescent idiopathic scoliosis (AIS) is to prevent further curve progression by obtaining solid arthrodesis and long-term balance of the spine in both sagittal and coronal planes, as well as to preserve the maximum number of motion segments. Several additional factors, e.g., safety, cost and morbidity, are important in the surgical decision-making. In recent years, with the advent of modern third-generation segmental posterior instrumentation, notably pedicle screw-only constructs, a significant deformity correction is also desired by both physicians and patients, whereas preservation or enhancement of pulmonary function is a strong consideration for thoracic curves.¹⁻⁵

The rib hump prominence associated with thoracic scoliosis is often a major cosmetic concern both for patients and their families. Since body contour and, in general, patient's back shape have been found to be important factors related to self-esteem, thoracoplasty by

Received for publication April 29, 2009; accepted November 23, 2009.
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means of multiple rib resections has been traditionally used to treat rib cage deformity in thoracic idiopathic scoliosis.^{6–12}

The association between spinal deformity and pulmonary impairment has been widely reported,^{11–18} with more severe curves (>100 degrees) considered to be responsible for a significant decrease in clinical pulmonary function. A recent multicenter study on 631 AIS patients has described moderate or severe pulmonary impairment in association with thoracic curves of <50 degrees, thus showing that some patients with AIS may have clinically relevant pulmonary impairment that is out of proportion to the corresponding severity of the spinal deformity.¹⁹

When compared to posterior-only fusion, posterior spinal arthrodesis with thoracoplasty and open anterior approach have been found to have a deleterious effect on pulmonary function during up to five years after the index procedure, and chest cage preservation has been recommended to maximize both absolute and percent-predicted pulmonary function values after surgical treatment of adolescent idiopathic scoliosis.²⁰ More recently, both the anterior open approach and thoracoplasty have been regarded as the only two variables to be related to a clinically significant reduction in the predicted 2-year pulmonary function of surgically-treated AIS patients. The magnitude of the effects of both these variables, however, has been found to be modest.²¹

With the advent of the latest generation of spinal deformity instrumentation, notably with the widespread use of thoracic pedicle screws, a true three-dimensional correction of the scoliotic deformity can be obtained,^{4–6} thus obviating the need for thoracoplasty, according to some authors, and eliminating its presumably negative effects on pulmonary function.^{9,10,12}

The aim of the present study was to compare two similar groups of adolescents, surgically treated for AIS using pedicle screws, either by posterior-only segmental fusion (PSF) or by posterior spinal fusion and thoracoplasty (PSF+T), focusing on the long-term effects of thoracoplasty on pulmonary function.

MATERIALS AND METHODS

A consecutive cohort of 40 patients with main thoracic AIS curves (Lenke type 1, 2, 3 and 4), surgically treated between 1998 and 2001 in a single Institution by PSF+T, was compared with a similar group of 40 adolescents treated in the same period by PSF alone. All patients were operated on using pedicle screw only instrumentation. In-patient and out-patient charts were used for collection of demographic data and annotation of any medical and surgical-related complications, including revision surgeries. The Lenke surgical classification of AIS²² was used to describe curve patterns. Standing posteroanterior and lateral long cassette (90 × 30 cm) radiographs were performed preoperatively, postoperatively and at last follow-up, and included Cobb measurements²³ of the major thoracic (MT) curve and thoracic kyphosis (T5–T12). A radiographic Rib Hump

(RH) assessment (Fig. 1), as proposed by Potter et al²⁴, was also performed. At the final visit, the SRS-30 questionnaire was administered and Pulmonary Function Test (PFT) were made. Standard protocol required Plethysmography and Spirometry testing to measure forced vital capacity (FVC), and forced expiratory volume (FEV1) in 1 second as these parameters provide a proper assessment of pulmonary volume and flow. The tests were performed with the patient in the sitting position, whereas the evaluation test was always repeated 3 times, with best effort been selected. The results of the pulmonary function test are expressed as absolute values and percent-predicted values, with the last been generated to normalize for age, gender, weight, and height, in order to compensate for changes in pulmonary function that occur with growth during the adolescent period.



FIGURE 1. Picture showing the measurement technique to assess Rib Hump (RH) deformity. The RH is the linear distance between the left and right posterior rib prominences at the apex of the rib deformity on lateral radiograph.²⁴

TABLE 1. Preoperative Evaluation of Demographic Data, Lenke’s Classification, and Radiographic Measurements of the Entire Series, Expressed as Means (Standard Deviation)

	PSF + T Group	PSF Group	P
Gender (M/F)	6M/34F	5M/35F	n.s
Age (years)	16.3 (2)	15.2 (1.9)	n.s
Lenke’s distribution	25 “1”/10 “2”/5 “3”	29 “1”/8 “2”/3 “3”	n.s
Preoperative main thoracic Cobb	66 (14)	63 (13)	n.s
Preoperative kyphosis (T5-T12)	35.32 (10.1)	35.22 (12.5)	n.s
Preoperative Rib hump (cm)	3.79 (0.44)	2.96 (0.63)	n.s

A minimum five-year follow-up was requested for inclusion in the study. During the period considered for the current investigation, the same surgical team (three surgeons) carried out all surgeries: indication for thoracoplasty was either a clinically relevant rib hump (manual scoliometer measurement >15 degrees), or a specific concern for such deformity expressed by the patient or their family.

Statistical analysis was performed using the *t*-test (paired and unpaired), the Wilcoxon test for non-parametric paired analysis and the Mann-Whitney test for non-parametric unpaired analysis. Results are expressed as mean (standard deviation), with *P* value equal to < 0.05 considered to be statistically significant.

RESULTS

The entire series of 80 patients was reviewed at an average clinical follow-up of 8.3 (1.6) years. There were no statistically significant differences between the two groups in terms of gender, age (PSF + T: 16.3 y vs. PSF: 15.2y), Lenke classification distribution and Cobb’s preoperative main thoracic (MT) curve magnitude (PSF + T: 66 degrees vs. PSF: 63 degrees), whereas both final MT percent correction (PSF + T: 53.03% vs. PSF: 51.35%; *P* < 0.03), RH absolute correction (PSF + T: -2.1 cm vs. PSF: -1.5; *P* < 0.01) and RH overall percent correction (PSF + T: 55.4% vs. PSF: 35.4%; *P* < 0.0001) were greater in the thoracoplasty group (Tables 1, 2) (Figs. 2, 3). No statistically significant differences were seen between the two groups in terms of sagittal contour, the thoracic kyphosis (T5-T12) angles

being similar for the two groups before surgery (PSF + T: 35.32 degrees vs. PSF: 35.22 degrees), in the immediate postoperative period (26 degrees vs. 29.3 degrees) and at last follow-up (28.4 degrees vs. 32.4 degrees).

With regards to PFTs, we found no statistically significant differences between the two groups in the preoperative evaluation, in terms of both absolute values of forced vital capacity (PSF + T: 2.87 L vs. PSF: 2.83 L; n.s) and forced expiratory volume in one second (PSF + T: 2.39 L vs. PSF: 2.41 L; n.s), and also percent predicted values of forced vital capacity (PSF + T: 85% vs. PSF: 84%; n.s) and forced expiratory volume in one second (PSF + T: 82% vs. PSF: 80%; n.s). The same trend of similar results between the two groups was also observed in the last follow-up evaluation, where both forced vital capacity and forced expiratory volume in one second, expressed either as absolute values or percent-predicted, resulted similar. Nevertheless, comparing preoperative to final values within each group, only in the PSF group both forced vital capacity and forced expiratory volume in one second showed a statistically significant improvement at final evaluation (Tables 3, 4).

Preoperative and postoperative SRS scores could not be compared since most of the patients in both groups had undergone surgery before an Italian version of the SRS-30 questionnaire was available. At last follow-up, no significant differences were found in terms of SRS-30 scores (questionnaire available in 72 out of 80 patients) between the two groups. In particular, both self-image, mental health, and overall satisfaction domains, but also SRS total score were found to be similar between the two groups, with mean scores shown in Table 2. This

TABLE 2. Follow-up Evaluation of Radiographic Measurements of the Entire Series, Expressed as Means (Standard Deviation) and SRS-30 Questionnaire

	PSF + T Group	PSF Group	P
Follow-up main thoracic Cobb	31 (11.2)	35 (13)	n.s
Percent overall main thoracic Cobb correction	53.03 (12.6)	51.35 (12.8)	0.03
Follow-up kyphosis (T5-T12)	28.4 (9.8)	32.4 (10.6)	n.s
Postoperative Rib hump (cm)	1.69 (0.77)	1.91 (0.4)	n.s
Overall Rib hump correction (cm)	-2.1 (0.9)	-1.05 (1.1)	< 0.01
Percent overall Rib hump correction	55.4 (10.4)	35.4 (8.8)	< 0.0001
SRS pain	4.16 (0.65)	4.23 (0.54)	n.s
SRS self-image	3.84 (0.53)	3.46 (0.71)	n.s
SRS function	3.54 (0.71)	3.25 (0.36)	n.s
SRS mental health	4.02 (0.35)	3.63 (0.46)	n.s
SRS satisfaction	4.3 (0.75)	4.5 (0.29)	n.s
SRS total score	4.1 (0.25)	4.3 (0.30)	n.s

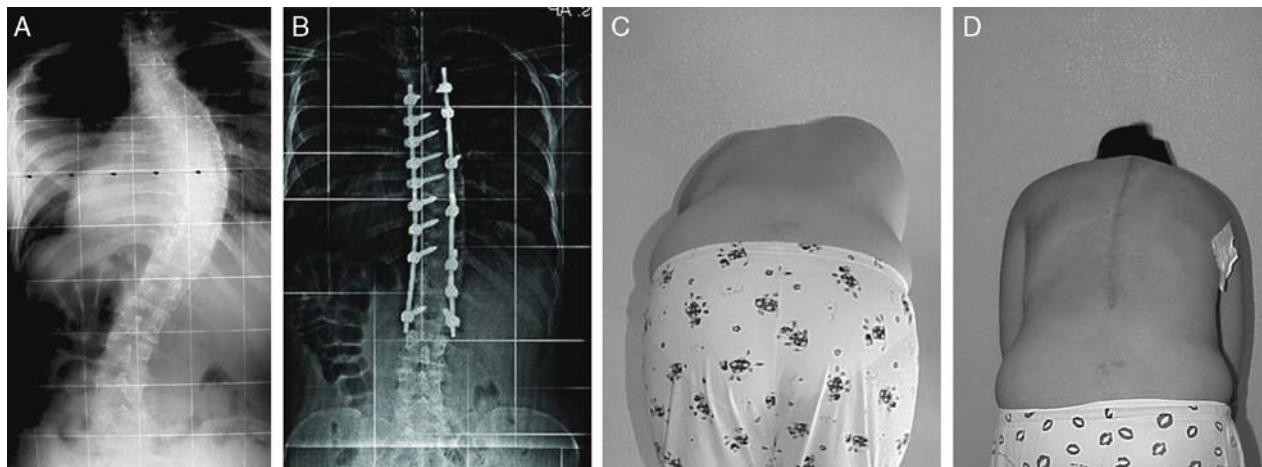


FIGURE 2. A 14 years old female with a Lenke 2AN curve, operated on by means of a T4-L1 pedicle screws posterior spinal fusion plus thoracoplasty (T6-T9). Clinical and radiographic results at 5.5 years from the index procedure.

probably came from similar global coronal and sagittal balance, which patients could easily recognize.

No fatal complications or neurological injuries, either acute or delayed deep wound infections, were observed for the present case series. In the PSF + T group, 3 surgery-related complications (2 proximal convex screw disengagements, 1 lateral malpositioning on concavity apex) in 3 patients (7.5%) led to 2 revision surgeries in 2 cases (in the immediate postoperative and at 3.2 years from the index procedure), whereas postoperative thoracoplasty-related pulmonary complications were encountered in 10 patients (moderate pleural effusion in 7, pneumonia secondary to moderate atelectasis in 2, pneumothorax in 1) and required chest tube placement in 3 cases: all of them healed uneventfully with no adverse effect on final results. In the PSF group, a revision surgery with complete instrumentation removal was performed in a 19-year-old female patient, 4 years after the index procedure, due to persistent late operative site pain;

intraoperative cultures were negative. Three postoperative complications were seen in this latter group (an acute cholecystitis, a superior mesenteric artery syndrome, a moderate pneumonia): they did not require any invasive procedure and healed uneventfully by conservative treatment.

DISCUSSION

Pulmonary function impairment associated with spinal deformity has been widely investigated in the literature: moderate or severe restrictive pulmonary disease has been reported in association with thoracic scoliotic curves even <50 degrees, showing a clinically relevant pulmonary impairment that is out of proportion with the severity of the spinal deformity.¹⁹ Recently, Newton et al²¹ have emphasized the concept that both the severity of the pulmonary function impairment associated with the spinal deformity and the effects of surgery are important factors

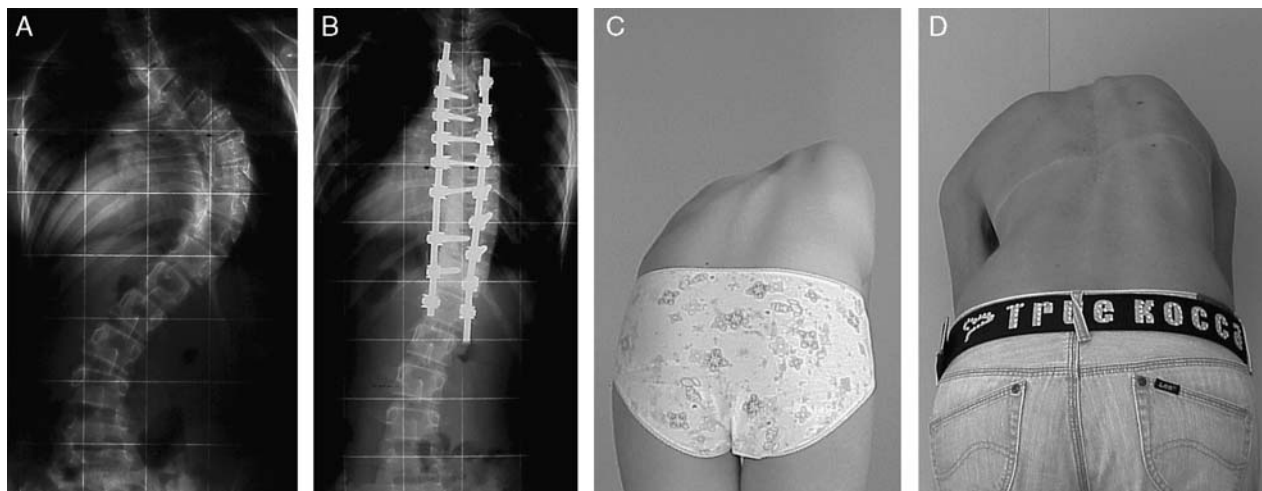


FIGURE 3. A 12.5 years old female with a Lenke 2AN curve, operated on by means of a T4-L1 pedicle screws posterior spinal fusion without thoracoplasty. Clinical and radiographic results at 6 years from the index procedure.

TABLE 3. Preoperative and Follow-up Evaluation of Pulmonary Function Test in Thoracoplasty Group, Expressed as Absolute Values and Percent Predicted (%)

	Preoperative	Follow-up	P
FVC (L)/FVC %	2.87 (0.75)/85% (15)	3.1 (0.60)/83% (14)	n.s.
FEV1 (L)/FEV1%	2.39 (0.48)/82% (12)	2.60 (0.36)/80% (11.5)	n.s.

FVC indicates forced vital capacity; FEV-1, forced expiratory volume in one second.

affecting the long-term pulmonary status of patients with scoliosis. The authors of the aforementioned paper have adopted the American Thoracic Society guidelines, which categorize severity of pulmonary impairment in 15% intervals²⁵ and, consequently, they used this threshold as minimal clinically significant difference on PFTs at a minimum 2-year follow-up. In a cohort of 254 surgically treated and prospectively studied AIS patients, both the anterior open approach and thoracoplasty were the only variables found to be related to a clinically significant reduction in the predicted 2-year pulmonary function. However, the magnitude of the effects of both variables was seen to be modest.

In the literature, the effects of thoracoplasty on long term PFTs remain controversial, with a reported initial post-operative decline followed either by a return to normal values or a decline observed at a minimum follow-up of 2 years.^{6,9,12,26} According to Lenke et al⁹, a distinction should be made between adolescents and adults when considering the post-operative effects of thoracoplasty on pulmonary function. At a 2-year follow up, the authors in fact observed a return to preoperative values and a statistically significant 23% decline in adolescents and adults, respectively. The causes of the reduction on PFTs after thoracoplasty are unknown, but they are likely to be related to the changes in chest cage volume, respiratory muscle scarring and postoperative pleural adhesions.²¹

More recently, Suk et al²⁷ have compared both radiographic and pulmonary function results in a sample of 87 AIS patients surgically treated by means of pedicle screw instrumentation alone as follows: 37 patients without thoracoplasty, 20 with thoracoplasty but without direct vertebral rotation (DVR)²⁸ and the remaining 30 by thoracoplasty plus DVR. The authors' analysis has demonstrated that pedicle screw instrumentation and rod

TABLE 4. Preoperative and Follow-up Evaluation of Pulmonary Function Test in Posterior Only Fusion Group, Expressed as Absolute Values and Percent Predicted (%)

	Preoperative	Follow-up	P
FVC (L)/FVC %	2.83 (0.8)/84% (14)	3.34 (0.5)/87% (18)	< 0.001
FEV1 (L)/FEV1%	2.41 (0.7)/80% (13)	2.84 (0.4)/83% (17)	< 0.001

FVC indicates forced vital capacity; FEV-1, forced expiratory volume in one second.

derotation without thoracoplasty could significantly correct both rib hump and spinal deformity, as further confirmed by the FVC and FEV-1 values recorded at a follow-up of 6 years and found to be slightly higher than preoperatively. Furthermore, no significant pulmonary compromise was observed in subjects treated with thoracoplasty at a minimum follow-up of 2 years and patients reported to be more satisfied in the SRS-30 questionnaire. Finally, when comparing the three groups, thoracoplasty plus DVR appeared to be the most effective method to correct the rib hump deformity in thoracic adolescent idiopathic scoliosis.

The present results confirm in part the aforementioned findings. At a mean follow-up of 8.3 years, in the PSF+T group both the absolute values of forced vital capacity and those of forced expiratory volume in one second registered preoperatively were found to be unchanged at last follow-up, thus confirming the clinically insignificant pulmonary compromise after thoracoplasty in adolescent idiopathic scoliosis at a long term evaluation. On the other hand, as already highlighted by Suk et al²⁷, both the forced vital capacity (from 2.83 to 3.34 L; $P < 0.0001$) and forced expiratory volume in one second (from 2.41 to 2.84 L; $P < 0.0001$) were found to be higher in the PSF group, showing the positive effect of pedicle screw instrumentation on long term PFTs. Nevertheless, we didn't observed, even on a long term basis, a statistically significant improvement on PFT's in the thoracoplasty group, similar to that seen in the PSF group (Tables 3, 4). It's difficult with current series numbers, and statistical analysis performed, to attribute such different trend only to thoracoplasty itself. As already suggested by Newton et al²¹, such difference probably may be of modest clinical importance in any case.

With regards to deformity correction, the current authors observed a better rib hump correction in the thoracoplasty group when compared to the posterior-only fusion group in terms of RH absolute correction (PSF+T: -2.1 cm vs. PSF: -1.05; $P < 0.01$) and RH overall percent correction (PSF+T: 55.4% vs. PSF: 35.4%; $P < 0.0001$). It should be anticipated that even if statistically significant (PSF+T: 53.03% vs. PSF: 51.35%; $P < 0.03$), the overall main thoracic curve percent correction difference between the two groups is probably of no clinical relevance. Thoracoplasty procedure in the authors' institution has always been performed after deformity correction had already been done, been used only as a secondary surgical time to address the rib hump deformity itself. As previously reported,^{10,27} such overall changes confirm that pedicle screw instrumentation alone, even without thoracoplasty, can significantly correct not only the spinal deformity itself, but also the rib hump. When thoracoplasty surgery is performed, a statistically significant better correction of both spinal deformity and rib hump should be expected, without any significant long-term adverse effect.

No fatal complications, neurological injuries, acute or delayed deep wound infections were observed in the current

case series, with 3 surgery-related complications in the PSF + T group (requiring 2 revision surgery in 2 patients) and one revision surgery in the PSF group (due to persistent late operative site pain). However, in line with previous reports in the literature,^{6,8,9,27} a higher incidence of immediate postoperative complications was observed in the PSF + T group, mainly due to the thoracoplasty-related pulmonary complications encountered in 10 patients, all healed uneventfully by conservative treatment and with no adverse effect on the final result.

Better SRS-30 scores were not seen in the PSF + T group, thus differing from previous reports,²⁷ and no statistical differences were observed between the two groups (total score PSF + T: 4.1 vs. PSF:4.3; n.s) (Table 2). These findings cannot be extrapolated to explain the current data: the low inherent discriminant validity of the SRS-30 in such similar groups, previously reported, is likely to be the reason. Other self-reported questionnaires, specifically introduced to assess self image and global contour, such as the Spinal Appearance Questionnaire (SAQ),²⁹ are currently being evaluated by the present authors.

The better performance of pedicle screw instrumentation in terms of maintaining, or even restoring, sagittal contour is well known^{5,28,30}; the present findings further confirm that enhanced correction on coronal and sagittal plane, as well as greater rib hump improvement, may account for the statistically significant positive effect on postoperative PFTs of posterior fusion by pedicle screws alone in AIS. None of the patients in the current study underwent posterior fusion with direct vertebral rotation,²⁴ as such technique has only been routinely performed at the authors' institution since late 2004. The preliminary results obtained with DVR, are consistent with its inventor's assertion²⁷ and also with the current findings: when compared with the authors' past experience, the powerful true derotation manoeuvre performed with the DVR technique has obviated the need for thoracoplasty or it has ensured significantly better cosmetic results when thoracoplasty was performed.

The findings reported here should be interpreted within the context of their limitations, including the retrospective nature of the review and the fact that the patients were not randomized between the thoracoplasty and no-thoracoplasty group. However, the current series is consecutive, with no statistical differences between the two groups in terms of age, gender, Lenke classification distribution, Cobb's preoperative main thoracic curve magnitude, sagittal preoperative contour, preoperative rib hump and baseline PFTs. The present results may therefore be useful to reduce some of the potential selection bias associated with non-randomized studies.

CONCLUSIONS

According to the current findings, thoracoplasty did not adversely affect long-term PFTs in AIS patients treated by posterior spinal fusion alone, as already suggested by previous reports. A relatively high incidence of perioperative

complications was observed in the thoracoplasty group when compared to the posterior-only fusion group, with no adverse effect on final results. A trend towards better coronal plane correction and rib hump improvement was seen, although not clearly reported by a self-assessment disease-specific questionnaire.

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