The Effect of Corrective Surgery on Pulmonary Function in Scoliosis

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ABSTRACT: **Pulmonary function was studied in thirty-five patients before, during, and immediately after major orthopaedic operations. One group of twenty patients had corrective procedures for idiopathic scoliosis. Fifteen patients had operations involving the extremities. In the patients with scoliosis we found that pulmonary mechanics, as expressed by flow resistance and elastic compliance, deteriorated during the operation; that pulmonary right-to-left shunting increased and arterial oxygen tension on air decreased immediately postoperatively; and that vital capacity was greatly reduced after the operation. No significant changes took place in the rest of the patients. We concluded that corrective operations for idiopathic scoliosis are associated with major reductions of pulmonary function in the immediate postoperative period, so that postoperative respiratory failure would be a risk in patients who had compromised pulmonary function preoperatively. We therefore recommend pulmonary function testing preoperatively and outline one approach to this problem.**

Patients with severe deformities of the spine often have had their pulmonary function compromised. In these patients we find decreased compliance [20], increased work of breathing related to the degree of angulation [11], increased pulmonary artery pressure [12], decreased vital capacity, and an abnormal relationship between pulmonary ventilation and perfusion [13,18]. Corrective surgery in these patients rarely improved their pulmonary function [13,18], but it may have helped to prevent further deterioration. In patients with decreased respiratory reserve, operative procedures in general, and operations to correct spinal curves in particular, may present an acute postoperative threat to the patient by further compromising pulmonary function.

We therefore designed the present study to determine the immediate effect of corrective surgery on pulmonary function in scoliotic children. We measured parameters of pulmonary function on the day before and on the day after surgery. Since anesthesia alone may affect the physiology of the lung [10], pulmonary function was also assessed after the induction of anesthesia but before the start of the operation, and again after the conclusion of the operation but before termination of anesthesia.

Method

Fifteen girls and five boys with idiopathic scoliosis were studied. The average age was fourteen years (range, five to eighteen years) and the average degree of angulation, 64 degrees (range, 40 to 80 degrees). The surgical procedure lasted an average of five hours and resulted in correction of the curve by an average of 40 per cent (range, 20 to 65 per cent). All except one of these patients were in Risser casts at the time of the preoperative and postoperative measurements. However, postoperatively the Risser cast was bivalved. In all but four of the patients with scoliosis Harrington rods were inserted during the operation. In addition, we studied fifteen patients, fifteen to twenty-eight years

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old, who were healthy except for orthopaedic conditions that required operations on the extremities. These operations lasted about two and a half hours.

All patients were lightly premedicated with a barbiturate and atropine. In the operating room anesthesia was induced with the patient in the supine position. Thiopental was injected intravenously and tracheal intubation was performed with the aid of succinylcholine. Anesthesia was maintained with halothane, nitrous oxide, and oxygen. After the establishment of an adequate depth of anesthesia, the pulmonary function tests were done in all patients. The patients with scoliosis then were turned to the prone position on a frame [17] that supported the lateral aspects of the body and pulmonary testing was repeated. After the surgical incision had been closed pulmonary function was again assessed. In the patients with scoliosis this was done first in the prone position on the frame. In all patients pulmonary function was measured in the supine position prior to discontinuation of anesthesia.

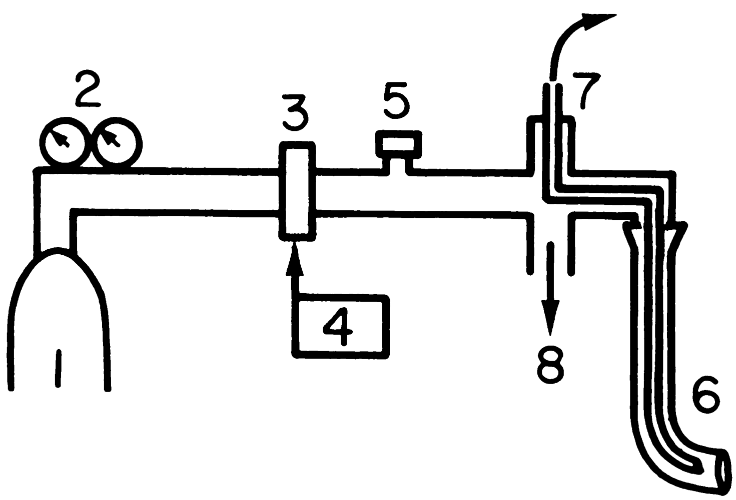

FIG. 1

Machine used for measurement of total flow resistance and total static compliance. Oxygen cylinder (1), reducing valve (2), solenoid valve (3), timer (4), safety valve (5), endotracheal tube (6), and recording catheter to transducer and recorder (7) and to anesthesia circuit (8).

The series of pulmonary function measurements included total flow resistance of the airway (TFR), total static compliance of lungs and chest wall (TSC), alveolar-arterial oxygen tension difference on 100 per cent oxygen ($[A\text{-}a]DO_2$), and dead space-to-tidal volume ratio (V_D / V_T). In addition we measured the alveolar-arterial oxygen tension difference, the total effective compliance (TEC), the arterial oxygen tension on air breathing (Pa_{O_2}), and the vital capacity (VC) one day before and one day after surgery.

The intraoperative measurements were made after the patient had been paralyzed with succinylcholine. The technique [1,6] in principle involved a sudden inflation of the lungs from the end-expiratory position with an oxygen flow of one liter per second. The duration of the gas flow was preset to last from 0.1 to one second in order to deliver a volume equal to twice the tidal volume of the patient as determined from the Radford nomogram. The apparatus is diagrammed in Figure 1. The intratracheal pressure was continuously recorded and was used for calculation of total flow resistance and total static compliance (Fig. 2). The uncorrected total flow resistance (in centimeters of water per liter per second) was read as the pressure at which the flow of gases into the lungs started. This measurement was then corrected by subtraction of the value for the same measurement performed in the isolated endotracheal tube. The total static compliance in milliliters per centimeter of water was assessed two to five seconds after the standard lung inflation, before the system was opened to the anesthesia circuit. At that time the pressure

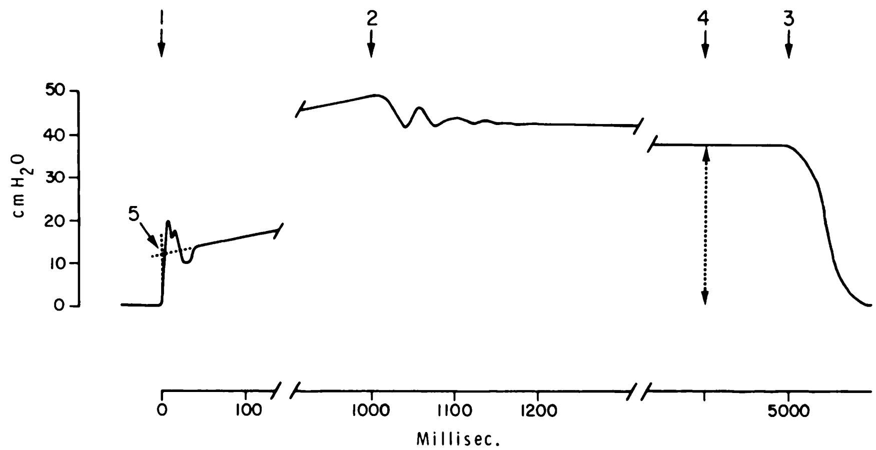

FIG. 2

Intratracheal pressure recording during constant-flow inflation. Flow — one liter per second for one second. Start of inflation (1), end of inflation (2), system opened (3), total static compliance = milliliters per centimeter of water (4), and total flow resistance = centimeters of water per liter per second (5).

fell less than 0.2 centimeter of water per second. The total static compliance was the ratio between the volume inflated and the pressure recorded. Each reported value represents the mean of five recordings.

The alveolar-arterial oxygen tension difference, in millimeters of mercury, was measured after the patient's lungs had been ventilated for twenty minutes with 100 per cent oxygen (during the anesthesia 100 per cent oxygen minus 0.5 to 1.5 per cent halothane was given). The barometric pressure, arterial carbon dioxide and oxygen tensions, and the water vapor pressure at the temperature measured in the esophagus permitted us to calculate the difference in oxygen tension between alveolar and arterial compartments [1].

The dead space-to-tidal volume ratio was calculated from the carbon dioxide tensions in mixed exhaled gases and arterial blood [1]. The total effective compliance, in milliliters per centimeter of water, was estimated by assisting the ventilation with a Bennett ventilator and recording end-inspiratory pressure and exhaled volume. The gas tensions, including the arterial oxygen tension on air breathing, were measured with Radiometer ultramicro-equipment, and the gas volumes including vital capacity were assessed with a Wright respirometer.

All results were listed as the mean ± one standard error, and the significance of the differences between pre and postoperative values was estimated with Student's paired t test. The values listed for pulmonary function during anesthesia in the patients with scoliosis are means of the measurements in the supine and prone positions.

Results

The findings are shown in Tables I and II. Pulmonary mechanics as expressed by total flow resistance and total static compliance deteriorated during the operation in the patients with scoliosis, while there were no significant changes in other patients. No significant changes took place in ventilation-perfusion relationships (alveolar-arterial oxygen tension difference to dead space-to-tidal volume ratio) during the procedure.

In the immediate postoperative period the alveolar-arterial oxygen tension difference, however, increased sharply (Fig. 3) in the patients with scoliosis, while this expression of pulmonary right-to-left shunting remained unchanged in the other patients. Consequently, the arterial oxygen tension on air breathing was also considerably lower after than before surgical procedures for correction of scoliosis.

TABLE I

PULMONARY FUNCTION BEFORE AND AFTER TWENTY SCOLIOSIS OPERATIONS

Measurement	Unit	During Anesthesia Before	After	Change (*per cent*)	p
TFR	cm H_2O/l/sec	4.4 ± 0.52	5.8 ± 0.94	+32	<0.01
TSC	ml/cm H_2O	55 ± 7.8	41 ± 6.3	−25	<0.01
(A-a)DO_2	mm Hg	132 ± 5.7	143 ± 10.6	+8	
V_D/V_T		0.38 ± 0.06	0.41 ± 0.07	+8	
Twenty-four Hours before and after Anesthesia					
VC	ml/kg	58 ± 2.6	33 ±2.7	−43	<0.01
TEC	ml/cm H_2O	88 ± 14.0	58 ± 5.6	−33	<0.01
Pa_{O_2}	mm Hg	90 ± 3.0	73 ± 2.5	−19	<0.01
(A-a)DO_2	mm Hg	126 ± 10.2	188 ± 18.8	+49	<0.01

The total effective compliance, which reflects elastic compliance more than flow resistance, indicated that the change in pulmonary mechanics experienced by the scoliosis patients during the operation lasted well into the postoperative period. The vital capacity, a parameter indicating pulmonary reserve, also was greatly reduced after operations for scoliosis.

The dead space-to-tidal volume ratio also was measured in some patients in both groups, twenty-four hours after the operation. This parameter never displayed a definite trend. The measurements of total flow resistance and total static compliance in the patients with scoliosis during anesthesia before and after surgery were largely the same in the supine and prone positions, although compliance was consistently lower by five milliliters per centimeter of water in the prone position. We do not consider this clinically important. The few patients who were not treated with Harrington rods did not display results different from the rest of the scoliosis patients.

Discussion

The patients who had operations on the extremities displayed no significant change in pulmonary function, which remained normal throughout. In contrast, the patients with scoliosis, who also had fairly normal pulmonary function preoperatively, showed impairment postoperatively, as has been reported previously [19]. It is well known that major upper abdominal and intrathoracic operations are associated with a deterioration of pulmonary function and, according to our study, so are operations for correction of scoliosis. A high frequency of postoperative pulmonary complications [1,2] may be expected under these circumstances. It is unlikely that the postoperative Risser cast played

TABLE II

PULMONARY FUNCTION BEFORE AND AFTER FIFTEEN OTHER ORTHOPAEDIC OPERATIONS

Measurement	Unit	During Anesthesia Before	After	Change (*per cent*)
TFR	cm H_2O/l/sec	4.7 ± 0.72	4.3 ± 0.63	−9
TSC	ml/cm H_2O	42 ± 5.2	44 ± 4.5	+5
(A-a)DO_2	mm Hg	130 ± 10.5	136 ± 15.6	+5
V_D/V_T		0.38 ± 0.03	0.38 ± 0.05	
Twenty-four Hours before and after Anesthesia				
VC	ml/kg	66 ± 3.8	63 ± 4.2	−5
TEC	ml/cm H_2O	95 ± 17.3	90 ± 12.8	−5
Pa_{O_2}	mm Hg	94 ± 4.3	86 ± 5.1	−8
(A-a)DO_2	mm Hg	118 ± 12.3	124 ± 10.9	+5

any role in the decline in pulmonary function because our measurement on patients preoperatively, in the cast, revealed no changes attributable to the cast itself. As for the measurements intraoperatively, anesthesia was relatively constant and moderate changes in halothane concentrations do not affect airway mechanics [15]. Serial measurements in a few patients showed that the changes in airway mechanics that we detected took place primarily during the early stages of the operation, so that it is unlikely that the protracted duration of the scoliosis operations played a role in producing those changes. All intraoperative measurements were done in the state of total muscle paralysis and after thorough suction of the trachea, so that no spontaneous change in these two factors would obtain [7].

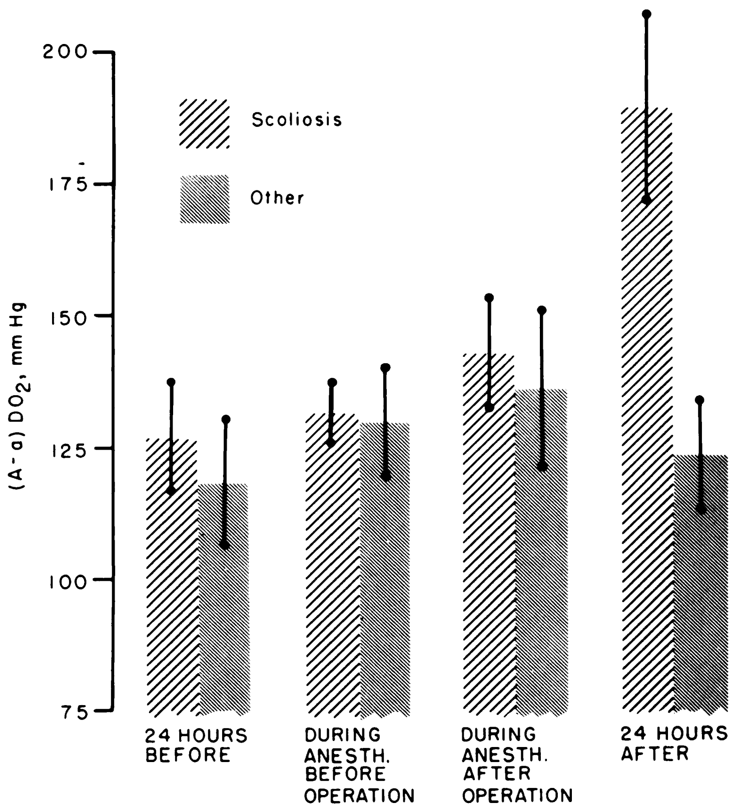

FIG. 3

Alveolar-arterial oxygen difference (oxygen breathing) in orthopaedic patients undergoing corrective operations for scoliosis or operations on the extremities (other). The measurements were made twenty-four hours, and immediately, before and after the operation.

It is interesting that the relationship between ventilation (as measured by dead space-to-tidal volume ratio) and perfusion (as measured by alveolar-arterial oxygen tension difference) showed only small changes during the operation, but deteriorated grossly postoperatively after discontinuation of anesthesia (Fig. 3). This course of events was contrasted by the changes in mechanics (as indicated in total flow resistance and total static compliance) which preceded the changes in ventilation-perfusion and were evident in the anesthetized patient immediately after completion of the operation. We interpret this to mean that the changes in pulmonary function took place during the operation and became manifest in the measurements of mechanics, but that artificial assistance of ventilation during the operation compensated for this so that the ratio of ventilation to perfusion was maintained at an acceptable level. Postoperatively, when the patient was breathing spontaneously, these changes in pulmonary function then manifested themselves also as impaired ventilation-perfusion ratios. We assume that interstitial edema and secretions must play an important role in these events.

In none of our patients did frank respiratory failure develop postoperatively and all were treated with nothing more than supplemental oxygen and pulmonary physical therapy. However, we agree with others [1,8] that such postoperative pulmonary changes as we found require from seven to ten days to recede. In our study the corrective operations for scoliosis consistently impaired pulmonary function. Therefore we predict that post-operative pulmonary insufficiency will increase if patients with scoliosis display major respiratory involvement preoperatively [1], and we suggest that it is necessary to assess pulmonary performance routinely in patients with scoliosis before surgery.

We recommend that initial screening include estimates of ventilation-perfusion ratio, pulmonary mechanics, and respiratory reserve:

Ventilation-perfusion ratio disturbances usually are associated with a decreased pressure of arterial oxygen on air breathing where values of about ninety millimeters of mercury may be acceptable, but lower values should prompt the measurements of alveolar-arterial oxygen tension difference on 100 per cent oxygen and dead space-to-tidal volume ratio. Serious impairment of pulmonary gas exchange is presumed when these three values are between seventy-five and ninety, 200 and 350, and 0.4 and 0.6, respectively, and further postoperative pulmonary insufficiency may be expected with more abnormal values than those listed, because lower values are in themselves indicative of pulmonary failure.

Pulmonary mechanics, compliance, and resistance all relate to the work associated with breathing. A total effective compliance of forty to twenty-five milliliters per centimeter of water would identify a patient as a high pulmonary risk. At present we have no simple bedside measurement to assess bronchial resistance to gas flow except the indirect estimate of timed vital capacity (forced exhaled volume in one second). This test measures the ability to expire gas rapidly. Patients with normal lungs should expire at least 70 per cent of their vital capacity in one second.

A certain ventilatory reserve is necessary for effective coughing, deep breathing, and those compensatory changes which must occur in minute ventilation when there is a spontaneous increase of dead space. The vital capacity is a useful index of reserve. It is normally greater than fifty milliliters per kilogram and values of forty to twenty-five milliliters per kilogram preoperatively may indicate postoperative insufficiency, because the vital capacity should be at least three times the average tidal volume for adequate reserve. If we accept an average predicted tidal volume of five milliliters per kilogram, the vital capacity needs to be more than fifteen milliliters per kilogram.

The measurements listed above are simple to perform at the bedside [1,3,16] and will suffice in assessing the operative pulmonary risk [1,9]. In our hands this approach proved practical and adequate, although we recognize that other tests and different methods could provide equally relevant and helpful information. We recommend that patients with scoliosis scheduled for corrective operations who are identified as serious pulmonary risks be further examined in the pulmonary function laboratory. Refined diagnostic techniques may help to evaluate the possibility of therapy and improvement of pulmonary function before the operation is undertaken.

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