CHANGES IN LUNG THORAX COMPLIANCE DURING ORTHOPEDIC SURGERY

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Positional requirements for certain procedures present special problems to be solved in order to provide convenient and safe anesthesia. Such problems are frequently encountered during operation for excision of herniated intervertebral disc with or without spinal fusion, or spinal fusion for correction of the deformities associated with idiopathic or acquired scoliosis.

In 1919, Haldane, Meekins and Priestly [1] observed that abnormal shallowness of breathing caused uneven ventilation, which in turn produced anoxemia. Case and Stiles [2] in 1946 studied the effects of various surgical positions on vital capacity. They found that conscious unmedicated patients showed a 10 per cent reduction in vital capacity in the unsupported prone position. They were unable to show any improvement in this measurement when these patients were supported by shoulder and hip rolls. Dutton [3] in 1932 demonstrated roentgenographically crowding of the thoracic cage in the kidney and lithotomy positions. Altschul [4] measured the changes in functional residual capacity (F.R.C.) in various positions and demonstrated a 15 to 20 per cent reduction in the recumbent position. McMichael [5] showed the F.R.C. to be reduced by 780 cc. in the recumbent position. They thought that elevation of the diaphragm cephalad was the most probable cause. Such elevation had been demonstrated by roentgenographic methods in 1933 by Hurado and Fray.[6]

We have noted that anesthetized patients in the supported prone position, breathing spontaneously, were unable to maintain an adequate respiratory minute volume. Many exhibited cyanosis, even though they were in light planes of anesthesia and had an unobstructed airway. Muscle relaxants were not administered. Although this condition improved with assisted or controlled respiration, rather high intratracheal pressures were necessary to maintain a satisfactory respiratory exchange. The prone position appeared to have an adverse effect on the mechanics of breathing in the anesthetized patient. In an effort to clarify the cause of these changes this study was undertaken.

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Methods

Measurements were made on 15 unselected patients scheduled for spinal fusion. Ten were for correction of scoliotic deformities and 5 for stabilization of the spinal column following removal of a herniated nucleus pulposus.

The patients were medicated in the following manner. Meperidine 100 mg. and scopolamine 0.6 mg. per 150 pounds of body weight were administered by intramuscular injection 45 minutes before induction of anesthesia. Thiopental, concentration 2.5 per cent, was injected intermittently until reflex motion of the eyelash was depressed. A standardized dose of succinylcholine chloride (100 mg.) was then administered intravenously. The patients were then hyperventilated with oxygen, and a large cuffed endotracheal tube inserted. The cuff was inflated to a tension sufficient to prevent leakage of gas between the wall of the tube and the trachea.

Pressure-volume data (lung-thorax compliance) were obtained with the apparatus seen in figure 1. A Monaghan ventilation meter was inserted on the inspiratory side of a circle system proximal to the "Y" endotracheal adapter. A calibrated aneroid manometer was connected to the endotracheal tube. Clamps were loosely placed on the expiratory hose, and just proximal to the manometer. Gas was then introduced into the lungs in 0.2-liter increments by manual compression of the rebreathing bag. During this phase clamp no. 1 (fig. 1) on the expiratory hose was tightened to eliminate distention of this compliant tubing. Following introduction of the gas the airway was occluded by tightening clamp no. 2 on the endotracheal tube. The pressure, which always fell a little initially, became stabilized after one or two seconds, and was read on the aneroid manometer and recorded. After each increment was introduced and measured, the clamps were released and the patient ventilated.

This procedure was repeated immediately after the patient was placed in the prone position (fig. 2) in preparation for surgery, again at the approximate mid-point of the operation, and finally directly after the patient was placed supine at the end of surgery.

Results

This method measured the "elastic" or static pressures resulting from volume change, in terms of compliance of the lung-thorax system, i.e., the volume change in liters which corresponds to a 1 cm. of water pressure variation. Normal values of total respiratory compliance in conscious subjects are about 0.10 to 0.15 l./cm.[7, 8] It has been shown, however, that the compliance values in the relaxed anesthetized patient are much lower, about 50 per cent of the control values.[7]

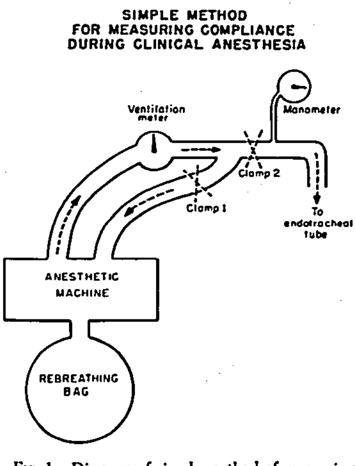

Fig. 1. Diagram of simple method of measuring compliance during clinical anesthesia (a modification of apparatus suggested by Nims, Conner and Comroe: J. Clin. Invest. 34: 744, 1955).

Measurements of compliance in the supine position prior to surgery were in agreement with those of previous investigators [7, 9] in those patients who did not have deformities of the chest. In patients with scoliosis who had deformities of the thoracic cage there was a severe reduction in compliance below the normal values for anesthetized supine patients. The average reading was 0.028 l./cm.

A further significant reduction in compliance was observed in all patients when they were placed in the prone position just prior to surgery. This reduction was consistent—about 30–35 per cent (table 1). An extreme reduction of compliance occurred in scoliotic patients in the prone position, the average measurement being 0.018 l./cm. (range 0.015 to 0.02 l./cm.). Low total respiratory compliance prevailed throughout surgery (table 1). However, spot checks during the procedure showed the further adverse effects of sustained pressure on the spine and operative trauma. Measurements made during such added stress revealed extremely low values.

Monitoring of end-tidal carbon dioxide by standard methods (Liston Becker infrared carbon dioxide analyzer) demonstrated that assisted or controlled respiration by manual methods failed to compensate for these severe changes in compliance. In three of the scoliotic patients normal carbon dioxide levels could not be maintained for more than short intervals of 5 to 10 minutes because of fatigue on the part of the anesthesiologist.

Following application of the dressing at the termination of surgery, the patient was turned to the supine position. Succinylcholine chloride 50 mg. was administered and measurements were again taken following a short period of hyperventilation. In all patients without thoracic deformity there was rapid return to the presurgical values for the supine position. However, such was not the case in the majority of the patients with scoliosis. Here, there was some increase in compliance, but not to their control values. It was noted that these patients required assisted respiration for a varying period of from 10 to 30 minutes before they could be safely transferred to the recovery room.

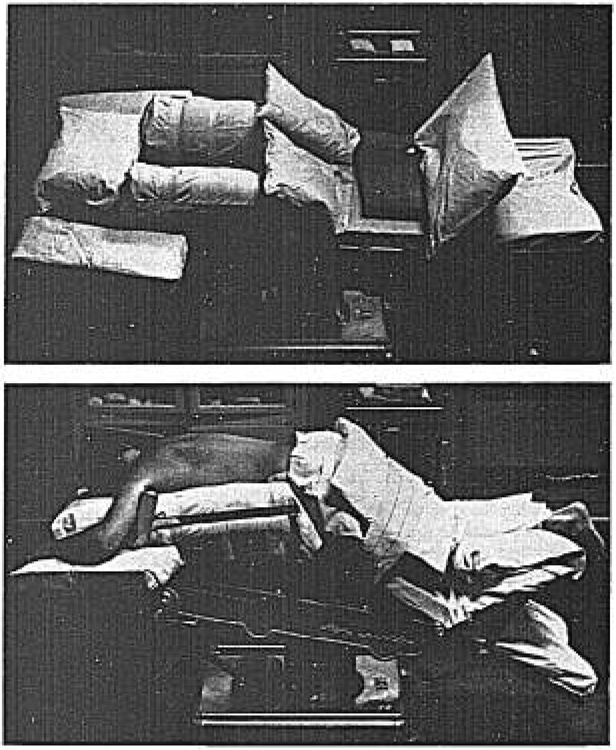

FIG. 2. Patient in prone position. The parallel hard rubber rolls support shoulders and hips so that there is minimal interference with excursion of the diaphragm and the lower rib cage. Pressure points are padded with foam rubber. The hips and knees are flexed and the head and limbs are supported.

DISCUSSION

The elastic properties of the lungs and thorax have been of interest to the anesthesiologist for some time. Recently an analysis of the pressure-volume diagram has been made [10] which shows the contributions of the chest wall alone and lungs alone to the total pressure developed at any volume. The pressure exerted by the chest wall is due to the force applied by deformed costal muscles and ligaments, altered center of gravity of the chest, by altered position of diaphragm, and displacement of viscera. The reactive force of the lung is mainly due to its elastic tissue.

The explanation of the decreased total compliance in the relaxed patient may be that less respiratory tissue is being expanded.[9, 11] This concept of reduction in effective alveolar space was supported by Bernstein's [12] findings on curarized rabbits. He found that when the lungs were inflated above a certain volume, compliance increased, suggesting the addition

TABLE 1

PRESSURE-VOLUME DATA IN TWO PATIENTS

(A) 12 Year Old Girl with Primary Dorsal Scoliosis

Volume (cc.)	Supine Preoperative		Prone During Operation		Supine Postoperative	
	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)
200	5	.025	15	.013	13	.016
400	16	.025	23	.017	21	.019
600	22	.030	31	.019	32	.019
800	30	.027	42	.019	42	.019
1000	37	.027	49	.020	49	.020

(B) Adult Male with Herniated Nucleus Pulposus

Volume (cc.)	Supine Presurgery		Prone During Surgery		Supine Postsurgery	
	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)	Pressure (cm. H_2O)	Compliance (l./cm. H_2O)
200	4	.050	6	.033	4	.050
400	7	.057	11	.036	8	.050
600	10	.060	14	.043	11	.055
800	12	.067	18	.044	14	.057
1000	15	.067	21	.048	20	.050

of more ventilating space. It would seem that the further reduction in compliance shown in this study can be readily explained on this concept. The prone position necessary for surgery of the spine and ribs places the lung-thorax system at a serious mechanical disadvantage. This position leads to elevation of the diaphragm and fixation of the anterior and lateral chest walls. Although our patients were supported by large lateral rolls there was relatively little chest expansion; ventilation was accomplished largely by downward motion of the diaphragm and extension of the spine. The relationship between vital capacity and compliance has been demonstrated.[13, 14] As shown by Marshall[15] there is also a significant correlation between compliance and functional residual capacity (F.R.C.). He suggests prediction of compliance can be obtained by the formula: $C = 0.050 \times F.R.C.$ when C = lung compliance and F.R.C. is expressed in liters. Marshall and Du Bois[16] reported that kyphoscoliotics had a small F.R.C. and low values for lung compliance. The present study seems to confirm these findings since the scoliotic patients showed lower values of compliance both in the supine and prone positions. This is most likely due to reduction in effective alveolar space because of their deformed thoracic cage. This was further aggravated in the prone position.

Consideration of the above findings suggested the use of a controlled volume type respirator. Such a respirator[17, 18] has the advantage of automatically adjusting its pressure so that the selected tidal volume will always reach the patient despite moment to moment changes in compliance which has been noted during this study. Such a respirator should be capable of delivering the preset volume even at pressures in excess of 40 mm. of mercury.

SUMMARY

The pressure volume relationship of the respiratory system in relaxed, anesthetized patients in the supine position was measured before and after operation, and in patients in the prone position during surgery for spinal fusion.

The measurements of compliance taken in the supine position were in agreement with previous work. A significant decrease in compliance was noted in patients with scoliosis.

TABLE 2

AVERAGE COMPLIANCE IN L./CM. IN EACH POSITION FOR THE PATIENTS STUDIED

(A) Scoliosis

Patient	Age (years)	Weight (pounds)	Compliance Supine Preoperative	Compliance Prone During Operation	Compliance Supine Postoperative
1	12	100	.025	.017	.019
2	12	96	.033	.021	.026
3	21	121	.035	.022	.026
4	13	104	.025	.019	.025
5	13	96	.022	.014	.018
6	19	110	.032	.022	.025
7	21	130	.028	.017	.020
8	16	90	.030	.020	.026
9	20	127	.025	.016	.020
10	16	86	.028	.015	.019

(B) Disc-Fusion

Patient	Age (years)	Weight (pounds)	Compliance Supine Preoperative	Compliance Prone During Operation	Compliance Supine Postoperative
1	25	175	.045	.033	.044
2	19	160	.042	.035	.040
3	54	188	.067	.036	.060
4	43	126	.050	.030	.045
5	46	158	.041	.022	.035

In the prone position a further reduction of 30 per cent in compliance was observed in all patients.

High airway pressures (range 20–40 mm. Hg) were necessary to maintain normal tidal volumes during the periods of reduced pulmonary compliance.

REFERENCES

1. Haldane, J. S., Meekins, J. C., and Priestly, J. C.: Effects of shallow breathing, J. Physiol. 52: 433, 1919.
2. Case, E. H., and Stiles, J. A.: Effects of various surgical positions on vital capacity, ANESTHESIOLOGY 7: 29, 1946.
3. Dutton, A.: Posture during anesthesia, California & West. Med. 37: 145, 1932.
4. Altschule, M. D.: Significance of changes in lung volume and its subdivisions during and after abdominal operations, ANESTHESIOLOGY 4: 385, 1943.
5. McMichael, J., and McGibbon, J. P.: Postural changes in lung volume, Clin. Sc. 4: 175, 1939.
6. Hurtado, A., and Fray, W. W.: Studies of total pulmonary capacity and its subdivisions; Correlation with physical and Radiological measurements, J. Clin. Invest. 12: 807, 1933.
7. Nims, R. C., Conner, E. H., and Comroe, J. H.: Compliance of human thorax in anesthetized patients, J. Clin. Invest. 34: 744, 1955.
8. Butler, J., White, H. C., and Arnott, M. W.: Pulmonary compliance in normal subjects, Clin. Sci. 16: 709, 1957.
9. Butler, J., and Smith, B. H.: Pressure volume relationships of the chest in completely relaxed anesthetized patient, Clin. Sci. 16: 125, 1957.
10. Otis, A. B., Fenn, W. O., and Rahn, H.: Mechanics of breathing in man, J. Appl. Physiol. 2: 592, 1950.
11. Bromage, P. R.: Total respiratory compliance in anesthetized subjects and modifications produced by noxious stimuli, Clin. Sci. 17: 217, 1958.
12. Bernstein, L.: Interpretation of pressure-volume curve of the rabbits lung, J. Physiol. 125: 380, 1954.
13. Brown, C. C., Jr., Fry, D. L., and Ebert, R. V.: Mechanics of pulmonary ventilation in patients with heart disease, Am. J. Med. 17: 438, 1954.
14. Frank, N. R., Mead, J., Siebens, A. A., and Storey, C. F.: Measurements of pulmonary compliance in seventy healthy young adults, J. Appl. Physiol. 9: 38, 1956.
15. Marshall, R.: Physical properties of lungs in relation to subdivisions of lung volume, Clin. Sci. 16: 507, 1957.
16. Marshall, R., and Du Bois, A. B.: Viscous resistance of lung tissue in patients with pulmonary disease, Clin. Sci. 15: 473, 1956.
17. Björk, V. O., and Engström, C. C.: Treatment of ventilatory insufficiency after pulmonary resection with tracheostomy and prolonged artificial respiration, J. Thoracic Surg. 30: 356, 1955.
18. Elam, J. O., Kerr, J. H., and Janney, C. D.: Performance of ventilators; Effect of changes in lung-thorax compliance, ANESTHESIOLOGY 19: 56, 1958.