Respiratory Mechanics in Anesthetized Young Patients with Kyphoscoliosis*

Immediate and Delayed Effects of Corrective Spinal Surgery


To our knowledge, the effects of corrective spinal surgery on total respiratory mechanics and its components in anesthetized patients with kyphoscoliosis have not been previously reported in detail. We studied 13 patients with kyphoscoliosis; their mean (± SD) age was 24.7±2.1 years; eight underwent anterior and posterior spinal fusions (AF and PF, respectively) two weeks apart (group A), four underwent PF alone (group B), and one had a three-stage procedure. Mean total respiratory elastance (Ers), static and dynamic lung elastance (Est,L and Edyn,L, respectively), chest wall elastance (Ew), and lung resistance (RL) were derived according to previously described methodology. In group A, Ers and Ew increased by 39 percent and 58 percent, respectively, following AF and by 20 percent and 129 percent following PF, while Est,L and Edyn,L did not change or declined following PF. Lung resistance increased 19 percent and 41 percent by the end of AF and PF, respectively, in group A. In group B, Ew more than doubled, resulting in a 39 percent increase in Ers. Increases in Ers, Ew, and respiratory flow resistance observed at the time of spinal corrective surgery for kyphoscoliosis may result from rib cage trauma and changes in airway caliber related to microatelectasis and uneven distribution of mechanical properties within the lungs. Spinal correction results in immediate and short-term deterioration of respiratory mechanics measured under anesthesia.

The deleterious effects of thoracic spinal deformity on respiratory mechanics have been reported by several investigators, most of whom have demonstrated decreases in lung volumes and peak flow rates in conscious patients. In only one study was total respiratory elastance and total flow resistance under anesthesia assessed before and after corrective procedures for idiopathic scoliosis. Lin and colleagues demonstrated that, at least in horizontal postures, total respiratory elastance and resistance in adolescents increased, on average, by 34.2 percent and 31.8 percent, respectively (both significant at p<0.01). By contrast, patients undergoing other orthopedic operations demonstrated no significant changes in respiratory mechanics. Patients in the study of Lin and coworkers underwent a single-stage procedure consisting of a posterior approach with insertion of Harrington rods. In recent years, a two-stage procedure, of which the first stage consists of a transthoracic, retroperitoneal anterior fusion followed by an extrathoracic posterior fusion, has been adopted in patients in whom there is a severe thoracic (or thoracic and lumbar) curve. This procedure has been advocated to facilitate rehabilitation and eliminate the time spent in a body cast. By its very nature, anterior spinal fusion is a riskier operation associated with a higher incidence of postoperative complications such as atelectasis, pleural effusions, and respiratory failure. No measurements of respiratory mechanics have been obtained in patients undergoing anterior fusion for thoracic scoliosis. In addition, there have been no reports of the partitioning of total respiratory elastance into its lung and chest wall components in such patients.

To investigate the effects of this procedure in detail, we measured total respiratory elastance and resistance and their components in a group of anesthetized patients undergoing two-stage anterior and posterior spinal fusions for their scoliosis. The effects of surgery were also compared with those in a smaller group undergoing posterior fusion alone, and in one patient undergoing a special three-stage procedure.

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\[ V = \text{flow}; \ V = \text{volume}; \ P_t = \text{tracheal pressure}; \ P_s = e\text{osphageal pressure}; \ P_t = \text{transpulmonary pressure}; \ E_r = \text{respiratory elastance}; \ \sigma = \text{coefficient of variation}; \ P_s = \text{static lung recoil pressure}; \ E_s, L = \text{static lung elastance}; \ E_w = \text{chest wall elastance}; \ E_d = \text{dynamic lung elastance}; \ R_L = \text{lung resistance} \]
MATERIALS AND METHODS

Thirteen nonsmoking patients with thoracic scoliosis alone or kyphoscoliosis underwent one of three different corrective procedures: (1) group A, eight patients underwent a two-stage, transthoracic anterior spinal fusion because of severe thoracic and lumbar scoliosis or kyphosis (subjects 1 through 8, Table 1). In this procedure, the lower thoracic and lumbar spine is exposed. The diaphragm is removed from its costal attachments. Intervertebral disks are removed. Following impact of bone graft from rib or iliac crest into the disk spaces, instrumentation of the vertebral bodies (of various types) are used for correction and stabilization. After reattachment of the diaphragm to its costal insertions, a chest tube is left in place for pleural drainage, and the chest is closed. (2) Group B: Four patients underwent a single-stage posterior fusion, the standard operation performed in most scolioses of moderate degree. The spine is exposed over the area of the curve, the posterior bony elements are decorticated, and bone graft is applied. Various instrumentation types are usually used to correct the curve, stabilize the spine, and aid fusion. (3) One patient (patient 13) who had a severe thoracic kyphosis underwent a three-stage procedure, in the following order: (a) transthoracic anterior decompression of the thoracolumbar spine with application of a halo ring, (b) posterior spinal fusion from the upper thoracic spine to L4 with Harrington rod instrumentation and bone grafting, and (c) transthoracic anterior spinal fusion, with autogenous strut grafting of the thoracolumbar spine. In all patients in whom multiple-stage procedures were performed, the operations were spaced two weeks apart.

All patients were free of cardiorespiratory symptoms of impairment. None of the patients smoked. Their mean (±SD) ages averaged 24.7 ± 7.6 years. Their physical characteristics are listed in Table 1. Mean (±SD) thoracic scoliosis was 65.5° ± 33.1° (measured by method of Cobb) and kyphosis was 54.3° ± 38.2°. Forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1) were measured with the patient seated prior to surgery with a 9-L Collins spirometer corrected for BTPS (Warren E. Collins, Brain-tree, MA). The highest of three FVC maneuvers was selected as the representative value for each subject. Mean (±SD) FVC and FEV1 of nine patients was 47.3 ± 2.2 percent and 51.8 ± 2.5 percent.

Table 1—Preoperative Physical Characteristics, Anesthetic Agents, Other Medications in 13 Patients with Spinal Deformity*

<table>
<thead>
<tr>
<th>Patient No./ Age</th>
<th>Diagnosis</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Thoracic Scoliosis, Deg</th>
<th>Thoracic Kyphosis, Deg</th>
<th>FVC, L</th>
<th>FEV1, L</th>
<th>Anesthetic (60%N2O-40%O2, 1.0 MAC)</th>
<th>Additional Medications</th>
<th>Interval between Preoperative and Postoperative Studies, h</th>
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<tbody>
<tr>
<td>Group A: Anterior and Posterior Fusion</td>
<td></td>
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</tr>
<tr>
<td>1/23/M</td>
<td>CP</td>
<td>163</td>
<td>38.6</td>
<td>117</td>
<td>2</td>
<td>0.90</td>
<td>0.90</td>
<td>Isoflurane</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2/23/F</td>
<td>CP</td>
<td>168</td>
<td>34.1</td>
<td>75</td>
<td>29</td>
<td>2.10</td>
<td>1.90</td>
<td>Halothane</td>
<td>—</td>
<td>Meperidine, 70 mg</td>
</tr>
<tr>
<td>3/26/F</td>
<td>CP</td>
<td>—</td>
<td>34.1</td>
<td>20</td>
<td>93</td>
<td>—</td>
<td>—</td>
<td>Halothane</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4/21/F</td>
<td>CP</td>
<td>178</td>
<td>55.5</td>
<td>41</td>
<td>80</td>
<td>1.05</td>
<td>0.70</td>
<td>Isoflurane</td>
<td>Fentanyl, 1.075 mg</td>
<td>—</td>
</tr>
<tr>
<td>5/16/M</td>
<td>CP</td>
<td>—</td>
<td>41.4</td>
<td>63</td>
<td>—</td>
<td>—</td>
<td>Enflurane</td>
<td>Fentanyl, 0.1 mg</td>
<td>—</td>
<td>7.0</td>
</tr>
<tr>
<td>6/38/M</td>
<td>CP</td>
<td>—</td>
<td>50.0</td>
<td>95</td>
<td>69</td>
<td>—</td>
<td>—</td>
<td>Isoflurane</td>
<td>—</td>
<td>—</td>
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<tr>
<td>7/18/M</td>
<td>CMT</td>
<td>198</td>
<td>45.6</td>
<td>54</td>
<td>78</td>
<td>3.20</td>
<td>2.70</td>
<td>Enflurane</td>
<td>Meperidine, 60 mg</td>
<td>Meperidine, 50 mg</td>
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<td>8/30/M</td>
<td>Idiop.</td>
<td>175</td>
<td>69.1</td>
<td>108</td>
<td>5</td>
<td>2.90</td>
<td>2.60</td>
<td>Isoflurane</td>
<td>Meperidine, 150 mg</td>
<td>Fentanyl, 0.45 mg</td>
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<tr>
<td>Group B: Posterior Fusion Alone</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>9/17/F</td>
<td>CP</td>
<td>—</td>
<td>38.1</td>
<td>76</td>
<td>80</td>
<td>—</td>
<td>—</td>
<td>Isoflurane</td>
<td>—</td>
<td>Meperidine, 70 mg</td>
</tr>
<tr>
<td>10/31/M</td>
<td>Idiop.</td>
<td>160</td>
<td>45.6</td>
<td>83</td>
<td>14</td>
<td>2.25</td>
<td>1.90</td>
<td>Enflurane</td>
<td>Fentanyl, 0.15 mg</td>
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</tr>
<tr>
<td>11/15/F</td>
<td>Idiop.</td>
<td>155</td>
<td>53.2</td>
<td>52</td>
<td>35</td>
<td>2.10</td>
<td>2.00</td>
<td>Enflurane</td>
<td>Meperidine, 80 mg</td>
<td>—</td>
</tr>
<tr>
<td>12/34/F</td>
<td>Idiop.</td>
<td>152</td>
<td>47.7</td>
<td>63</td>
<td>43</td>
<td>2.90</td>
<td>2.60</td>
<td>Enflurane</td>
<td>—</td>
<td>Meperidine, 140 mg</td>
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<tr>
<td>13/20/F</td>
<td>TB.Sp</td>
<td>157</td>
<td>32.7</td>
<td>0</td>
<td>122</td>
<td>1.20</td>
<td>1.00</td>
<td>Isoflurane</td>
<td>Fentanyl, 0.1 mg</td>
<td>Fentanyl, 0.1 mg</td>
</tr>
<tr>
<td>Mean ±SE</td>
<td></td>
<td></td>
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</tbody>
</table>

*Definition of abbreviations: Deg = degrees; MAC = minimal alveolar concentration; AF = anterior fusion; PF = posterior fusion; ASCD = anterior spinal cord decompression; ASG = anterior strut grafts; CP = cerebral palsy; CMT = Charcot-Marie-Tooth disease; Idiop = idiopathic scoliosis; TB.Sp = tuberculous spondylitis.
predicted, respectively.11 Four patients could not provide spirometric measurements because of mental retardation or severe muscle spasticity. After approval for the study by our institutional research review board, informed consent was obtained from all subjects of their legal guardians.

Flow (V) was recorded with a heated No. 1 Fleisch pneumotachograph (Fleisch, Lausanne, Switzerland) connected to a breathing circuit and a Validyne MP 45-1 differential pressure transducer (Validyne Corp, Northridge, CA). Volume (V) was obtained by integration of the flow signal (Gould Brush integrator, Gould Instruments, Cleveland, OH). Tracheal pressure (Ptr) was measured through a polyethylene catheter (length, 90 cm; internal diameter, 1.4 mm) attached to a side port mounted at the distal end of the anesthesia circuit, using another Validyne MP 45-1 differential pressure transducer. The equipment dead space was 100 ml (not including the endotracheal tubes). Inspired O2 concentration was monitored with an IL-402 oximeter (Instrumental Laboratories, Lexington, MA). A three-way valve was used to occlude the airway opening or connect the endotracheal tube to the anesthesia circuit or to the room.

Esophageal pressure (Pes) was measured by means of an esophageal balloon (length, 5 cm; internal diameter, 1.5 cm when empty) sealed over a polyethylene catheter (length, 90 cm; internal diameter, 1.5 mm) and filled with 0.5 ml of air. The balloon-catheter system had a pressure-volume curve flat over a volume range between 0.2 and 5 ml. It was connected to a third Validyne MP 45-1 pressure transducer. The Pes and Ptr systems were tested with a sine-wave pressure generator according to the method of Baydur and colleagues,12 and they were found to have a flat frequency response of as high as 22 cps. The balloon was introduced into the stomach by means of a wide-bore esophageal catheter. The validity of the esophageal balloon technique for recording esophageal pressure and measuring respiratory mechanics in supine patients was tested according to the "occlusion test" method of Baydur and colleagues12 and Higgs and coworkers.13 The balloon was withdrawn to a position in the esophagus where (1) cardiogenic oscillations were the smallest, and (2) where the ratio of change in esophageal pressure to change in tracheal pressure (ΔPes/ΔPtr) measured during inspiratory occlusive efforts at end-expiration was 1.00 or within ±10 percent of this ratio.14

Transpulmonary pressure (Ptrp) was obtained by subtracting Pes and Ptr. All signals were amplified and recorded on a four-channel recorder (Gould Brush 2400, Gould Instruments, Cleveland, OH).

**Procedure**

All patients were studied in the supine position. Before each stage of surgery, they were premedicated with atropine (0.3 to 0.4 mg), hydromorphone (0.7 mg/kg), and meperidine (1 mg/kg). Induction was achieved 15 minutes later with thiopental given alone intravenously (6 to 10 mg/kg) or in combination with Fentanyl (0.1 to 1.1 mg). Curare (3 to 8 mg), succinylcholine (1.5 mg/kg), or pancuronium (0.04 to 0.1 mg/kg) was administered to facilitate intubation. Anesthesia was maintained constant through the endotracheal tubes at a minimal alveolar concentration15 of approximately 1.0 with isoflurane, enflurane, or halothane in 60 percent N2O-40 percent O2 (Table 1). Every effort was made to administer the same anesthetic mixture and concentration during all stages of surgery for each patient.

Suctioning was performed immediately after intubation and induction and before obtaining measurements of respiratory mechanics. In addition, passive hyperinflations were given immediately following intubation and induction, and equaled about twice the average tidal volume (about 0.4 to 0.6 l). Thereafter, sighs were limited to every 20 minutes during the period of study, and no measurements were made within 3 minutes of any sigh. Once respiratory muscle paralysis had worn off (demonstrated by the onset of spontaneous respirations), the patient was allowed to breathe until a stable ventilatory pattern was achieved (a period of 10 to 15 minutes). A series of five to ten end-inspiratory airway occlusions were then obtained at eight to ten breath intervals. Each occlusion was held until the subject relaxed his respiratory muscles, as demonstrated by the presence of a "plateau" in Ptr reflecting the elastic recoil pressures of the total respiratory system.16,17 As soon as a stable Ptr plateau was reached, the occlusion was suddenly released, and the patient was allowed to exhale passively to end-expiratory volume (Fig 1). The airway occlusions at end-inspiration were held as short as possible (about 1 s) to avoid active inspiration before the passive exhalation was completed. Demonstration of expiration to end-expiratory volume was supported by the following: (1) an end-expiratory pause (ie, a period of zero flow toward the end of expiration, as shown by the example in Fig 1), indicating a return to the elastic equilibrium point of the respiratory system, and (2) when in the same subjects the airways were occluded at end-expiration, Ptr during the occluded expiration returned to zero (atmospheric) pressure.18,19 The end-inspiratory volume was deliberately varied (volume range between Vt and 50 percent Vt) to demonstrate a linear relationship between V and Ptr (ie, the constancy in respiratory elastance [Ers]). Patients were then allowed to breathe another 15 to 20 minutes during which time no further occlusions were performed, and tracings of V, V, and Pes were obtained for later analysis of pulmonary flow resistance and dynamic elastance.

Measurements were made twice during each stage, the first time just before surgery commenced, starting at the onset of steady-state spontaneous breathing, and the second time, just after completion of surgery but before anesthesia was allowed to wear off. Thus, preoperative and postoperative measurements of respiratory mechanics could be compared between different stages of surgery.

**Figure 1.** Tracing of flow (V), volume (V), esophageal pressure (Pes), and tracheal pressure (Ptr) in a spontaneously breathing anesthetized patient with kyphoscoliosis. In top tracing, arrows indicate points of airway occlusion and release at end-inspiration (Ers = total respiratory system elastance; Est = static lung elastance; Vt = tidal volume).
In group A, the interval between the preoperative and postoperative measurements averaged (± SD) 7.1 ± 0.9 h and 6.7 ± 0.9 h during the anterior and posterior fusions, respectively. The interval in group B (posterior fusion alone) was 6.4 ± 0.9 h. The interval between preoperative and postoperative measurements in subject 13 was about 7 h in all three stages. To assure that lung mechanics were measured under similar conditions each time, the esophageal balloon was placed in the esophagus with its bubble of air at the same level above the carotidoesophageal junction with the help of markings on its catheter. Air volume in the balloon was checked frequently throughout the study to assure that it remained at 0.5 ml.

Data Analysis of Total Respiratory Elastance and Its Components

The elastic and flow-resistive properties of the respiratory system were measured by the method of Zin and coworkers in anesthetized animals and Behrakis and colleagues in anesthetized humans.

Passive elastance of the total respiratory system (Ers) was determined by dividing the elastic recoil pressure of the total respiratory system during relaxation (Pst, r) by the corresponding volume above the end-expiratory volume (Fig 1). By oscillography, the airway at different volumes between end-expiratory volume and Vr, Ers was shown to be constant. Mean coefficient of variation (cv) of Ers for all patients undergoing their first (or only) stage of surgery was 8.1 percent and 10.7 percent, preoperatively and postoperatively, respectively. Mean cv for group A undergoing their second stage (posterior fusion) was 8.4 percent and 10.7 percent, preoperatively and postoperatively, respectively. Ers, L was taken as the value of Pes at the end of relaxation-expiration, allowing for the pause of zero flow at the end of expiration. Static lung elastance (Est, L) was measured by dividing the change in Ptp (Ptr-Pes) by the corresponding volume at end-inspiration. These measurements correspond to the same maneuvers during which Ers was measured (Fig 1). Chest wall elastance (Ew) was obtained by subtracting Est, L from Ers. Dynamic lung elastance (Edyn, L) was computed by dividing changes of Ptp by the corresponding volume changes between points of zero flow during steady-state breathing.

Lung Resistance

Lung resistance (RL) was obtained by dividing the difference in Ptp by the sum of inspiratory and expiratory flow rates at iso-volume points at mid thoracic volume during spontaneous breaths and subtracting the flow resistance of the endotracheal tube, pneumotachograph, and connectors (Res). In such computations, the tube equipment flow-resistance constants, K and Kz, derived from Rohrer’s relationship were subtracted from corresponding values for intubated patients during the iso-volume method to provide RL. The validity of this subtraction method to obtain intrinsic RL has been previously discussed in detail.

When appropriate, results were compared with and discussed in the light of a previous study by these authors in which ten normal young adults were studied under similar conditions, using identical methods.

Statistical Analysis

Within group A, the Wilcoxon signed-rank test was applied to statistically assess changes in each of the response parameters with respect to the following: (1) values obtained prior to vs immediately following anterior fusion; (2) values obtained prior to vs immediately following posterior fusion; and (3) values obtained prior to anterior fusion vs prior to posterior fusion. A nonparametric test was selected because of the skewed nature of many of the difference score distributions. Due to the limited power resulting from the small number of subjects (n = 8), both marginally significant (0.05 < p < 0.10) and conventionally significant (p < 0.05) test results are noted in Table 2.

Because group B contained only four patients, no attempt was made to assess the statistical significance of pre-to-post surgery changes; however, when present, trends were noted and are discussed in the following sections.

Results and Discussion

Elastance

In group A, end-inspiratory volumes used to compute Ers, Est, L, and Ew were randomly varied, and there was no statistically significant change between their mean preoperative and postoperative values of the anterior fusion (308 ml and 277 ml, respectively). However, posterior fusion resulted in a mean 34 percent increase in Vr (282 ml to 377 ml) (p < 0.10). In contrast, the Vr used to compute Edyn, L and RL decreased from 319 to 270 ml (p < 0.05) at the end of anterior fusion, but increased from 288 to 360 ml (statistically not a significant change) by the end of the posterior fusion. Frequency increased 43 percent (from 19.8 to 28.3 breaths per minute) at the end of anterior fusion (p < 0.05), but did not change significantly by the end of the posterior fusion. The mean intragroup coefficients of variation for Vr were 9.9 percent and 9.1 percent at the beginning and end of the anterior fusion, respectively, and 14.8 percent and 12.4 percent at the beginning and end of the posterior fusion, respectively.

Values of static lung recoil, total respiratory, lung, and chest wall mechanics for group A are shown in Table 2. Overall, mean Ers, L remained unchanged between surgeries and the beginning and end of each surgery, although there was variability in direction and magnitude among patients. The Ers and Ew increased by a mean of 39 percent (p < 0.05) and 58 percent, respectively, by the end of the first operation. The Ers and Ew also increased by 20 percent and 129 percent at the end of the posterior fusion. The Est, L tended to increase by a mean of 25.8 percent at the end of the anterior fusion but had decreased 36 percent by the end of the posterior fusion. The Edyn, L did not change appreciably throughout the two weeks except at the end of the posterior fusion at which time it tended to decrease by 37 percent. In this connection, breathing frequency increased 43 percent at the end of the anterior fusion (p < 0.05) and did not change significantly by the time of end of the posterior fusion.

In line with previous reports of conscious patients with kyphoscoliosis, breathing in our patients was rapid and shallow (Table 2). Mean Vr was 5.5 percent lower than mean Vr in our previously reported cases of normal anesthetized subjects, while f was 16.5 percent higher than 7 reported in the same group of patients.

In group B, mean end-inspiratory volume used to measure Ers, Est, L, and Ew were not significantly different between the start and end of surgery (254
ml and 272 ml, respectively). Likewise, mean tidal volume used to measure Edyn, L and RD did not change significantly (261 ml and 293 ml, respectively). The mean intrathoracic cv of Vt were 14.0 percent and 9.3 percent at the beginning and end of posterior fusion, respectively. The Ers and Ew in group B increased by 39 percent and 115 percent, respectively.

In patient 13, end-inspiratory volume decreased from 225 to 188 ml at the end of her transthoracic anterior spinal cord decompression, and remained unchanged at 193 ml through the posterior spinal fusion with application of Harrington rods. After recovery from the second operation, her Vt increased by 29 percent, then fell again to 0.19 L or by 16 percent of the preoperative value before the first operation (Table 2). After a transient increase to as high as 45 percent above presurgical value, the Ers fell to its baseline value at the end of the third operation. The increase in Ers was accounted for by more than doubling of Est, L observed at the beginning of the second operation. Similarly, Edyn, L more than doubled at the beginning of the second operation before declining to preoperative values.

In normal nonanesthetized sitting subjects, in the resting tidal volume range, Ers amounts to about 0.45 cm H2O for each percentage change of vital capacity. 24 In those patients whose VC could be measured, preoperative Ers amounted to 0.80 cm H2O per percent change of vital capacity, similar to values previously reported for normal anesthetized subjects whose cases were reported by our group, 16 Behrakis and colleagues, 16, 18 and Westbrook and coworkers 25.
(0.92, 1.03, 0.81, and 0.53 cm H₂O/percent VC, respectively). These findings suggest that the increased Ers in patients with kyphoscoliosis is due to the same factors that increase Ers in supine, anesthetized individuals (normal Ers in upright conscious subjects 10 cm H₂O L⁻¹). Functional residual capacity during anesthesia is decreased, attributed to a change in the pressure-volume characteristics of the chest wall,⁵,⁶ gas trapping,⁷ and increased stiffness of the lung, possibly associated with a decrease in surfactant production and atelectasis.⁸ Other mechanisms cited have included a reduction in amplitude of rib cage expansion, loss of rib cage stability, and paradoxic thoracoabdominal motion.⁹

The overall 39 percent increase in Ers following anterior fusion in eight patients (group A) is in contrast to our previous study of ten normal anesthetized subjects undergoing nonthoracic orthopedic surgery.¹⁵ The latter group demonstrated no change in Ers at the end of their procedures, regardless of time elapsed under anesthesia (which ranged from 0.42 to 5.00 h). All conditions under which the measurements were made in both studies were kept the same, including the interval and numbers of sighs during anesthesia. These findings suggest that thoracotomy results in an increase in Ers beyond that which might be expected to occur with anesthesia. Whether, in the case of those with kyphoscoliosis undergoing anterior fusion, the trauma to the rib cage contributed to the increase in Ew (observed in seven of eight patients here [Table 2]), can only be speculated. The direction and magnitude of change in Est,L in this group of patients was inconsistent and variable, suggesting that lung injury was not the major factor contributing to the increase in Ers. These findings are somewhat different than in patients with ischemic heart disease undergoing cardiopulmonary bypass in whom the increase in Ers is due to a consistent increase in Est,L,⁹,¹⁰ attributed to increases of extravascular lung water and alveolar collapse.¹¹,¹² Apart from the works of Auler and colleagues¹³ and Zin and coworkers,¹⁴ ours is the only study in which Ers has been partitioned into Est,L and Ew in both before and after patients undergoing thoracotomy.

The 39 percent increase in Ers observed in the four patients who underwent posterior fusion alone (group B, Table 2) is similar to the results obtained by Lin and co-workers.⁹ However, there were some methodologic differences between their study and ours. The patients of Lin and colleagues were adolescents (mean age, 14 years) whose mean total Ers was only 18.2 cm H₂O L⁻¹, 52 percent less than the corresponding mean in our young adult population. Indeed, their mean Ers is even 20 percent lower than that reported for normal supine anesthetized young adults.¹⁵,¹⁶ Finally, Lin and colleagues¹⁴ obtained their measurements during anesthesia-paralysis while in our patients they were obtained during spontaneous ventilation, after paralysis had worn off.

The preoperative percentage ratio of Est,L to Ers in all 13 patients averaged 58 percent. In normal awake supine individuals, this ratio tends to be lower than 50 percent,²⁴,²⁵,²⁶ indicating that in anesthetized subjects Est,L tends to increase proportionately more than Ew, reflecting the effects of anesthesia on lung parenchyma (atelectasis, etc). On the other hand, Est,L/Ers in our patients was somewhat lower than values reported for normal anesthetized subjects,¹⁹,²⁵,²⁶,²⁷,²⁸ reflecting the higher Ew compared with Est,L in anesthetized patients with kyphoscoliosis. The high Ew of our patients (15.0 cm H₂O L⁻¹) probably reflects increased rib cage stiffness due to deformity, as postulated by Bergofsky et al.¹ In our subjects there was substantial intersubject variability of Est,L/Ers (mean cv: 33 percent, range: 16 to 17 percent). Similar intersubject differences in Est,L/Ers have been previously reported by other investigators.¹⁹,²⁵,²⁶,²⁷,²⁸,²⁹,³⁰

In both groups A and B, Est,L/Ers decreased by the end of both surgical stages. In particular, the decrease was marked following posterior fusion (24 percent and 25 percent, in group A and group B, respectively). These findings reflect the more profound effect on Ew produced by the posterior fusion. The Est,L/Ers tended to be higher before and between each stage of surgery in patient 13, probably more a reflection of her relatively low vital capacity than of her severe kyphosis.

Preoperative dynamic lung elastance, Edyn,L, was, overall, 12 percent higher than corresponding values of Est,L and is in line with previous reports indicating frequency of pulmonary compliance during anesthesia.²⁰ Changes in Edyn,L generally paralleled changes in Est,L.

**Resistance**

Mean RL at the beginning of the study was more than three times the value previously reported by our group¹⁵ for normal subjects (1.39 cm H₂O L⁻¹s) and almost seven times the values reported by Behrakis and coworkers¹⁹ (0.8 cm H₂O L⁻¹s). Several factors influence the increase in RL in anesthetized patients, including lung volume,²¹,²⁷ type and dose of premedication and anesthetics used,²⁶,²⁷,²⁸,²⁹ and breathing frequency.³⁰ The higher values of RL in our kyphoscoliosis patients compared with normal controls most likely reflect the curvilinear relationship between lung resistive pressure and flow. This finding has previously been observed in anesthetized patients with valvular heart disease undergoing open heart surgery²⁶,²⁹ and has been attributed to hemodynamically unfavorable conditions causing an uneven distribution of mechanical properties within the lungs. In our patients, there
was no clinical evidence of left ventricular failure, but microatelectasis with small airway involvement may have contributed to the high RL.\textsuperscript{25,27} In addition, both meperidine and Fentanyl are known to cause large airway constriction.\textsuperscript{26,29} Overall, there was no statistical difference between the preoperative and postoperative measurements in RL during each operation. There was a marginally significant increase in RL in the two weeks that elapsed between the anterior and posterior fusions in group A. This finding may also reflect the effects of microatelectasis and uneven time constants among different regions within the lung. By contrast, in our previous study of normal anesthetized subjects undergoing nonthoracic surgery, we found that preoperative values of RL increased by a mean of 45 percent during anesthesia; this was attributed to accumulated airway secretions.\textsuperscript{15} Finally, we found no correlation between surgery-related changes in total Ers (and its components) and resistance and changes in the degree of curvature of the scoliosis and/or kyphosis (Table 2).

Of incidental interest, we were able to obtain follow-up FVC and FEV\textsubscript{1} data in five of the nine patients (patients 4, 7, 8, 12, and 13) who had preoperative pulmonary function measurements from 1.7 to 3.0 years following surgery. Only one patient (patient 4) demonstrated an increase in FVC and FEV\textsubscript{1} (of 24 percent and 57 percent, respectively). The other four patients demonstrated mean decreases in FVC and FEV\textsubscript{1} of 19.5 percent and 21.2 percent, respectively. Furthermore, there was no correlation between the change in the angle of curvature measured immediately postoperatively and the changes in vital capacity recorded in these patients. This is in keeping with previous work that has also failed to relate lateral spinal curvature with other aspects of pulmonary function because of the variable influences of etiology of scoliosis, age, growth rate, and associated muscle weakness. Our findings are similar to those of other studies that have demonstrated that surgical correction of scoliosis does not improve vital capacity and, in fact, may result in a decrease in pulmonary function in patients with paralytic and nonparalytic (idiopathic) scoliosis who are followed up for up to ten years after surgery.\textsuperscript{5,6,20,41} Thus, while spinal correction may resolve back pain and improve cosmetic appearance, particularly in young adults, few longitudinal studies are available that prove that spinal correction by fusion or by external supports or traction leads to real improvement of pulmonary function. While our immediate postoperative results may not have a direct relationship to such long-term findings, the failure to improve and, indeed, a deterioration in respiratory mechanics must be reconciled against the present practice of performing spinal fusion at adolescence well after the time of when alveolar development is complete.\textsuperscript{6}

In summary, this study has, for the first time, systematically measured changes in total respiratory mechanics and their components in young adults before and after surgery (single or multiple stage) for correction of spinal curvature. In general, an increase in preoperative static chest wall elastance was accompanied by corresponding increases in static and dynamic lung elastance and lung resistance. We were unable to distinguish any trend in postoperative changes in respiratory mechanics in relation to whether the nature of their scoliosis was paralytic or not. Finally, changes in respiratory mechanics did not correlate with roentgenographically measured changes in thoracic spinal curvature. These immediate and short-term findings, in conjunction with previous works describing minimal improvement or even decline in pulmonary function over the long-run, suggest a need for reevaluation of the indication for spinal correction for preventing deterioration in lung volumes and respiratory mechanics.

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CHEST / 97 / 5 / MAY, 1990 1163
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