Intermittent Deep Breaths and Compliance During Anesthesia in Man

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PULMONARY compliance decreases whenever deep breaths are not a part of the ventilatory pattern. This was demonstrated in anesthetized dogs by Mead and Collier [1] and confirmed in human volunteers by Ferris and Pollard.[2] The gradual fall with time in pulmonary compliance is assumed to reflect some collapse of airspace with every return to the resting end-expiratory position; higher airway pressures than normal are needed for reopening of collapsed airspace.[1] An occasional deep breath is necessary for this purpose.

If the concept of a gradual fall in compliance as a consequence of constant volume ventilation is accepted, lack of intermittent hyperinflation should be an important and easily demonstrable cause of decreased compliance during anesthesia. We have attempted to show with simple means the presence of this problem in routine clinical anesthesia.

Method

Compliance was measured 211 times in 36 patients during anesthesia and operation. The type of patient, the operation in progress, the position of the patient and type of ventilation before the study are shown in table 1. No attempt was made to influence the anesthetist in his choice of anesthetic agent or pattern of respiration or regulate the time during the operation that the studies were done. Cuffed endotracheal tubes were inserted in all patients. All patients were apneic during the time compliance was measured; those who had been breathing spontaneously during the operation were made apneic with either succinylcholine or cyclopropane.

Total pulmonary compliance (lungs and chest wall) was measured with a syringe cali-

brated to inject 500 ml. of air; pressure was recorded when air flow ceased with an aneroid manometer accurate to 1 cm. of water.[3] Duplicate measurements of compliance for 500 ml. showed an average difference of 0.53 cm. of water pressure. Several maneuvers were carried out to study their effect upon compliance. Twenty-eight patients received two or three deep breaths approaching the vital capacity and sustained at a pressure between 20 and 30 cm. of water for five seconds. In 15 of these patients, the procedure was repeated from five to ten minutes later. In 19 patients, we inserted a suction catheter size 12 French into the endotracheal tube and aspirated for five seconds; the flow of air sucked through the catheter was from 15 to 25 liters per minute. Each patient served as his own control. Differences were tested for statistical significance using the t test.

Results

The average compliance, first measured at the start of the study, was 39.2 ml./cm. of water ± S.E. 2.17.[*] Comparing control compliance with the compliance obtained immediately after several deep breaths, we found a significant difference ($P < .01$); compliance may be improved by passive hyperinflations during anesthesia (table 2). This was true for all of the patients except two; these two patients, 17 and 29, were both anesthetized by a resident who also worked in the laboratory and had had the importance of the intermittent deep breath thoroughly impressed upon him. Both patients had received deep breaths every five minutes throughout the course of the anesthetic. Table 2 shows that in most patients compliance can be improved again within five to ten minutes. Table 3 demonstrates the drop in compliance ($P <$

[*] Standard error of mean.

Table 1. Types of Patients Studied

Number of patients	36
Age, years	57.8 (15–84) *
Height, inches	64.0 (60–72)
Weight, pounds	147.4 (90–180)
Number having abdominal operations	30
Number having respirations controlled	22
Number breathing spontaneously	14
Number under ether anesthesia	9
Number under nitrous oxide-curare	11
Number under cyclopropane anesthesia	10
Number under halothane anesthesia	5
Number with no anesthesia†	1
Number in supine position	23
Number in lateral or Trendelenburg	13

* Average (range).

† Decerebrate patient, respirations controlled through tracheostomy tube.

.01) following suction of the trachea; after several hyperinflations compliance was again improved. In the two patients, 11 and 17, in whom compliance rose after suctioning, we were able to remove secretions from the trachea.

Differences between the groups comparing the type of anesthesia were not tested and would not be valid because the type of anesthetic drug and technique were not randomized; the groups were not homogeneous (table 1). For example, no difference was found among the patients breathing spontaneously and those whose respirations were controlled despite the fact that this difference has been demonstrated previously.[4] For these reasons, we have only presented data which compares the patients with their own control values. To check this decision, we compared eight patients who were in Trendelenburg position (mean control compliance 33.6 ml./cm. of water ± S.E. 4.73) with 21 patients who were in the supine position (mean control compliance 42.7 ml./cm. of water ± S.E. 2.77); the difference was not statistically significant. However, in nine other patients (mean compliance 46.8 ml./cm. of water in the supine position) who were tilted into a 20-degree Trendelenburg position, compliance fell 6.75 ml./cm. of water ± S.E. 1.75 which was significant ($P < .01$), as has been reported.[4]

Discussion

There is no doubt that atelectasis may occur during the progress of anesthesia.[1] Our data suggest that atelectasis during general anesthesia is a common occurrence. Measuring total pulmonary compliance to test for atelectasis, as we have, is less accurate than measuring only lung compliance since chest wall compliance is not affected by alveolar collapse.[1] Because of the simplicity of Janney's syringe,[3] we have accepted this source of variation in the data. Both chest wall and lung compliance, however, are affected during op-

Table 2. Compliance is Higher after Deep Breaths Than When Measured at Random During Operation *

Patient	Control Compliance (ml./cm. H₂O)	Compliance after Deep Breaths	Compliance 5–10 Minutes Later	Compliance after Deep Breaths
1	27.8	29.4		
2	33.3	38.5		
7	54.2	64.8		
12	23.8	38.4		
13	50.0	62.5		
14	38.5	45.5		
15	41.6	50.0		
16	41.6	45.5	38.4	41.7
17	55.5	45.5		
18	35.7	62.5	45.4	55.5
19	27.8	33.3	29.4	29.4
20	22.8	26.3	23.8	23.8
21	27.8	31.3	35.7	38.5
22	41.7	55.5		
23	33.3	50.0		
24	33.3	35.7	29.4	33.3
25	41.7	50.0	29.4	35.7
26	22.7	26.3		
27	26.4	31.2	26.3	31.2
28	35.7	47.6	38.5	41.7
29	45.5	45.5		
30	27.8	29.4		
31	42.7	50.0	45.5	41.7
32	20.8	26.3	26.3	29.4
33	35.7	38.4	35.7	41.7
34	41.7	62.5	62.5	62.5
35	25.7	31.2	28.8	31.2
36	41.7	45.5	45.5	50.0
Mean	35.6	42.8	36.1	39.2
S.D.	9.18	10.6	10.4	10.5

* Mean rise in compliance after deep breaths the first time was 7.2 ml./cm. of water ± S.D. 1.27 ($P < .001$); the second time five–ten minutes later, compliance rose 3.11 ml./cm. of water ± S.D. 3.07 ($P < .01$).

eration. Expanding the lung improves lung compliance by reopening atelectatic alveoli. Aspirating the trachea would improve lung compliance *if* secretions obstructing the airways are removed; otherwise, aspirating air from the trachea will lower lung compliance. Chest wall compliance is reduced when the patient is placed in the Trendelenburg position.

Our compliance measurements are lower than previously reported during anesthesia. Nims, Conner and Comroe [5] reported an average compliance during anesthesia of 62 ml./cm. of water; Howell and Peckett [6] reported an average compliance of 57 ml./cm. of water. Our control compliance was 39.2 ml./cm. of water. This may be because we measured compliance during the progress of the operation in most cases. We have seen compliance fall when the surgeons retract the abdominal contents or lean on the chest as have Safar and Aguto-Escarraga.[4] Also, many of our patients were obese or had chronic lung diseases which lower compliance. These and other possible influences may explain the low control compliance in our patients. Despite these variables, we have been able to show an improvement in compliance by passive hyperinflation of the lungs during anesthesia. Finding that compliance had dropped to previous levels within five to ten minutes is interesting in the light of data recently obtained by Bendixen [7]; using a pneumograph, he found that healthy subjects would unconsciously take a deep breath (about three times the mean tidal volume) approximately ten times per hour. We have concluded that lung compliance should be maintained by administering a deep sigh every five or ten minutes during anesthesia.

Demonstrating pulmonary atelectasis by physical signs or roentgenogram would seem of doubtful value; the lack of useful tools for measuring collapse of the lungs probably explains the difficulty in obtaining useful data. Another method of estimating the number of respiratory units which are being perfused but not ventilated, *i.e.*, atelectatic, is by measuring the degree of venous admixture in the pulmonary circulation, comparing the alveolar-arterial P_{O_2} gradients.[8] Using this method, Stark and Smith [9] have shown that the shunt of venous blood into the arterial circulation increased as anesthesia progressed. Presumably, they did

TABLE 3. Suction of the Trachea Lowers Compliance; Several Hyperinflations Return Compliance to Previous Levels*

Patient	Compliance (ml./cm. H₂O)		
	Before Suction	After Suction	After Deep Breaths
1	29.4	26.3	31.3
2	38.5	31.3	33.3
3	46.7	43.8	49.0
4	83.5	79.3	83.5
5	33.4	22.2	36.4
6	50.7	50.7	53.3
7	64.8	49.8	60.8
8	54.2	46.5	50.0
9	39.7	37.2	51.7
10	79.3	79.3	83.5
11	40.8	42.5	43.2
12	38.4	31.2	38.4
13	62.5	45.5	62.5
14	41.7	27.8	38.5
15	50.0	41.6	45.5
16	45.5	38.5	41.6
17	45.5	50.0	55.5
19	29.5	27.8	31.3
21	31.3	27.8	29.4
Mean	47.7	42.0	48.3

* Mean fall in compliance after aspiration = 5.75 ml./cm. of water ± S.E. 1.41, $P < .01$. Mean rise after deep breaths = 6.29 ± S.E. 1.1, $P < .01$.

not administer an occasional deep breath every five to ten minutes during anesthesia.

Rosen and Hillard [10] have shown that the lung may be collapsed by suction of the trachea. Downes, Wilson and Goodson [11] state that suction does not lower arterial oxygen saturation; their results are variable but their own data show that when the patients' tracheas were aspirated, the average oxygen saturation was 1.6 per cent below the measurements made when no suction was done. Our data show that compliance may be lowered by suction of the trachea and we believe that the mechanism responsible for this is collapse of alveoli [1]; several deep breaths (airway pressure maintained around 20 cm. of water for five seconds) after aspiration improved compliance. Deep inflations would seem a useful procedure following suction of the tracheobronchial tree.

Stark and Smith [9] reported no difference in shunting ($P_{A_{O_2}} - Pa_{O_2}$) between patients having intra-abdominal operations and patients

having extra-abdominal operations. This would mean that the type of operation did not affect the likelihood of developing atelectasis which is in complete disagreement with studies of clinical atelectasis. Clinical signs of atelectasis are much more likely to appear if a patient has had an abdominal operation than if he had his operation in a more peripheral location.[12] These divergent views can be reconciled if one postulates that atelectasis develops during a narcotized state[13] but is reversed if the patient awakes rapidly and is able to stretch his lungs; if, however, the patient develops pain each time he takes a deep breath postoperatively or if he receives narcotics and becomes less interested in maintaining normal pulmonary mechanics, then the collapse which he has already developed during operation may be aggravated. We have data to show that patients who are having pain from an abdominal incision take a deep breath periodically. Treatment with a narcotic stops this.[*] Assisting the patient to hyperinflate his lungs occasionally during the postoperative period may allow the patient the benefit of pain relief from a narcotic and still maintain expansion of the alveoli.

Summary

Total pulmonary compliance was measured in 36 patients during anesthesia and operation. Passive hyperinflations were found to improve compliance. In the absence of deep breaths a fall in compliance could be demonstrated after five to ten minutes. Aspirating the trachea lowered compliance; passive deep inflations returned compliance to control levels. We believe that a fall in compliance may reflect pulmonary atelectasis. Intermittent passive hyperinflations, imitating the spontaneous occasional sigh, are suggested as an important prophylactic measure to prevent atelectasis during anesthesia.

* Egbert, L. D., Laver, M. B., and Bendixen, H. H.: Unpublished data.

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