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J. Bone Joint Surg. Am. 88:1022-1034, 2006. doi:10.2106/JBJS.E.00001

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Background: Posterior spinal fusion with segmental instrumentation is the gold standard for the surgical treatment of thoracic adolescent idiopathic scoliosis. More recently, anterior surgery and video-assisted thoracoscopic surgery with spinal instrumentation have become available. The purpose of the present study was to compare the radiographic and clinical outcomes as well as pulmonary function in patients managed with either anterior thoracoscopic or posterior surgery.

Methods: Radiographic data, Scoliosis Research Society patient-based outcome questionnaires, pulmonary function, and operative records were reviewed for fifty-one patients undergoing surgical treatment of scoliosis. Data were collected preoperatively, immediately postoperatively, and at the time of the final follow-up. The radiographic parameters that were analyzed included coronal curve correction, the most caudad instrumented vertebra tilt angle correction, coronal balance, and thoracic kyphosis. The operative parameters that were evaluated included the operative time, the estimated blood loss, the blood transfusion rate, the number of levels fused, the type of bone graft used, and the number of intraoperative and postoperative complications. The pulmonary function parameters that were analyzed included vital capacity and peak flow.

Results: The thoracoscopic group included twenty-eight patients with a mean age of 14.6 years, and the posterior fusion group included twenty-three patients with a mean age of 14.3 years. The percent correction was 54.5% for the thoracoscopic group and 55.3% for the posterior group. With the numbers available, there were no significant differences between the two groups in terms of kyphosis ($p = 0.84$), coronal balance ($p = 0.70$), or tilt angle ($p = 0.91$) at the time of the final follow-up. The mean number of levels fused was 5.8 in the thoracoscopic group, compared with 9.3 levels in the posterior group ($p < 0.0001$). The estimated blood loss in the thoracoscopic group was significantly less than that in the posterior fusion group (361 mL compared with 545 mL; $p = 0.03$), and the transfusion rate in the thoracoscopic group was significantly lower than that in the posterior fusion group (14% compared with 43%; $p = 0.01$). Operative time in the thoracoscopic group was significantly greater than that in the posterior group (6.0 compared with 3.3 hours, $p < 0.0001$). There were no intraoperative complications in either group. Vital capacity and peak flow had returned to baseline levels in both groups at the time of the final follow-up. Patients in the thoracoscopic group scored higher than those in the posterior group in terms of the total score ($p < 0.0001$) and all of the domains ($p < 0.01$) of the Scoliosis Research Society questionnaire at the time of the final follow-up.

Conclusions: Thoracoscopic spinal instrumentation compares favorably with posterior fusion in terms of coronal plane curve correction and balance, sagittal contour, the rate of complications, pulmonary function, and patient-based outcomes. The advantages of the procedure include the need for fewer levels of spinal fusion, less operative blood loss, lower transfusion requirements, and improved cosmesis as a result of small, well-hidden incisions. However, the operative time for the thoracoscopic procedure was nearly twice that for the posterior approach. Additional study is needed to determine the precise role of thoracoscopic spinal instrumentation in the treatment of thoracic adolescent idiopathic scoliosis.

Level of Evidence: Therapeutic Level III. See Instructions to Authors for a complete description of levels of evidence.

Anterior spinal surgery recently has been proposed for the treatment of thoracic adolescent idiopathic scoliosis. Nevertheless, posterior spinal fusion with use of segmental instrumentation involving hook or pedicle screw-hook constructs remains the gold standard by which other approaches are measured. Posterior surgery with current spinal instrumentation systems can result in curve correction, spinal balance in both the coronal and sagittal planes, and a solid fusion with a low rate of complications[1-4].

Patient satisfaction as measured with use of various outcome measures has been very good in association with posterior techniques[5,6]. Radiographic and clinical correction of deformity has improved further in association with newer thoracic pedicle screw techniques[7,8]. Nevertheless, the posterior technique has associated drawbacks, including the necessity to fuse more levels, substantial blood loss, a limited ability to correct hypokyphosis, and a long posterior midline scar[9,10]. Late operative site pain related to implant prominence or infection also may occur. In one series, implant removal was required because of infection or instrument prominence in twenty-eight (2.25%) of 1247 patients[11].

Anterior spinal surgery for scoliosis has its origins with Dwyer and later Zielke, who developed anterior instrumentation for thoracolumbar and lumbar scoliosis[12,13]. The anterior approach offers the ability to fuse a smaller number of vertebral segments, to achieve greater coronal plane correction, and to achieve better restoration of kyphosis in thoracic scoliosis, with generally less blood loss than is the case with posterior spinal surgery[14,15]. Anterior surgery, when performed by means of open thoracotomy, however, has the disadvantage of impairing pulmonary function, at least temporarily. Open thoracotomy also may result in a large scar and marked postoperative pain[10,16-19]. Finally, if there is substantial growth remaining in the teenage spine, anterior fusion can lead to hyperkyphosis[20].

Thoracoscopic approaches have been developed as a natural outgrowth of other minimally invasive procedures. Video-assisted thoracoscopic surgery first was developed for anterior disc and ligament release for the treatment of severe spinal deformity, for vertebral biopsy, and for thoracic decompression and more recently was expanded to encompass anterior spinal instrumentation.

Thoracoscopic spinal instrumentation retains the advantages of open anterior surgery while offering the potential for a decreased impact on pulmonary function, decreased postoperative pain, and improved cosmesis as a result of the use of small incisions[18,19]. The concerns associated with the procedure include a steep learning curve, the potential for vascular or neurological injury, pseudarthrosis, and implant breakage[21-24].

The purpose of the present study was to compare the results of thoracoscopic anterior spinal fusion and instrumentation with those of posterior spinal fusion and segmental spinal instrumentation in a consecutive group of patients with thoracic adolescent idiopathic scoliosis, with all surgical procedures being performed by the same surgeon. A comparison of radiographic and operative data, pulmonary function test results, and patient-based outcome assessments was conducted.

Materials and Methods

A retrospective analysis of patients who had had an operation for the treatment of thoracic adolescent idiopathic scoliosis between January 1999 and February 2002 was conducted. Twenty-three consecutive patients who had undergone posterior segmental spinal instrumentation and twenty-eight consecutive patients who had undergone thoracoscopic spinal fusion with anterior instrumentation met the inclusion criterion of a minimum of twenty-four months of follow-up. The patients in the thoracoscopic instrumentation group represent the first patients who had been managed by the surgeon (B.S.L.) with use of this technique. The study was approved by the institutional review board.

All patients had a Lenke type-1 curve (that is, a single structural thoracic curve)[25]. All patients in the thoracoscopic group had complete radiographic data, including preoperative standing posteroanterior, lateral, and right and left supine anteroposterior bending radiographs. Ten of the twenty-three patients in the posterior group did not have preoperative lateral radiographs; all had anteroposterior and bending radiographs. Most recent follow-up posteroanterior and lateral radiographs were available for all patients. Preoperative, postoperative, and final follow-up radiographs were compared. Coronal curve correction, the most caudad instrumented vertebra, correction of the tilt angle of the most caudad instrumented vertebra, coronal balance (measured as the offset of a plumb line from T1 from the midpoint of the sacrum), and thoracic kyphosis were determined for all patients by comparing preoperative, postoperative, and final follow-up radiographs. Fusion was evaluated for all patients as well.

Operative parameters were evaluated and compared for each group. The operative data that were assessed included the operative time, the estimated blood loss, the transfusion rate, the number of levels fused, the type of bone graft used, and the complication rate.

Pulmonary function was assessed in all patients preoperatively, postoperatively, and at the time of the final follow-up. Spirometry was performed to assess vital capacity (as a measure of restrictive lung disease) and peak flow (as a measure of large airway function) in all patients[26]. Postoperative and follow-up data were compared with preoperative data to determine the effect of the surgical procedures on pulmonary function.

The Scoliosis Research Society-22 (SRS-22) outcome questionnaire was administered to all patients preoperatively, postoperatively, and at the time of the final follow-up[27]. Total scores and the individual domain scores for pain, self-image, function, mental health, and satisfaction were compared between the two groups. Absolute values and the change from the preoperative values were compared between groups.

The t test was used to compare radiographic and pulmonary parameters at the designated interval periods at the 95% confidence level. One-way analysis of variance, used to examine the differences between the two groups for all potential outcome variables, was performed for all operative parameters. SRS-22 scores were compared with use of the nonparametric Wilcoxon rank sum (Mann-Whitney) test. The level of significance was set at $p < 0.05$.

Indications for Surgery

Surgery was recommended for the treatment of progressive thoracic scoliosis associated with a Cobb angle of ≥40°. Patients with curves of ≥70° typically were managed with anterior thoracoscopic release and posterior spinal fusion with instrumentation; such patients were excluded from the present study. For patients who had hyperkyphosis (>40°), anterior surgery was not recommended and only posterior surgery was offered. For all other patients, either a thoracoscopic anterior spinal instrumentation or posterior approach was offered. The perceived advantages and disadvantages of the two techniques were presented to the family and guardians, who then decided which technique would be used. They were made aware of the fact that, if the procedure was to be performed thoracoscopically, it would be among the senior author's early procedures with use of this relatively new technique and that long-term outcome data for the procedure were lacking. Informed consent was obtained.

Surgical Technique

Posterior spinal instrumentation and fusion was performed with use of all hook anchors or hooks in the thoracic spine and transpedicular screws in the lumbar spine. Postoperative bracing was not utilized for any of these patients. The selection of fusion levels and construct hook-screw patterns was based on established principles[28,29].

Thoracoscopic spinal instrumentation was performed on the basis of the technique described by Picetti et al.[22] and modified as follows. Under fluoroscopic guidance, portal sites were marked on the skin with the patient in the left lateral decubitus position (as all patients had a right thoracic curvature). Typically, three posterior axillary line portals and two anterior axillary line portals were made (Fig. 1). The first three procedures were performed with use of four posterior portals only. Portal location was designed to allow for access to the middle portion of the vertebral bodies to be instrumented. Sometimes, this required separate intercostal incisions cephalad and caudad to an individual rib through the same skin incision to allow for optimal screw placement. Five-centimeter segments of two ribs separated by one intact rib were harvested through the caudad two posterior portals. Usually, segments from the seventh and ninth or the eighth and tenth ribs were taken and morselized for use as bone graft. In several cases, cancellous allograft was used as a graft extender.

Pleural dissection and discectomies were performed through the anterior portals. Segmental vessels over all of the instrumented levels were cauterized with use of a harmonic scalpel. Temporary occlusion of vessels was not done. Continuous somatosensory-evoked potential monitoring was performed for all patients in this series. Occasionally, the cephalad or caudad end discs were not easily accessible and were addressed through the posterior portals. After the release was completed, instrumentation was performed as described previously[22]. In the latter half of the series, a guidewire technique was utilized only for the most cephalad screw to determine accurate screw length with use of a calibrated guidewire. The use of a guidewire was later abandoned completely. The Eclipse titanium spinal implant (CD Horizon; Medtronic-Sofamor-Danek, Memphis, Tennessee) with a 4.5-mm rod was utilized in all cases. After screw placement, final end plate preparation for fusion and autogenous rib-grafting was performed after first measuring and preparing an appropriately sized rod for implantation. The remainder of the procedure was performed as described previously[22].

Chest tube placement was done through the caudad anterior portal. Postoperative bronchoscopy was not performed in the operating room following the procedure in any patient. Suctioning through both lumens of the double-lumen endotracheal tube was performed immediately after the right lung was reventilated. The patient was placed in a thoracolumbosacral orthosis after the chest tube was removed. Braces were prefitted and fabricated prior to surgery. The brace was worn full time for three to four weeks after surgery and thereafter only when the patient was out of bed, for a total of three to four months.

Results

The thoracoscopic surgery group included twenty-eight patients (nineteen female patients and nine male pa-

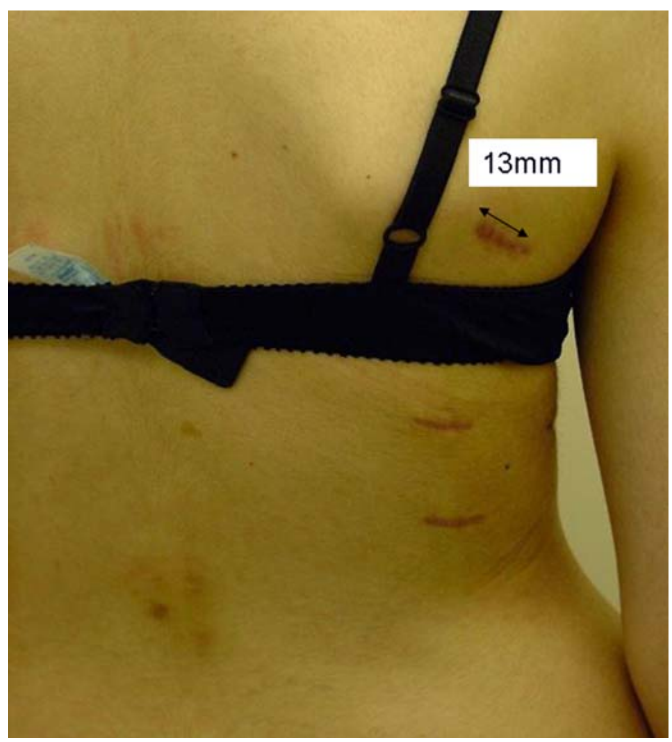

Fig. 1
Photograph showing the thoracoscopic portals.

TABLE I Demographic Data

	Thoracoscopic Surgery	Posterior Surgery
Number of patients	28	23
Age* *(yr)*	14.6 ± 1.54 (10-17)	14.3 ± 2.46 (10-21)
Female:male ratio	19:9	14:9
Lenke classification *(no. of patients)*		
1A	16	12
1B	10	7
1C	2	4
Preoperative major curve magnitude* *(deg)*	48.1 ± 5.12 (41-61)	48.1 ± 6.89 (40-68)
Duration of follow-up* *(mo)*	30.7 ± 5.86 (24-43)	39.6 ± 10.7 (24-58)

*The data are given as the mean and the standard deviation, with the range in parentheses.

tients) with a mean age of 14.6 years. Five of the nineteen female patients were premenarchal. All patients had a Lenke type-1 curve (a single structural thoracic curvature). Sixteen curves (57%) were associated with lumbar modifier A; ten (36%), with lumbar modifier B; and two (7%), with lumbar modifier C. (In this classification system, the lumbar modifier indicates the degree of deviation of the lumbar curve apex from the midline, with a vertical line perpendicular to the midpoint of the sacrum as the reference point. Modifiers are indicated by the reference line falling between the apex vertebrae pedicles [A], through the concave pedicle [B], or outside of the concave pedicle [C]). All patients had thoracic kyphosis within the range of 6° to 44°. The posterior surgery group included twenty-three patients (fourteen female patients and nine male patients) with a mean age of 14.3 years. Five of the fourteen female patients were premenarchal. All patients had a Lenke type-1 curve. Twelve curves (52%) were associated with lumbar modifier A; seven (30%), with modifier B; and four (17%), with modifier C. Two patients had thoracic hyperkyphosis of >40°, two had hypokyphosis of <10°, and nine were normokyphotic; for the remaining ten patients, preoperative lateral radiographs were not available. The average duration of follow-up was thirty-one months (range, twenty-four to forty-three months) for the thoracoscopic surgery group and forty months (range, twenty-four to fifty-eight months) for the posterior surgery group. Demographic data are shown in Table I.

Radiographic Results

In the thoracoscopic surgery group, the major curve was corrected from 48.1° preoperatively to 21.9° at the time of the latest follow-up (a 54.5% correction). In the posterior surgery group, the mean curve was corrected from 48.1° to 21.5° at the time of the final follow-up (a 55.3% correction) (Table II). A significant difference in curve correction in favor of the posterior group was found immediately postoperatively ($p = 0.007$). However, with the number available, this difference was no longer detectable on the final follow-up radiographs ($p = 0.80$) (Figs. 2-A through 2-D).

Coronal balance, measured with a plumb line from T1, was corrected to within 1 cm of the midpoint of the sacrum in both groups, and the tilt angle of the most caudad instrumented vertebra (that is, the angle of tilt of the vertebra from the horizontal) was corrected to <10° in both groups as well (Table III).

Preoperatively, the mean thoracic kyphosis in the posterior surgery group (for the thirteen patients in whom it was measured) was greater than that in the thoracoscopic surgery group (34.2° compared with 25.8°). Postoperatively, kyphosis was increased slightly in the thoracoscopic surgery group and was decreased slightly in the posterior surgery group but

TABLE II Major Curve Correction

	Thoracoscopic Surgery (N = 28)	Posterior Surgery (N = 23)	P Value
Magnitude of major curve* *(deg)*			
Preoperative	48.1 ± 5.12 (41-61)	48.1 ± 6.89 (40-68)	0.73
Immediate postoperative	16.5 ± 8.09 (1-32)	11.1 ± 5.00 (1-20)	0.007
Final follow-up	21.9 ± 9.09 (4-38)	21.5 ± 7.71 (10-40)	0.87
Percent correction at final follow-up† *(%)*	54.5 ± 17.1	55.3 ± 12.0	0.80

*The data are given as the mean and the standard deviation, with the range in parentheses. †The data are given as the mean and the standard deviation.

TABLE III Coronal and Sagittal Measurements

	Thoracoscopic Surgery (N = 28)	Posterior Surgery (N = 23)	P Value
Coronal balance* *(cm)*			
Preop.	1.29 ± 1.03 (0-3.6)	1.04 ± 0.68 (0.2-2.5)	0.34
Follow-up	0.77 ± 0.61 (0-2.5)	0.77 ± 0.69 (0-3.3)	0.70
Tilt angle of most caudad instrumented vertebra* *(deg)*			
Preop.	23.1 ± 4.16 (13-30)	17.2 ± 8.37 (2-35)	0.006
Follow-up	8.39 ± 3.98 (3-15)	8.57 ± 6.32 (0-25)	0.91
Kyphosis *(deg)*			
Preop.*	25.8 ± 8.40 (6-44)	34.2 ± 10.2 (13-55)	0.008
Postop.	27.5 ± 7.66 (11-45)	31.2 ± 8.54 (23-53)	0.17
Follow-up†	31.1 ± 6.84 (20-43)	30.6 ± 9.79 (21-48)	0.84

*The data are given as the mean and the standard deviation, with the range in parentheses. †In the posterior surgery group, only the thirteen patients who had complete radiographic measurements were included in the evaluation of kyphosis.

remained within normal limits in both groups (Table III).

Operative Parameters

The mean estimated blood loss (and standard deviation) was significantly less in the thoracoscopic surgery group than in the posterior surgery group (361 ± 189 mL compared with 545 ± 388 mL; p = 0.03). In addition, 14% of patients in the thoracoscopic surgery group received blood transfusions,

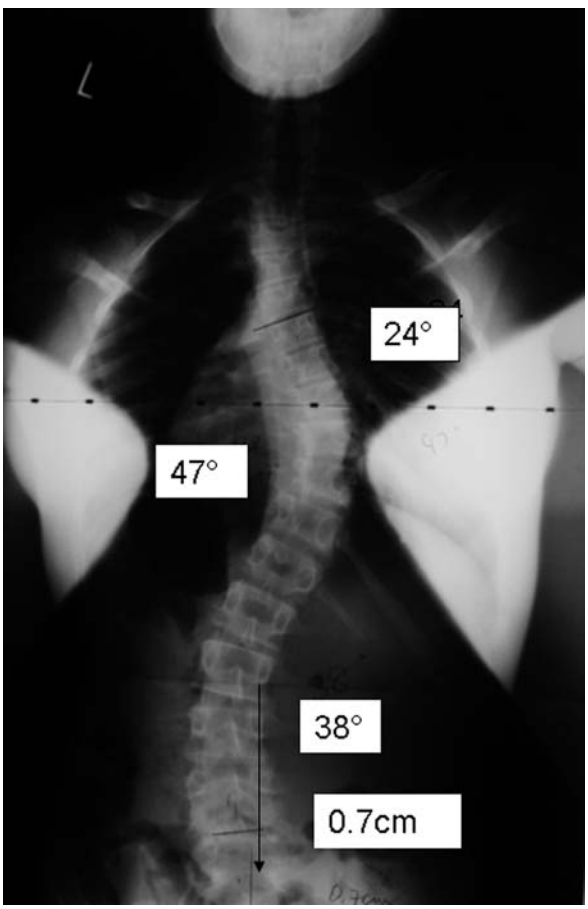

Fig. 2-A

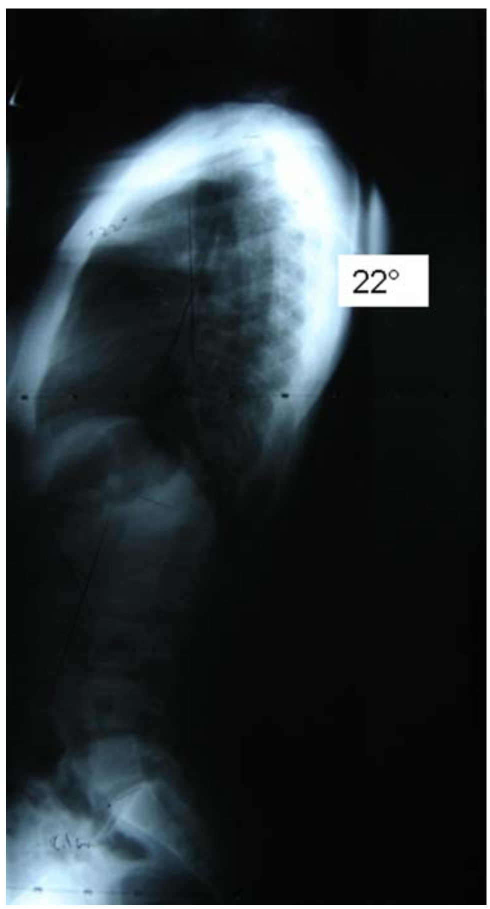

Fig. 2-B

Figs. 2-A through 2-D Radiographs of the spine in a patient managed with thoracoscopic anterior spinal fusion. **Figs. 2-A and 2-B** Preoperative anteroposterior (Fig. 2-A) and lateral (Fig. 2-B) radiographs.

compared with 43% of those in the posterior surgery group ($p = 0.01$). The mean operative time was 6.0 hours for the thoracoscopic surgery group and 3.3 hours for the posterior surgery group ($p < 0.0001$). The mean number of levels fused was significantly less in the thoracoscopic surgery group than in the posterior surgery group (5.8 levels compared with 9.3 levels; $p < 0.0001$) (Table IV).

In the thoracoscopic surgery group, the most caudad level fused was L1 (two patients), with the fusion ending at T12 in most (sixteen) of the twenty-eight patients. In the posterior surgery group, the caudad level of fusion extended into the lumbar spine in ten (43%) of the twenty-three patients.

Complications

In the thoracoscopic surgery group, there was a total of five complications, for a rate of 17.9%. The complications included a mucous plug, a pneumothorax, one case of proximal screw pull-out associated with a pseudarthrosis, and two broken rods. The mucous plug occurred on the second postoperative day and was treated with bronchoscopy. The patient recovered uneventfully. The persistent pneumothorax was asymptomatic and was noted on a routine chest radiograph following chest tube removal, and it resolved over several days. The one pseudarthrosis occurred in association with partial cephalad screw pull-out at the T4 and T5 levels. It was revised by means of a mini-thoracotomy, removal of the cephalad aspect of the rod and the two cephalad screws, and posterior fusion with instrumentation. The T4-T5 and T5-T6 disc spaces were noted to be inadequately prepared for fusion, and, in retrospect, the T4 screw placement was suboptimal with a trajectory in an oblique cephalad direction into the vertebral body. The patient was doing well at six months following the revision procedure. The other two complications in the thoracoscopic group were two broken rods in the middle portion of the construct. However, in both cases, the arthrodesis was found to be complete on computed tomographic scans, including coronal and sagittal reformatted images (Fig. 3).

In the posterior surgery group, there were three complications, for a rate of 13%. These complications included one case in which a hook pulled through the caudad (T12) lamina, one broken rod, and one superficial wound infection. The hook cut-out occurred within three weeks postoperatively when the patient lifted a heavy object. Revision of the instrumentation down to the L1 level with lumbar pedicle screws was performed. The broken rod required no treatment as the fusion appeared solid and the patient was asymptom-

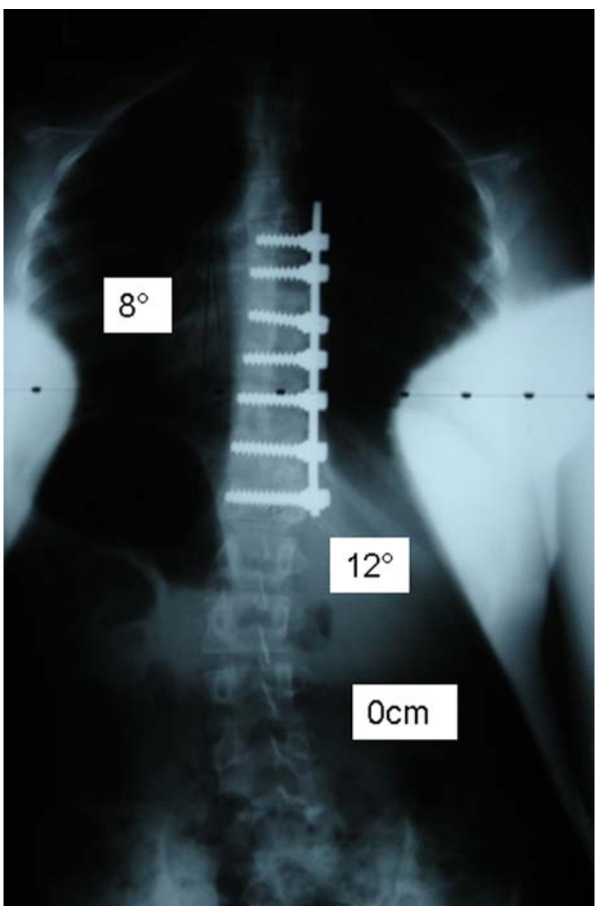

Fig. 2-C

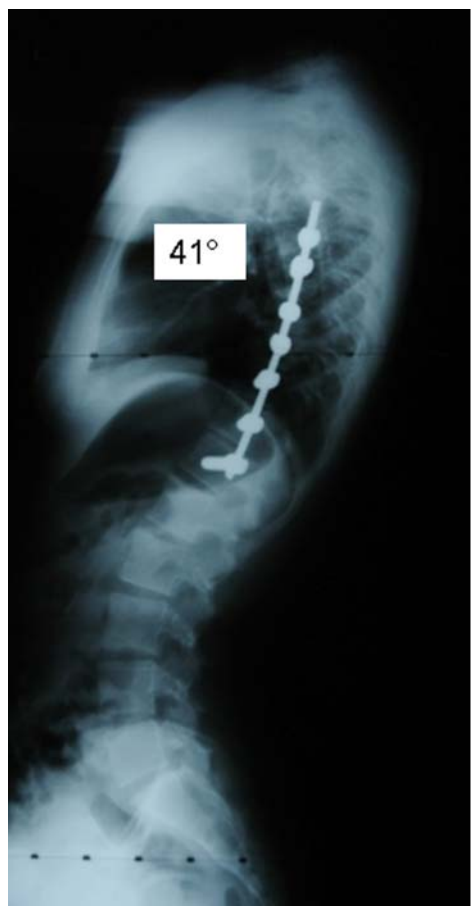

Fig. 2-D

Figs. 2-C and 2-D Follow-up anteroposterior (Fig. 2-C) and lateral (Fig. 2-D) radiographs made twenty-nine months after surgery.

TABLE IV Operative Data

	Thoracoscopic Surgery (N = 28)	Posterior Surgery (N = 23)	P Value
No. of levels fused*	5.8 ± 0.5 (5-7)	9.3 ± 1.6 (6-13)	<0.0001
Type of graft†			
Rib	24	16	
Rib + allo	3	0	
Allo	1	0	
ICBG	0	4	
Rib + ICBG	0	3	
Operative time* *(hr)*	6.0 ± 1.23 (4.0–9.8)	3.3 ± 0.60 (2.2-4.6)	<0.0001
Estimated blood loss* *(mL)*	361 ± 189 (100-1000)	545 ± 388 (150-1500)	0.03
Transfusion rate‡ *(%)*	14% (4 patients received 1 unit each)	43% (8 patients received 1 unit each, and 2 patients received 2 units each)	0.01
Length of hospital stay* *(day)*	4.4 ± 0.9 (3-7)	5.7 ± 0.6 (5-7)	<0.001
Intraoperative complications§	None	None	NS

*The data are given as the mean and the standard deviation, with the range in parentheses. †Rib = rib autograft, allo = crushed cancellous allograft, and ICBG = iliac crest bone graft. ‡Autologous in all cases. §NS = not significant.

atic. The superficial infection was treated with oral antibiotics and resolved.

Pulmonary Function

Vital capacity and peak flow diminished in both groups but to a significantly greater extent ($p < 0.001$ and $p = 0.001$, respectively) in the thoracoscopic group at the time of the first postoperative visit. In the thoracoscopic surgery group, vital capacity and peak flow decreased by 28% and 17%, respectively, following surgery. This decrease was significant for both param-

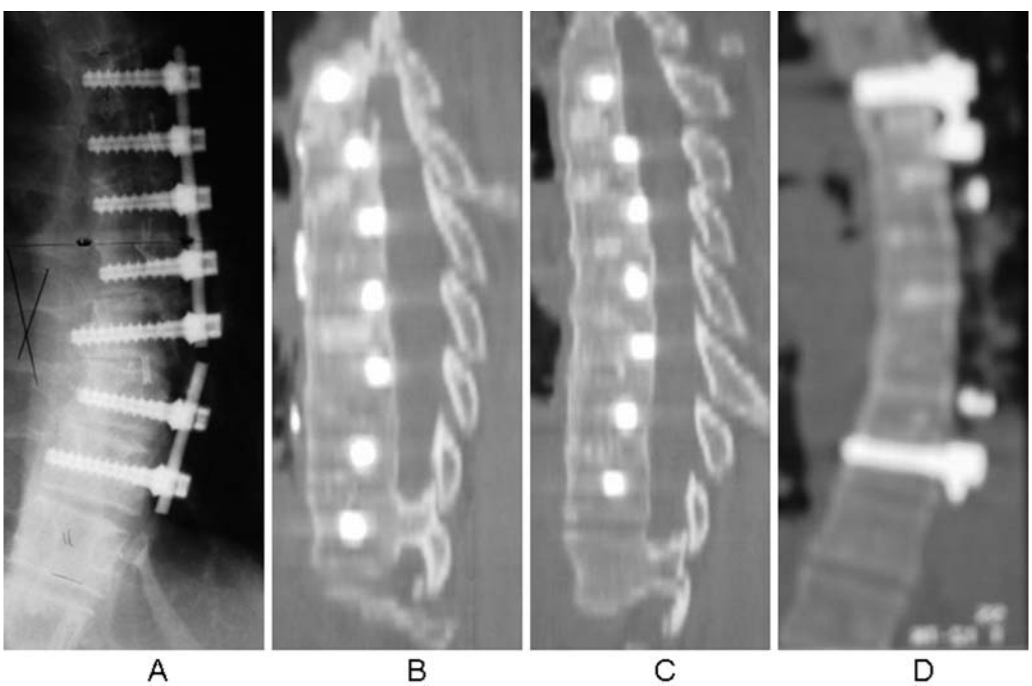

Fig. 3

A through D, Radiograph and computed tomographic scans of the spine of a fourteen-year-old girl who was noted to have an asymptomatic fractured rod at the ten-month postoperative visit. *A,* Radiograph of the spine, showing the broken rod. *B, C, and D,* Computed tomographic scans, including sagittal and coronal reformatted images, revealing a solid arthrodesis.

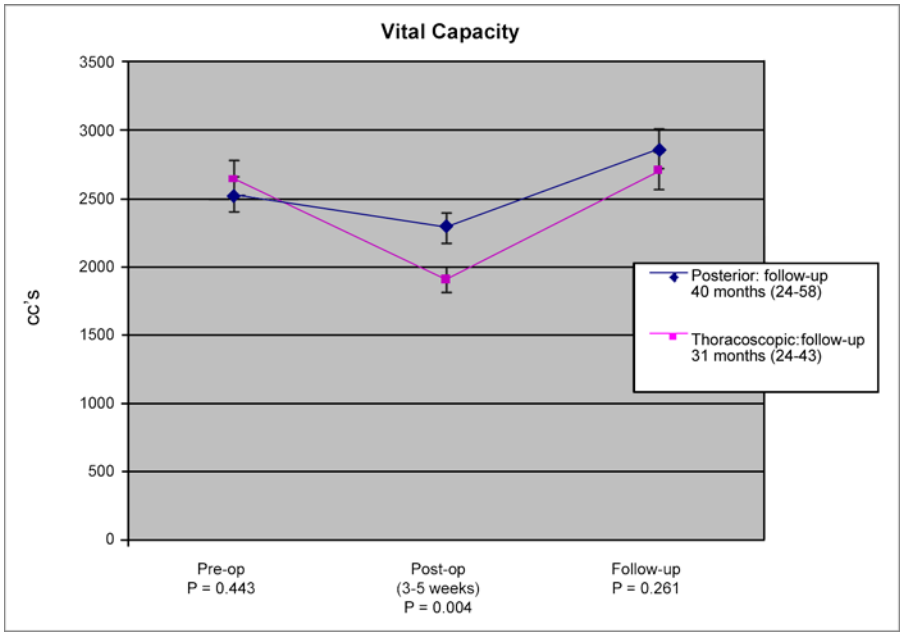

Fig. 4

Graph illustrating the effect of the surgical procedures on vital capacity.

eters ($p < 0.001$ and $p < 0.001$). In the posterior surgery group, vital capacity and peak flow diminished by 11% and 6.3%, respectively. With the numbers available, neither difference was found to be significant (peak flow, $p = 0.25$; vital capacity, $p = 0.08$). At the time of the final follow-up, vital capacity and peak flow returned to baseline levels in both groups (Figs. 4 and 5).

Preoperatively, vital capacity and peak flow were similar in the two groups. At the time of the first postoperative examination, both parameters decreased significantly more ($p = 0.004$ and $p = 0.014$, respectively) in the thoracoscopic surgery group compared with the posterior surgery group. However, at the time of the final follow-up, with the numbers available, there were no significant differences in peak flow ($p = 0.18$) or vital capacity ($p = 0.67$) between the groups. Of note, no patient in either group had severe pulmonary disease, although four patients in the thoracoscopic group and five patients in the posterior group had mild asthma.

SRS-22 Outcome Scores

The mean total SRS-22 scores improved in the thoracoscopic

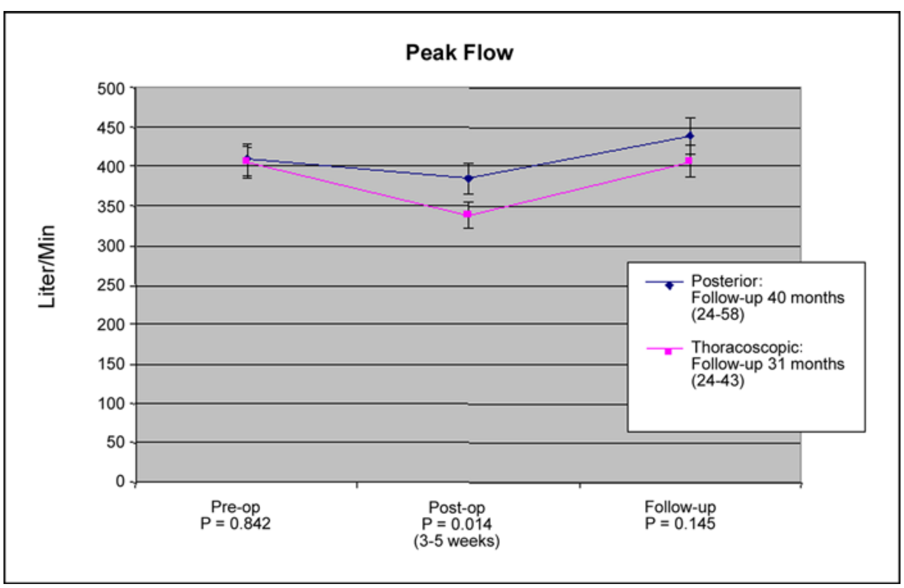

Fig. 5

Graph illustrating the effect of the surgical procedures on peak flow.

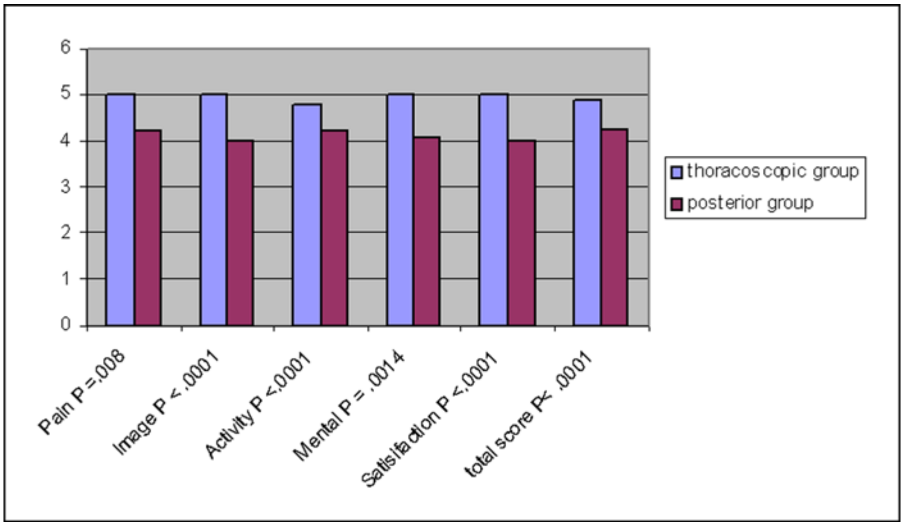

Fig. 6

Graph illustrating the mean scores on the SRS-22 outcome questionnaire at the time of the final follow-up.

surgery group and remained the same in the posterior surgery group when compared with preoperative values. Although the mean total scores were similar between the two groups preoperatively, the difference in mean total scores at the time of follow-up was significant ($p < 0.0001$), favoring the thoracoscopic group. The thoracoscopic surgery group had better scores in all domains of the questionnaire when compared with the posterior surgery group at the time of the final follow-up (Fig. 6).

Discussion

Thoracoscopic spinal fusion compared favorably with posterior spinal fusion for the treatment of thoracic adolescent idiopathic scoliosis in the present series. Coronal plane correction was similar for both groups, and curve correction in the posterior surgery group mirrored that in numerous studies in which hook or combination hook-screw constructs were utilized[1-4,10,30]. Coronal balance was improved in both groups and was within normal limits in both groups at the time of the final follow-up. Thus, the goal of partial curve correction and coronal balance was achieved similarly in both groups. The tilt angle of the most caudad instrumented vertebra was corrected to a greater extent in the thoracoscopic surgery group (from 23.1° to 8.4°) than in the posterior surgery group (from 17.2° to 8.6°), although the final tilt angles were equivalent. The long-term effects of residual tilt angle are not known, although there may be a greater potential for adjacent segment disc degeneration in association with larger residual tilt angles[15].

It has been reported that, in patients managed with Harrington rod instrumentation and fusion, the more caudad a fusion is extended below the third lumbar vertebra, the more likely there will be late caudad disc degeneration and back pain[31]. In the present study, the most caudad extent of the fusion was in the upper lumbar spine in the majority of patients in the posterior surgery group whereas it was in the lower thoracic spine in the majority of patients in the thoracoscopic surgery group. Whether or not differences in the rate of caudad segment disc degeneration and back pain or thoracolumbar flexibility will be found in the future is unclear and will require longer follow-up.

Curve correction with thoracoscopic instrumentation may increase as the surgeon's experience grows. In one study of fifty patients who were managed with thoracoscopic spinal instrumentation, curve correction averaged 50% in the first forty patients and improved to 69% in the last ten patients[22]. Recently, Wong et al. reported a mean thoracic curve correction of 62% with use of a thoracoscopic approach[32]. The radiographic results in the present series are similar to those reported in a number of studies of anterior thoracic instrumentation performed by means of thoracotomy. Thoracic curve correction associated with the use of threaded flexible rods, single solid rods, or dual rod constructs has ranged from 45% to 71%[10,14,33-37]. Newer posterior techniques involving the use of thoracic pedicle screws may duplicate the larger amounts of correction seen in some studies of anterior surgery. Furthermore, the new posterior techniques appear to increase coronal plane correction more than hook-rod constructs do[7,8].

One weakness of the present study is that it was retrospective in nature and therefore was not randomized. However, aside from the slightly greater amount of kyphosis in the posterior group, the two groups were similar in terms of age, preoperative curve size and range, and gender.

The mean preoperative kyphosis (T2-T12) was greater in the posterior surgery group (among the patients in whom it was measured) than in the thoracoscopic group (34° compared with 26°), perhaps reflecting a selection bias in that patients with kyphosis of >40° were not offered the thoracoscopic procedure. Hyperkyphosis following anterior spinal instrumentation with a flexible rod system in patients with preoperative kyphosis of >20° has been reported[10,16]. Hyperkyphosis was not seen in our patients who were managed with thoracoscopic surgery involving the use of a 4.5-mm titanium rod. Furthermore, junctional kyphosis cephalad or caudad to the construct was not seen in either surgical group.

The majority of patients in both groups had a Lenke type-1A or 1B curve (i.e., a lumbar curve not crossing the midline); thus, a meaningful comparison between the groups for selective thoracic fusion cannot be made. Two patients in the thoracoscopic surgery group who had a Lenke type-1C curve (i.e., a lumbar curve crossing the midline) and four such patients in the posterior surgery group had balanced corrections. Despite early reports of coronal decompensation and junctional kyphosis in patients undergoing posterior segmental fixation, we did not encounter the problem, which is minimized with proper fusion level selection[4]. Lenke et al. reported better major curve correction and spontaneous lumbar curve correction in patients undergoing selective thoracic fusion by means of the anterior approach as compared with the posterior approach[37]. It remains to be seen whether this finding will hold true for the thoracoscopic approach.

One advantage of the thoracoscopic approach in the present series was the ability to save caudad fusion levels. In twenty-six of the twenty-eight patients in the thoracoscopic surgery group, the caudad extent of the fusion was at or cephalad to T12. The remaining two patients had fusions to L1. In comparison, ten of the twenty-three patients in the posterior surgery group had fusions into the upper lumbar spine, two of which extended to L3. Betz et al. compared anterior surgery with posterior surgery for the treatment of thoracic scoliosis and found that an average of 2.5 caudad fusion levels were saved with the anterior approach[10]. It has long been recognized that anterior surgery is expected to save one or more fusion levels when compared with posterior surgery for the treatment of thoracolumbar or lumbar scoliosis[14,16,38,39]. Fewer levels were fused anteriorly in our patients, with a mean of 5.8 levels fused in the thoracoscopic surgery group and 9.3 levels fused in the posterior surgery group. Although the function domain score on the SRS outcome questionnaire was better for the thoracoscopic surgery group than for the posterior surgery group at the time of follow-up, it is unclear if this finding was a reflection of the smaller number of levels fused and better spinal flexibility.

Complications requiring revision surgery occurred in one patient in each group. In the posterior surgery group, a hook broke through the twelfth thoracic lamina and was successfully revised with pedicle screw instrumentation to L1. In the thoracoscopic surgery group, revision was required in a patient in whom a pseudarthrosis developed in the cephalad two levels of the fusion, with associated implant displacement. On the basis of the intraoperative findings at the time of revision and assessment of screw placement, the pseudarthrosis resulted from residual disc material noted in the disc spaces. Animal studies comparing thoracoscopic techniques with open anterior techniques or evaluating thoracoscopic techniques alone have demonstrated equivalent results in terms of the degree of release, the amount of disc removed, and the rates of radiographic, biomechanical, and histological fusion[40-44], but care is required to ensure satisfactory disc excision to allow fusion to occur[21].

The fusion rate in the thoracoscopic surgery group in the present series compares favorably with that in the study by Picetti et al., who reported pseudarthrosis in ten (20%) of fifty patients undergoing thoracoscopic fusion[22]. Nine of the ten pseudarthroses occurred in patients in whom demineralized bone matrix had been utilized as a substitute for autograft. The use of allograft alone for fusion after disc excision has been shown, in an animal model, to result in a lower fusion rate than was the case when autograft was used[42]. In the present study, the pseudarthrosis rate in the thoracoscopic surgery group was 3.6% (one of twenty-eight). Wong et al. reported no cases of pseudarthrosis in a series of twelve patients who had been managed with thoracoscopic instrumentation[32].

Rod breakage occurred in one patient in the posterior surgery group and two patients in the thoracoscopic surgery group. Although rod breakage may be a sign of nonunion, none of these patients had loss of correction after the three-month postoperative evaluation, and none of them had pain at the time of follow-up. In addition, a solid arthrodesis was documented with computed tomography scanning in both of the patients in the thoracoscopic surgery group. While it has been reported that rod breakage may allow controlled settling and gradual arthrodesis, avoiding breakage is preferred[17]. In both of the patients in the thoracoscopic surgery group in whom rod breakage occurred, 4.5-mm titanium rods had been used and the fracture may have occurred as a result of fatigue due to stressing and notching of the titanium rod during cantilever reduction of the curvature. Currently, we use 4.5-mm stainless steel rods because less rod breakage is predicted[45]. Betz et al. noted that if an anterior rod breaks, it will do so by two years postoperatively[10].

In the thoracoscopic surgery group, one patient had a mucous plug that was thought to be the result of a prolonged operative time with the patient in the lateral decubitus position, in which the dependent lung had become hyperemic and congested[21,22]. We have not noted this problem recently as our operative times have decreased. Aggressive fiberoptic suctioning through the double-lumen endotracheal tube is performed after each procedure prior to extubation, and we believe that postoperative bronchoscopy should be considered in cases in which the operative time exceeds five hours.

Major complications in the form of vascular or neurological injury did not occur in either group. We are not aware of any reported cases of vascular or neurological injury associated with thoracoscopic instrumentation, although this concern has been raised. Sucato et al.[46] documented the proximity of the aorta to the tips of the vertebral screws in the anterolateral aspect of the thoracic spine. The spinal rotation that occurs in patients with right thoracic scoliosis changes the relationship of the vertebrae to the thoracic aorta and may make the aorta more vulnerable to iatrogenic injury from the screws[46]. Bicortical screw purchase must be done in a manner to minimize screw tip protrusion beyond the vertebral body[23]. A unicortical screw design is now available and may allow the surgeon to minimize this concern. The guidewire technique that we initially used was abandoned because of the potential for migration into the contralateral side of the chest, risking injury to the aorta or lung[47].

The thoracoscopic procedure compared favorably with the posterior procedure in terms of intraoperative blood loss and the requirement for blood transfusions. The mean blood loss was 361 mL in the thoracoscopic surgery group, compared with 545 mL in the posterior surgery group. In the thoracoscopic surgery group, four patients received a one-unit transfusion of autologous blood. In the posterior surgery group, eight patients received a one-unit transfusion and two patients received a two-unit transfusion. Although the estimated blood loss was roughly 200 mL greater in the posterior surgery group, the transfusion rate may have been affected by the anesthesiologists' tendency to return autologous blood to patients after there had been 500 mL of blood loss. The mean operative time in the thoracoscopic surgery group (6.0 hours; range, 4.0 to 9.8 hours) was significantly greater than that in the posterior surgery group (3.3 hours; range, 2.2 to 4.6 hours) ($p < 0.0001$). The first three thoracoscopic procedures exceeded nine hours in length, with the operative time decreasing to as low as four hours later in the series. The learning curve associated with thoracoscopic surgery has been previously documented for anterior disc releases without instrumentation[22,24].

The length of the hospital stay was approximately one and one-half days shorter in the thoracoscopic surgery group, suggesting less immediate postoperative pain and more rapid early recovery from surgery. Data regarding the length of stay in the intensive care unit were not collected. Typically, patients undergoing thoracoscopic surgery were monitored in an intermediate care unit for one to two days before being transferred to a standard nursing care unit. Patients undergoing posterior surgery usually stayed in the standard nursing unit during the entire hospital stay. While a cost-analysis comparison of thoracoscopic and thoracotomy disc releases has been reported[48], we did not compare costs in the present study.

Pulmonary function is only temporarily diminished following thoracoscopic surgery. In the present series, vital capacity decreased by 28% at three weeks postoperatively and returned to baseline by one year. This temporary decline is consistent with the findings of other studies assessing the effect of open thoracotomy on pulmonary function[19,49-51]. Thoracoscopic surgery causes less chest-cage disruption and pulmonary compromise than open thoracotomy does[19]. In the posterior surgery group, vital capacity initially declined by 11% and then returned to baseline by the time of the final follow-up. This initial decline was likely related to a thoracoplasty being performed in thirteen of the twenty-three patients[51,52]. Thoracoplasty is less likely to be performed today in association with the use of thoracic pedicle screws but was commonly performed in patients managed with all-hook or hybrid constructs. Peak flow also diminished more in the thoracoscopic surgery group than in the posterior surgery group immediately postoperatively. In summary, our data demonstrated that the thoracoscopic approach had no significant final deleterious effect on pulmonary function and was not significantly different from the posterior approach in this regard.

Patient-based outcomes as assessed with the SRS-22 questionnaire revealed improvement in the total score and in the self-image domain in both groups. Patients in the thoracoscopic surgery group had higher scores in all domains than those in the posterior surgery group did, despite similar scores preoperatively. Overall, both groups of patients fared well and our findings were in agreement with the published results from a multicenter outcomes assessment in patients with adolescent idiopathic scoliosis who were managed with either anterior or posterior surgery[5].

To our knowledge, the present report describes the largest study in which thoracoscopic spinal fusion and instrumentation has been compared with posterior spinal fusion and instrumentation for the treatment of thoracic adolescent idiopathic scoliosis and is the only published comparison to date that includes both pulmonary function and patient-based outcomes. Thoracoscopic spinal instrumentation compared favorably with the posterior procedure in terms of coronal plane curve correction and balance, sagittal contour, the complication rate, pulmonary function, and patient-based outcomes. The procedure offers the advantages of fewer levels of spinal fusion, less operative blood loss, lower transfusion requirements, and improved cosmesis as a result of small, well-hidden incisions. Concerns about the procedure include a steep learning curve and the potential for pseudarthrosis and/or rod breakage. Over the course of the present series, the operative time for the thoracoscopic surgery group was nearly double that for the posterior surgery group. Additional time and experience are required in order to determine the precise role of thoracoscopic spinal instrumentation in the treatment of thoracic adolescent idiopathic scoliosis. ■

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The authors did not receive grants or outside funding in support of their research for or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

doi:10.2106/JBJS.E.00001

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