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Pulmonary Function in Adolescent Idiopathic Scoliosis Relative to the Surgical Procedure

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Background: The long-term pulmonary function of patients with adolescent idiopathic scoliosis undergoing surgical correction is uncertain. To our knowledge, no report has demonstrated the changes in pulmonary function five years or more following spinal arthrodesis with use of modern segmental spinal instrumentation techniques for the treatment of all types of adolescent idiopathic scoliosis in a similar adolescent population.

Methods: One hundred and eighteen patients with adolescent idiopathic scoliosis undergoing surgical treatment at a single institution were evaluated with pulmonary function tests to assess the absolute and percent-predicted value of forced vital capacity and forced expiratory volume in one second at the preoperative examination and at regular intervals postoperatively. The patients were divided into four groups depending upon the surgical procedure: Group 1 comprised forty-nine patients who had posterior spinal arthrodesis with iliac crest bone graft; Group 2, forty-one patients who had posterior spinal arthrodesis with thoracoplasty; Group 3, sixteen patients who had open anterior spinal arthrodesis with a rib resection thoracotomy; and Group 4, twelve patients who had combined anterior and posterior spinal arthrodesis with a rib resection thoracotomy and iliac crest bone graft, respectively.

Results:A comparison of absolute pulmonary function values from the preoperative and final follow-up evaluations demonstrated a significant ($p < 0.0001$) increase in both the forced vital capacity and the forced expiratory volume in one second for Group 1, whereas no change was seen in those values for Groups 2, 3, and 4. A comparison of the changes in the percent-predicted pulmonary function values demonstrated significant ($p < 0.05$) decreases in forced vital capacity and forced expiratory volume in one second for Groups 2, 3, and 4, except for the latter value for Group 4, whereas Group 1 had no change.

Conclusions: Patients who have had any type of chest cage disruption during the surgical treatment of adolescent idiopathic scoliosis demonstrate no change in the absolute value and a significant decline in the percent-predicted value of pulmonary functions at five years following surgery. Chest cage preservation is recommended to maximize both absolute and percent-predicted pulmonary function values after surgical treatment of adolescent idiopathic scoliosis.

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

The scoliotic spinal deformity of lateral flexion and rotation of the involved vertebrae around a vertical axis and the attached ribs causes chest cage stiffness, reduced hemidiaphragmatic movement, and uneven distribution of the inhaled air on the concave side resulting in a decrease in pulmonary function[1-3]. The effect of surgical correction on the pulmonary function of patients with adolescent idiopathic scoliosis is controversial. Although some investigators have shown that surgical correction of scoliosis substantially improves measured pulmonary functions such as vital capacity[4-11], others have demonstrated no major improvement in pulmonary function after operative correction[11-15] or have reported loss of pulmonary function postoperatively[15-19]. The controversies could perhaps be attributed to the fact that these studies were done on nonhomogeneous populations with different treatment modalities, age distribution, gender, curve patterns, curve severity, and etiology of the scoliosis and with various measurement techniques and parameters of pulmonary function evaluation such as the use of absolute versus percent-predicted values. Only one study that we know of has described the long-term effect of pulmonary function changes relative to the types of surgical procedure used for spinal arthrodesis in patients with adolescent idiopathic scoliosis[10].

The purpose of the present study was to evaluate prospectively, at regular intervals for a minimum of five years postoperatively, the changes in pulmonary function after surgical correction of adolescent idiopathic scoliosis.

Materials and Methods

Following institutional review board approval, we studied 118 patients with adolescent idiopathic scoliosis who were surgically treated by two surgeons at our institution between 1985 and 1997. Both the data on pulmonary function and radiographic changes at the preoperative and postoperative examinations were obtained prospectively and then were retrospectively evaluated. All patients had a minimum of five years of follow-up (mean, six years; range, five to sixteen years). No patient had prior spinal surgery.

Demographic Data

There were 110 girls and eight boys. The mean age (and standard deviation) of the patients was 14.4 ± 1.9 years (range, 10.9 to eighteen years).

The patients were classified according to the surgical classification system of adolescent idiopathic scoliosis described by Lenke et al.[20]. Sixty-three patients (53%) had type-1 curves (main thoracic); eighteen (15%), type-2 curves (double thoracic); seven (6%), type-3 curves (double major); four (3%), type-4 curves (triple major); fifteen (13%), type-5 curves (major thoracolumbar/lumbar); and eleven (9%), type-6 curves (major thoracolumbar/lumbar and minor thoracic structural). Forty patients had a lumbar A modifier; twenty-two, a lumbar B modifier; and fifty-six, a lumbar C modifier. The lumbar spine modifier was based on the relationship of the center sacral vertical line, which should bisect the cephalad aspect of the sacrum and be perpendicular to the true horizontal to the lumbar curve on the coronal radiograph. The lumbar A modifier is used when the center sacral vertical line runs between the lumbar pedicles at the apex of the lumbar curve. The lumbar B modifier is used when the center sacral vertical line touches the lumbar concave pedicle at the apex of the lumbar curve. The lumbar C modifier is used when the center sacral vertical line falls completely medial to the concave pedicle at the apex lumbar vertebra. The sagittal thoracic modifier revealed normal kyphosis (T5 to T12 was +10° to +40°) in eighty-five patients, hypokyphosis (T5 to T12 was less than +10°; mean, 2.2°; range, –12° to 9°) in twenty-six patients, and hyperkyphosis (T5 to T12 was greater than +40°; mean, +46.3°; range, +42° to +53°) in seven patients.

For the purposes of evaluation, the patients were divided into four groups depending upon the surgical procedure used for the spinal arthrodesis. The surgical procedure was chosen on the basis of the curve type, magnitude, flexibility, cosmetic appearance, and surgeon's preference. Indications for anterior release included a major coronal Cobb angle of >80° with lessened flexibility, thoracic hypokyphosis or hyperkyphosis, and skeletal immaturity of the patient. Indications for anterior spinal arthrodesis and instrumentation included a single thoracic or thoracolumbar curve with a hypokyphotic thoracic spine and, preferably, instrumentation involving less than seven vertebral bodies. Indications for a thoracoplasty included a preoperative rib prominence of >15°, measured with use of a scoliometer, and an expressed concern with the prominence of the rib hump deformity by the patient and/or the caregiver. Without any of the specific indications mentioned above, posterior spinal arthrodesis and segmental spinal instrumentation with iliac crest bone graft was preferred. The patients were divided into four groups depending upon the surgical approach: Group 1 included forty-nine patients who had posterior spinal arthrodesis with iliac crest bone graft; Group 2, forty-one patients who had posterior spinal arthrodesis with thoracoplasty; Group 3, sixteen patients who had open anterior spinal arthrodesis with a rib resection thoracotomy; and Group 4, twelve patients who had a combined anterior and posterior spinal arthrodesis with a rib resection thoracotomy and iliac crest bone graft, respectively.

Pulmonary Function

All patients in this study had pulmonary function tests to evaluate pulmonary volume and flow preoperatively and at three months, one year, two years, and five years or more postoperatively. We excluded the patients who were smokers and those with any comorbidities such as acute and chronic upper respiratory infection or asthma. All pulmonary function tests were performed on the same computerized spirometer (6200 Autobox; SensorMedics, Yorba Linda, California) that had an accuracy of ±3%, which met the criteria of the American Thoracic Society[21]. The tests were performed with the patient standing, each measurement was repeated three times, and the highest reading was selected. Pulmonary function test results were expressed both as absolute values as well as percent-predicted values with use of the arm span as representative of height[22,23]. The reason we used arm span rather than height was to make up for the loss of trunk height caused by the scoliosis and the subsequent gain of trunk height resulting from the spinal instrumentation. For the purposes of analysis and comparison of pulmonary function of the four groups of patients, we chose the forced vital capacity and forced expiratory volume in one second. The forced expiratory volume in one second is a measurement both of volume and of mean flow over the first second. The reductions in forced expiratory volume in one second reflect the total effects of reduction in total lung capacity, obstruction of the airways, loss of lung recoil, and relatively uncommon, gross weakness of respiratory muscles. We chose these two parameters because they provide an adequate assessment of the volume and flow functions as measured by the pulmonary function tests[15]. The severity of the abnormality in forced expiratory volume in one second was categorized as a mild, moderate, or severe impairment. Mild impairment was defined as 65% to 80% of the normal value, moderate impairment was 50% to 64% of the normal value, and severe was <50% of normal[24].

Radiographic Measurements

Coronal and lateral radiographs of the spine on 91-cm-long cassettes were made with the patient standing. Preoperative and postoperative radiographic measurements of the spinal curvature in the coronal plane were performed with use of the Cobb method[25]. Kyphosis of the thoracic spine was measured, with use of the Cobb method, from the superior end-plate of T5 to the inferior end-plate of T12. All radiographic measurements were done by one of the authors (Y.J.K.), a senior spinal surgeon, independent of the operative team.

Operative Procedure

All forty-nine patients in Group 1 had a posterior arthrodesis of the spine with segmental Cotrel-Dubousset instrumentation with hooks, wires, and screws (Medtronic Sofamor Danek, Memphis, Tennessee) and iliac crest bone-grafting. Cotrel-Dubousset instrumentation was used in forty-three patients, and Cotrel-Dubousset Horizon instrumentation (CDH; Medtronic Sofamor Danek) was used in six patients.

All forty-one patients in Group 2 had a posterior arthrodesis of the spine with use of Cotrel-Dubousset instrumentation (thirty-six had Cotrel-Dubousset instrumentation, and five had CDH instrumentation) with a thoracoplasty as described by Lenke et al.[16]. A mean of six ribs (range, five to eight ribs) were partially resected for the thoracoplasty. After segmental excision, the ribs were not sutured tightly nor approximated. The transverse processes were not excised.

In the sixteen patients in Group 3, an anterior arthrodesis of the spine with a rib resection thoracotomy was performed. In thirteen patients, an anterior arthrodesis of the spine by means of a rib resection thoracotomy as well as a retroperitoneal approach (thoracolumbophrenotomy) was done. Fourteen patients were managed with a flexible rod system; nine of them had Harms instrumentation (DePuy AcroMed, Raynham, Massachusetts), and five had Zielke instrumentation (Osteonics, Allendale, New Jersey). Solid Cotrel-Dubousset instrumentation was used in the remaining two patients.

The twelve patients in Group 4 had an anterior arthrodesis of the spine by means of a rib resection thoracotomy with or without a retroperitoneal approach to the spine combined with a posterior arthrodesis and segmental instrumentation of the spine as described above. Autogenous rib and posterior iliac crest bone grafts were used for anterior and posterior arthrodesis, respectively. Seven of the twelve patients in Group 4 also had anterior instrumentation (Zielke anterior instrumentation in four patients, Harms anterior instrumentation in two patients, and Texas Scottish Rite Hospital anterior instrumentation in one patient) combined with a posterior Cotrel-Dubousset implant (Cotrel-Dubousset instrumentation in eight and CDH instrumentation in four patients). Noninstrumented anterior spinal arthrodesis was performed in the remaining five patients.

Postoperatively, no patient in Groups 1, 2, or 4 was managed with immobilization in an orthosis. The patients were initially engaged in a supervised physical therapy program to encourage gentle mobilization of the unfused segments of the spine. They were given a home exercise protocol to be done for four to six months until they regained the preoperative level of daily physical activities. Six patients in Group 3 were placed in a molded thoracolumbosacral orthosis for four months. These patients were subsequently given the same home exercise protocol as the patients in Groups 1, 2, and 4. No patient had a video-assisted thoracoscopic surgery.

Statistical Analysis

The data were analyzed with use of the Statistical Analysis System (version 8.2, 1999; SAS Institute, Cary, North Carolina). The distributions of the variables are given as the means, standard deviations, and ranges. Pearson correlations were used to assess the association among radiographic measurements and pulmonary function test results at the preoperative and final time-points. Comparisons across the groups for measurements made at one time-point were performed with use of analysis of variance. The Tukey honestly significant difference test was used to determine which groups were significantly different. For continuous variables measured at two time-points, paired t tests were used for assessment of the change over time within a group. For variables measured at more than two time-points, longitudinal analyses were carried out with use of mixed-model repeated-measures analysis of variance. The primary focus of analysis testing for change-over-time within a group was on the significance of the time effect. When the time effect was significant and within the framework of the mixed-model analysis, the appropriate statistical contrasts were used in testing the null hypothesis that no change occurred between two specific time-points. Of particular interest were comparisons assessing the change between the values at the preoperative evaluation and those at each follow-up examination and assessing the change between the values at the two-year and final follow-up evaluations. A p value of <0.05 was considered significant.

Results

Radiographic Results

The mean Cobb angles at the preoperative and final follow-up evaluations were 56° and 28° (a 50% correction), respectively, for Group 1; 64° and 36° (a 44% correction) for Group 2; 56° and 24° (a 57% correction) for Group 3; and 66° and 35° (a 47% correction) for Group 4. The mean thoracic kyphosis angles at the preoperative and final follow-up examinations were 16° and 22°, respectively, for Group 1; 27° and 27° for Group 2; 17° and 27° for Group 3; and 22° and 24° for Group 4 (Table I). A negative correlation was detected between the preoperative Cobb angle of the major curve and both the percent-predicted forced vital capacity (r = –0.18, p = 0.04) and the forced expiratory volume in one second (r = –0.26, p = 0.005). A negative correlation was found between the number of involved vertebrae in the major curve and both the percent-predicted forced vital capacity (r = –0.27, p = 0.003) and the forced expiratory volume in one second (r = –0.23, p = 0.02) at the preoperative evaluation and between the number of involved vertebrae in the major curve and the percent-predicted forced vital capacity (r = –0.34, p = 0.0002)

TABLE I Preoperative and Postoperative Radiographic Measurements in 118 Patients with Adolescent Idiopathic Scoliosis

	Mean Cobb Angle			Mean Thoracic Kyphosis Angle		
Groups	Preop.	Postop.	Difference*	Preop.	Postop.	Difference*
1 (n = 49)	56°	28°	28° ± 10°†	16°	22°	–6° ± 13°†
2 (n = 41)	64°	36°	28° ± 11°†	27°	27°	0° ± 10°
3 (n = 16)	56°	24°	32° ± 13°†	17°	27°	–10° ± 15°†
4 (n = 12)	66°	35°	31° ± 15°†	22°	24°	–2° ± 12°

*The values are given as the mean and the standard deviation. A negative value indicates that the value was greater than that before the surgery. †The difference is significant (p < 0.05).

and forced expiratory volume in one second (r = –0.32, p = 0.0005) at the final follow-up evaluation. We did not measure the vertebral rotation because the Cobb angle difference and the number of involved vertebrae in the major curve are closely related and because of the known inaccuracy of measurements of vertebral body rotation. However, no correlation was detected between the number of fused vertebral bodies and the final pulmonary function tests.

Because there were too few patients with Lenke type-3, 4, and 6 curves and as the curves had common characteristics, we grouped them together to reduce the statistical bias in the comparison of Lenke curve types. Analysis of variance indicated that there was a slightly significant difference between Lenke groups (p = 0.045). We found that patients with a Lenke type-5 curve (thoracolumbar/lumbar) had a significantly larger forced expiratory volume in one second preoperatively than did those with a Lenke type-1 curve (main thoracic) (p = 0.045). A comparison of the preoperative and postoperative pulmonary function tests among the three different sagittal modifiers demonstrated no significant differences, with the numbers available (p = 0.061 for preoperative forced vital capacity, p = 0.42 for final forced vital capacity, p = 0.61 for preoperative forced expiratory volume in one second, and p = 0.30 for final forced expiratory volume in one second).

Group 1: Posterior Spinal Arthrodesis with Autogenous Iliac Crest Bone Graft

The mean age of the forty-nine patients in Group 1 was 14.3 ± 1.9 years (range, 10.9 to eighteen years), and the mean follow-up period was 6.9 years (range, five to sixteen years). Twenty-nine patients had type-1 curves; six, type-2 curves; three, type-3 curves; five, type-5 curves; and six, type-6 curves. Eighteen patients had a lumbar A modifier; eight, a lumbar B modifier; and twenty-three, a lumbar C modifier. Fifteen patients had a hypokyphotic sagittal modifier, thirty-three had a normal sagittal modifier, and one had a hyperkyphotic sagittal modifier. The mean Cobb angle was 56° ± 10° (range, 37° to 82°) preoperatively and 28° ± 11° (range, 9° to 48°) at the final evaluation. The mean thoracic kyphosis was +16° ± 12° (range, –9° to 50°) preoperatively and +22° ± 9° (range, 7° to 42°) at the time of the final follow-up. A significant change was detected in the Cobb angle and the thoracic kyphosis after surgery compared with the preoperative values (p < 0.05) (Table I).

Group 2: Posterior Spinal Arthrodesis with Concomitant Thoracoplasty

The mean age of the forty-one patients in Group 2 was 14.4 ± 1.8 years (range, 11.5 to eighteen years), and the mean follow-up period was six years (range, five to nine years). Twenty-one patients had type-1 curves; ten, type-2 curves; three, type-3 curves; three, type-4 curves; one, a type-5 curve; and three, type-6 curves. Fourteen patients had a lumbar A modifier; eight, a lumbar B modifier; and nineteen, a lumbar C modifier. Four patients had a hypokyphotic sagittal modifier, thirty-two had a normal sagittal modifier, and five had a hyperkyphotic sagittal modifier. The mean Cobb angle was 64° ± 11° (range, 45° to 88°) preoperatively and 36° ± 10° (range, 17° to 54°) at the time of the last follow-up. The mean thoracic kyphosis was +27° ± 13° (range, –6° to 53°) preoperatively and +27° ± 11° (range, 6° to 60°) at the time of the final follow-up. A significant change was detected in the Cobb angle compared with the preoperative values (Table I). A total of 226 (90%) of the 250 resected ribs regenerated three to six months after the operation. The shape of the regenerated area assumed a lazy s-shape with deformed ribs in the coronal plane. Some of them demonstrated synostosis around the resection site.

Group 3: Anterior Spinal Arthrodesis with a Rib Resection Thoracotomy

The mean age of the sixteen patients in Group 3 was 15.4 ± 1.5 years (range, 13.7 to 17.8 years), and the mean follow-up period was 5 ± 0.7 years (range, five to 7.5 years). Ten patients had type-1 curves, one had a type-2 curve, and five had type-5 curves. Four patients had a lumbar A modifier; six, a lumbar B modifier; and six, a lumbar C modifier. Six patients had a hypokyphotic sagittal modifier, and ten had a normal sagittal modifier. The mean Cobb angle was 56° ± 8° (range, 43° to 74°) preoperatively and 24° ± 12° (range, 4° to 43°) at the time of the last follow-up. The mean thoracic kyphosis was 17° ± 15° (range, –12° to 34°) preoperatively and 27° ± 11° (range, 2° to 41°) at the time of the last follow-up. A significant change was detected in the Cobb angle and the thoracic kyphosis after surgery compared with the preoperative values (p < 0.05) (Table I).

Group 4: Combined Anterior and Posterior Spinal Arthrodesis with Autogenous Rib and Iliac Crest Bone Graft, Respectively

The mean age of the twelve patients in Group 4 was 13.7 ± 2.1 years (range, eleven to 17.8 years), and the mean follow-up period was 5.3 ± 0.5 years (range, five to 6.2 years). Three patients had type-1 curves; one, a type-2 curve; one each, a type-3 and a type-4 curve; four, type-5 curves; and two, type-6 curves. Four patients had a lumbar A modifier, and eight had a lumbar C modifier. One patient had a hypokyphotic sagittal modifier, ten had a normal sagittal modifier, and one had a hyperkyphotic sagittal modifier. The mean Cobb angle was 66° ± 22° (range, 35° to 110°) preoperatively and 35° ± 16° (range, 7° to 55°) at the final follow-up evaluation. The mean thoracic kyphosis was +22° ± 11° (range, 4° to 42°) preoperatively and 24° ± 12° (range, 4° to 39°) at the time of the final follow-up. A significant change was detected in the Cobb angle after surgery compared with the preoperative values ($p < 0.05$) (Table I).

Pulmonary Function Test

When the severity of the pulmonary impairment was analyzed preoperatively, fifty-four (46%) of the 118 patients had normal findings. Forty-three patients (36%) demonstrated mild impairment, and twenty-one (18%) had moderate impairment. Forty-four patients (37%) had normal findings at the final follow-up evaluation. Forty-nine patients (42%) demonstrated mild impairment, and twenty-five (21%) had moderate impairment at the final follow-up evaluation.

When all patients were evaluated, the mean absolute forced vital capacity was 2.84 ± 0.72 L (range, 1.39 to 5.67 L) at the preoperative examination and increased to 3.14 ± 0.66 L (range, 1.49 to 5.87 L) at the final follow-up examination. The mean absolute forced expiratory volume in one second was 2.41 ± 0.62 L (range, 0.98 to 4.98 L) at the preoperative evaluation and increased to 2.56 ± 0.55 L (range, 1.40 to 4.96 L) at the final follow-up evaluation. The mean percent-predicted forced vital capacity was 85% ± 16% (range, 50% to 134%) at the preoperative examination and decreased to 78% ± 14% (range, 44% to 114%) at the final follow-up examination. The mean percent-predicted forced expiratory volume in one second was 80% ± 16% (range, 49% to 131%) at the preoperative evaluation and decreased to 75% ± 13% (range, 44% to 105%) at the time of the final follow-up.

Group 1: Posterior Spinal Arthrodesis with Autogenous Iliac Crest Bone Graft

At a mean follow-up of 6.9 years, the absolute value of forced vital capacity and forced expiratory volume in one second demonstrated continued improvement compared with the preoperative values (the forced vital capacity increased from 2.81 to 3.23 L [$p < 0.0001$] and forced expiratory volume in one second increased from 2.41 to 2.71 L [$p < 0.0001$]) (see Appendix). During the same time-period, the percent-predicted values of forced vital capacity and forced expiratory volume in one second demonstrated no change between the preoperative and final follow-up values (84% and 82%, respectively, for forced vital capacity [$p = 0.63$] and 81% and 80% for forced expiratory volume in one second [$p = 0.52$]) (see Appendix).

Group 2: Posterior Spinal Arthrodesis with Concomitant Thoracoplasty

At a mean follow-up of six years, the absolute values of forced vital capacity were unchanged from 2.92 to 3.0 L ($p = 0.16$) and those of forced expiratory volume in one second were unchanged from 2.43 to 2.52 L ($p = 0.36$) (see Appendix). During the same time-period, the percent-predicted values of forced vital capacity decreased from 86% to 76% ($p = 0.0005$), and those of forced expiratory volume in one second decreased from 80% to 72% ($p = 0.009$) (see Appendix).

Group 3: Anterior Spinal Arthrodesis with a Rib Resection Thoracotomy

At a mean follow-up of five years, the absolute values of forced vital capacity were unchanged from 3.07 to 2.8 L ($p = 0.06$), and those of forced expiratory volume in one second were unchanged from 2.6 to 2.4 L ($p = 0.07$) (see Appendix). However, these data suggest a trend toward a decline in the postoperative pulmonary function test values. At the same time-period, the percent-predicted values of forced vital capacity decreased from 90% to 75% ($p < 0.0001$), and those of forced expiratory volume in one second decreased from 83% to 72% ($p = 0.002$) (see Appendix). This group can be subdivided into the thoracotomy group (ten patients) and the thoracoabdominal approach group (six patients). In the thoracotomy group, the absolute values of forced vital capacity decreased from 2.9 to 2.6 L, and the percent-predicted values changed from 86% to 69%. The values for forced expiratory volume in one second decreased from 2.6 to 2.2 L, and the percent-predicted values changed from 79% to 67%. In the thoracoabdominal approach group, the absolute values of forced vital capacity decreased from 3.2 to 3.10 L, and the percent-predicted values changed from 96% to 84%. The values for forced expiratory volume in one second decreased from 2.76 to 2.65 L, and the percent-predicted values changed from 91% to 80%. This group was also subdivided into the hypokyphosis group (six patients), which demonstrated a mean thoracic kyphosis increase from 1° preoperatively to 22° at the time of the last follow-up, and the normal kyphosis group (ten patients), which demonstrated a mean increase in the thoracic kyphosis from 26° preoperatively to 30° at the time of the last follow-up. In the hypokyphosis group, the absolute values of forced vital capacity decreased from 2.92 to 2.62 L, and the percent-predicted values changed from 83% to 66%. The values of forced expiratory volume in one second decreased from 2.75 to 2.33 L, and the percent-predicted values changed from 79% to 67%. In the normal kyphosis group, the absolute values of forced vital capacity decreased from 3.16 to 2.95 L, and the percent-predicted values changed from 94% to 80%. The values of forced expiratory volume in one second decreased from 2.63 to 2.48 L, and the percent-predicted values changed from 86% to 75%.

Group 4: Combined Anterior and Posterior Spinal Arthrodesis with Autogenous Rib and Iliac Crest Bone Graft, Respectively

At a mean follow-up of five years, the forced vital capacity (absolute value) showed no significant change from 2.38 to 2.55 L ($p = 0.15$). The forced expiratory volume in one second (absolute value) showed a similar change from 2.00 to 2.14 L ($p = 0.20$) (see Appendix). At the same time-period, the percent-predicted value of forced vital capacity demonstrated a significant decrease from 81% to 70% ($p = 0.02$). The percent-predicted value of forced expiratory volume in one second demonstrated no significant change from 73% to 67% ($p = 0.16$). Thus, the percent-predicted values at five years in this group showed a significant decrease compared with preoperative values in the forced vital capacity, but only a trend toward a decrease in the forced expiratory volume in one second.

Discussion

Although the rapid growth in the total number of pulmonary alveoli ends around two years of age, the growth and development of the pulmonary system is completed at about fifteen to sixteen years of age in girls and eighteen to nineteen years of age in boys[26]. After a plateau period until the age of thirty-five years, there is a definite decline in pulmonary function during the remainder of adult life[27]. The growth rate of the pulmonary function tests also varies with a child's stage of growth[23,28]. The point estimates of the somatic growth peak velocities precede all peak pulmonary function tests in both males and females[29]. Before Wang et al.[23] reported the pulmonary function data of children between six and eighteen years old, which was based on 82,462 annual measurements from 11,630 white children and 989 black children in 1993, reference pulmonary function test data were subjective and were based on small population groups. Because adolescence is a period of rapid growth and pulmonary function changes occur independently of growth (by maturation ["age effect"]), sex, race, body surface, smoking habit, and age at which peak velocity occurs, we need to standardize the data to isolate the effect of the surgical technique itself on pulmonary function tests as much as possible[23,27-31]. Our data did not include all of these compounding factors, and we have no knowledge of their influence on these patients. Because there is a discrepancy between arm span and height due to the changes that occur with thoracic fusion, we elected to use both percent-predicted pulmonary function test values as well as absolute values as objective and reliable parameters for comparison on the basis of arm span, age, sex, race, and the published reference values in the study by Wang et al.[23].

The current study demonstrated a significant negative correlation between the preoperative Cobb angle and percent-predicted pulmonary function test values and a significant negative correlation between the number of involved vertebrae in the major curve and percent-predicted pulmonary function test values. The smaller number of involved vertebrae in the major curve had a strong correlation with higher pulmonary function test values preoperatively, as in Lenke type-5 curves. However, the number of fused vertebrae did not demonstrate any correlation with change in the pulmonary function test values. Regarding the differences and changes in thoracic kyphosis, no correlations were detected between the thoracic kyphosis and pulmonary function tests. These results supported the finding that the larger Cobb angle and more involved vertebrae in the major curve had a strong correlation with poor pulmonary function tests, while the differences in the thoracic kyphotic angle in adolescent idiopathic scoliosis did not affect the pulmonary function tests because of small differences between patients with normal kyphosis and those with hyperkyphosis or hypokyphosis.

The reported results of Harrington instrumentation and posterior spinal arthrodesis with iliac crest bone graft on pulmonary function have varied from an improvement in pulmonary function after surgery[4-7,9-11] to no change[12,14] or to a postoperative decline in pulmonary function[17-19]. After the introduction of modern segmental spinal instrumentation systems with multiple hook and rod constructs aiming at three-dimensional correction, the reported pulmonary function values have also varied, showing an improvement in pulmonary function after surgery[8,32] to no change[15] or to a postoperative decline in pulmonary function[17-19]. In the current study, the patients in Group 1 (posterior spinal arthrodesis with iliac crest bone-grafting) demonstrated a significant increase in absolute pulmonary function; however, the change in percent-predicted pulmonary function during the mean 6.9-year follow-up period was not found to be significant. This suggests that the correction of the deformity and a posterior spinal arthrodesis with use of iliac crest bone graft stabilizes pulmonary function during the remainder of adolescent growth.

Several studies have focused on pulmonary function test changes after thoracoplasty in patients with adolescent idiopathic scoliosis[15,16,33,34]. Pulmonary function test values after posterior spinal arthrodesis with thoracoplasty have demonstrated initial substantial declines with a return to normal values[16,33,34] or a decline at the time of the final follow-up after surgery[15,16]. In the current study, the patients in Group 2 (those who had posterior spinal arthrodesis and thoracoplasty) demonstrated no significant change in absolute pulmonary function; however, they had a significant decrease in the percent-predicted pulmonary function at a mean of six years postoperatively. This suggests that the regenerated ribs, which appeared between three and six months postoperatively, did not allow proper function of the chest cage because of a nonunion or a deformed shape of the regenerated rib or because of a synostosis between the regenerated ribs created by the thoracoplasty procedure.

Recently, thoracoscopic or open anterior spinal arthrodesis alone has become a more accepted option in the treatment of thoracic adolescent idiopathic scoliosis. Several studies have focused on pulmonary function test changes after anterior spinal arthrodesis with a rib resection in patients with adolescent idiopathic scoliosis[7,15,35,36]. The pulmonary function test values after anterior spinal arthrodesis with a rib resection demonstrated no change[15] or a decrease at the time of the final follow-up[7,35,36].

The current study showed that the patients in Group 3 (anterior spinal arthrodesis) demonstrated a significant decrease in percent-predicted pulmonary function at the mean five-year follow-up evaluation. This suggests that an open anterior approach requiring resection of the rib, with transection and scarring of the respiratory muscles and postoperative pleural adhesions including the intercostal muscles and diaphragm (six patients), may have a deleterious effect on pulmonary function for as long as five years postoperatively. We had too few patients in this group to determine whether there was a difference between the ten patients who had a thoracotomy for correction of a thoracic curve and the six patients who were managed with a thoracoabdominal approach for correction of a thoracolumbar or lumbar curve. Although six patients with thoracic hypokyphosis (a sagittal Cobb angle between T5 and T12 of <10°) demonstrated a decrease in pulmonary function despite an increase in thoracic kyphosis (from 1° to 22° in the sagittal Cobb angle), they are too few to determine whether increasing kyphosis might enhance pulmonary function.

Several studies have focused on changes in the pulmonary function tests after a combined anterior and posterior spinal arthrodesis in patients with adolescent idiopathic scoliosis, demonstrating no change in values[15,37] or a decrease at the time of the final follow-up[6,34,35]. The current study showed that the patients in Group 4 (anterior and posterior spinal arthrodesis) demonstrated no significant change in absolute pulmonary function; however, a significant decrease in the percent-predicted forced vital capacity and a tendency toward a decrease in the percent-predicted forced expiratory volume in one second were detected at an average of five years postoperatively.

The strengths of this study include a population of patients who were similar in terms of age (all were between ten and eighteen years old), diagnosis, severity of the Cobb angle (ninety-eight patients had between 45° and 75°), and thoracic kyphosis (eighty-five patients had normal kyphosis); comparison with the standardized percent-predicted values based on large population reference data corrected by arm span, age, sex, and race; and the use of a senior spinal surgeon reviewer who was completely independent of the surgical team. It is still unknown whether a 10% to 20% reduction in pulmonary function at five years after thoracotomy or thoracoplasty has any clinical importance and whether moderate restrictive pulmonary function has any clinical or functional importance. However, preservation of possible maximal pulmonary function is recommended, considering the natural deterioration of pulmonary function as a result of aging, smoking, asthma, and other pulmonary problems.

Appendix

eA Tables presenting the forced vital capacity and forced expiratory volume in one second for all four patient groups over time are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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