Effect of body position on esophageal pressure and measurement of pulmonary compliance[1]

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FERRIS, BENJAMIN G., JR., JERE MEAD AND N. ROBERT FRANK. *Effect of body position on esophageal pressure and measurement of pulmonary compliance.* J. Appl. Physiol. 14(4): 521–524. 1959.—In order to assess the effect of body position on esophageal pressure and pulmonary compliance, esophageal pressures were measured by means of a 'long' thin-walled balloon at the same lung volumes in different body positions in human subjects. Pulmonary compliance was measured by relating esophageal pressure change to associated lung-volume change. The data indicate that in the supine position false values of esophageal pressure and pulmonary compliance may be obtained. These false values appeared to be caused by an altered esophageal pressure as a result of gravity pressing other mediastinal structures against the esophagus. In the upright, lateral and prone positions esophageal pressures were similar to each other but different from those obtained in the supine position. These results suggest that measurements of esophageal pressure and pulmonary compliance in recumbent subjects are most reliable when made in the prone or lateral positions.

IN MOST STUDIES of the mechanical properties of human lungs esophageal pressure has been used as a measure of pleural pressure. Since altered pulmonary mechanics have been reported when measurements were made in different body positions (1), the question arises whether these were true differences or whether they reflect changes in esophageal pressure independent of lung surface pressures. The present experiments were designed in an attempt to answer this question. Records were taken of esophageal pressure in different positions during breath holding at fixed volumes of the lungs. In this way transpulmonary pressure was held nearly constant, and, making these measurements at different volumes of the lungs, the influence of posture on measurements of compliance could also be assessed.

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METHODS

Six healthy adults were studied. Their physical characteristics are presented in table 1. Esophageal pressure was measured from a balloon, 15 cm in length, attached to the end of a polyethylene catheter. The balloon was inflated with 1 ml of gas (2). It was passed a distance of 38–45 cm beyond the nares, depending on the size of the subject. The tip of the balloon was estimated to be in the lower third of the thoracic esophagus and was kept in the same position throughout each study. The pressure difference was measured with a differential inductance manometer and recorded on a direct-writing oscillograph. One side of the manometer was connected to the balloon and the other to a pressure tap in the mouthpiece. Changes in volume of the lungs were recorded on a spirometer. Subjects were studied in the supine, prone, lateral and upright positions. To change the position from supine to prone or supine to lateral the subject rolled into the new position while lying horizontal. The change from horizontal to upright or its reverse was accomplished in 12 seconds by means of a motor-driven tilting bed. (J. H. Emerson Co., Cambridge, Mass.) The angle of tilt was recorded by means of a rotating potentiometer.

The following procedure was used. The subject hyperventilated for about 1 minute and then relaxed to his resting end-expiratory volume. The mouthpiece was then obstructed beyond the pressure tap in the mouthpiece. The glottis was kept open. Studies were usually begun in the supine position. After a relatively stable esophageal pressure was obtained, the subject was tilted or rolled into the next position to be studied. Measurement was made of the change in esophageal pressure associated with the change in position, when the volume of the lung was kept constant.[2] With breath holding alone up to 90 seconds there was no significant change in

[2] A small change in lung volume probably did occur if the respiratory exchange ratio was not one. It would be small and, for this study, has been ignored.

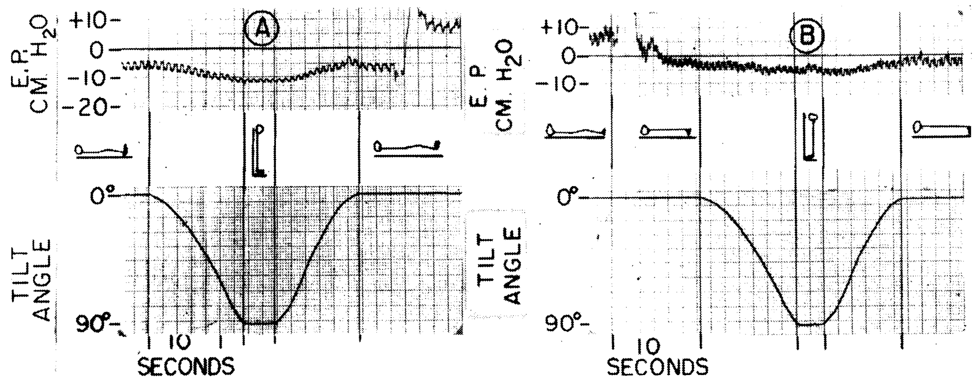

FIG. 1. *A*. Effect of supine and upright positions on esophageal pressure (E.P.) at supine FRC. *B*. Effect of supine, prone and upright positions on esophageal pressure at supine FRC.

TABLE 1. *Physical Characteristics of Subjects*

Subj.	Sex	Age, yr.	Ht., cm	Wt., kg	V.C. (L)	Residual Vol. (supine) (L)	FRC (supine) (L)	FRC (upright) (L)
BF	M	38	188	82	5.72	2.12	3.36	4.98
RF	M	33	178	71.7	4.48	2.30	3.26	4.10
IG	M	27	179	84	5.64	2.29	3.52	4.46
JM	M	37	187	86.5	6.00	2.63	4.00	4.95
JW	M	40	186.5	86	6.50	2.80	3.64	5.44
NW	F	33	170	55	4.54	1.09	2.44	3.60

TABLE 2. *Average Resting End-Expiratory Intraesophageal Pressures at Various Body Positions and Lung Volume Equal to FRC Supine*

Subject	Supine	Prone	Lateral	Upright
BF	+3.6	−2.6	−1.0	−3.4
RF	−0.2	−2.0	−2.6	−3.4
IG	+0.6	−1.0	−2.8	−3.8
JM	+1.6	−1.4	−1.8	−2.2
JW	+2.5	−1.0	−2.3	−2.6
NW	+1.6	−1.5	−2.3	−2.5
Mean	+1.6	−1.6	−2.1	−3.0
S.D.*	±1.35	±0.62	±0.65	±0.64

* Small numbers correction applied. Student's paired *t* test for difference between body positions: supine vs. prone, $P = 0.01$; supine vs. lateral or upright, $P < 0.01$; prone vs. lateral, not significant statistically; lateral vs. upright, $0.05 > P > 0.01$; prone vs. upright, $P \leqq 0.01$.

mean pressure, although the cardiac pressure oscillations increased during this interval.

In another procedure the subject was tilted from the horizontal to vertical position and then allowed to inspire a measured volume. Following inspiration the airway was obstructed and the subject relaxed against the obstruction while keeping his glottis open. The bed was then tilted back to the horizontal position. This maneuver permitted measurement of esophageal pressure over the same range of lung volume in two body positions. The volume inspired from the supine resting end-expiratory position was varied to include most of the inspiratory capacity. From pairs of volume-pressure points it was possible to measure the compliance of the lungs at different volumes.

Functional residual capacity was measured with the subject in the supine and sitting positions by means of the helium dilution technique (3). These measurements were not made simultaneously with the tilting runs. All volumes were expressed at BTPS.

RESULTS AND DISCUSSION

Typical recordings obtained when the subject was tilted from the horizontal (0°) to vertical (90°) and back are shown in figure 1. In figure 1*A* the subject was tilted from supine to upright at a constant lung volume (supine functional residual capacity). This change of position at a fixed lung volume made esophageal pressure approximately 10 cm H_2O more negative. Upon the subject's return to the horizontal position, esophageal pressure also returned to its previous level with an increase in the cardiac pressure oscillations. Similar changes were noted when the subject turned from the supine to prone positions (fig. 1*B*), but there was little change in esophageal pressure when the subject was tilted from the prone to the vertical position.

The average end-expiratory esophageal pressures at the supine functional residual capacity for all positions are presented in table 2. In each subject the esophageal pressure relative to atmospheric pressure was highest in the supine position. It was lowest in the upright position in all subjects and in five out of six subjects it was lower in the lateral than in the prone position. Esophageal pressures in the prone and lateral positions were more like those in the upright position than the values in the supine position.

It was thought that these changes in end-expiratory pressure were related to the pressure exerted on the esophagus by other mediastinal structures. In the supine position the heart and great vessels, due to gravity, might be expected to press down on the esophagus thereby increasing esophageal pressure. As the subject changed to lateral, prone or upright positions, gravity would cause the heart and great vessels to fall away from the esophagus and esophageal pressure would be expected to decrease.

By combining the data of table 2 with measurements of esophageal pressure at larger volumes of the lung, it is possible to construct volume-pressure relationships for the lungs in different body positions. The slope of the volume-pressure relationship expresses compliance. It is

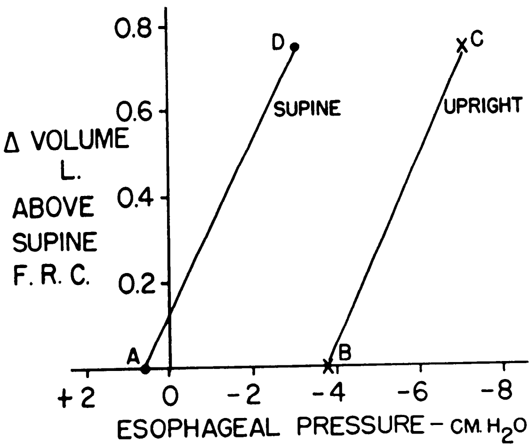

FIG. 2. Effect of body position on measurement of pulmonary compliance.

to be emphasized that all such comparisons were made at the same absolute volumes. Under this condition, the values for compliance should reveal whether the pressure exerted on the esophagus by mediastinal structures changes with lung volume. If such a change occurs, compliance would be different in the different positions even though measured at the same absolute volumes. If the opposite were true and the pressure exerted by other structures were insensitive to change of volume, then the slopes of these volume-pressure curves would be the same and only the intercepts would vary.

To investigate this, data were obtained as indicated in figure 2: the subject started from the relaxed supine position (*A*), the airway was closed while the bed was tilted to upright (*B*) and a volume of gas was inhaled (*C*); the bed was then returned to the horizontal position (*D*). The average of three or more runs was used for each point on each subject.

An example of volume-pressure relationships obtained on a subject over an extended volume range is shown in figure 3. Pulmonary compliance values were obtained from such plots as the slope of the line between selected lung volumes in the supine and upright positions. The results obtained in this manner on the six subjects are presented in table 3, where it can be seen that the differences between the upright and supine compliances were usually greater at the lower rather than at the higher lung volumes. In addition, compliance in the supine position at the lower lung volumes was less than in the upright position in five out of the six subjects. These findings are similar to those obtained by other workers using somewhat different techniques (4, 5).

The earlier comparisons of lung compliance in the upright and supine positions (1) took into account the change in lung volume which the authors felt could not account for all of the change observed, and they therefore attributed some of the decrease in compliance in the supine position to pulmonary congestion. In view of our observations and others (4, 5), much of the difference appears to be due to artifacts associated with using the

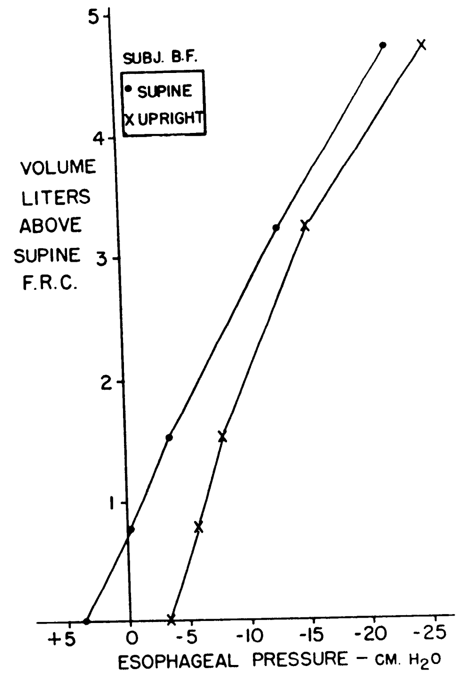

FIG. 3. Effect of body position and lung volume on measurement of pulmonary compliance.

TABLE 3. *Pulmonary Compliance (L/cm H_2O) at Lung Volumes Above Supine FRC in Two Body Positions*

Subject	0–0.75		0.75–1.5		1.5–3.0		3.0–4.2	
	Sup.*	Up.†	Sup.	Up.	Sup.	Up.	Sup.	Up.
BF	0.200	0.282	0.211	0.308	0.182	0.222	0.162	0.156
RF	0.341	0.441	0.221	0.259	0.161	0.170		
IG	0.206	0.227	0.293	0.328	0.139	0.158	0.197	0.194
JM	0.268	0.357	0.192	0.202	0.223	0.200		
JW	0.259	0.465	0.259	0.465	0.286	0.279		
NW	0.266	0.258	0.238	0.216	0.238	0.216		
Mean	0.257	0.338	0.236	0.296	0.205	0.208	0.178	0.175

* Sup. = supine. † Up. = upright.

esophagus as a site to measure the pressure applied to the surface of the lungs.

These observations raise the question of whether previously reported data (6) on convalescent poliomyelitic patients are valid. Ie that report only two normal subjects were studied in the supine position. Additional data have been collected during another study where supine lung compliances were obtained in poliomyelitic and normal patients (manuscript in preparation). Comparison of these data indicates that the average values for the normal subjects are 2.6–3.1 times greater than those obtained for the patients. This was true in the three positions studied; supine, prone and lateral, and the change is consistent with the previously reported data.

Studies of the mechanics of respiration in newborn infants (7) have been made in the supine position and are therefore difficult to compare with studies in older individuals who were seated. Similarly, when measurements in supine anesthetized patients are compared with upright values (8) the effect of the supine positions on the measurements should be considered.

The differences in resting end-expiratory pressures were relatively small among the upright, lateral and prone positions compared with the differences between the upright and supine positions. It is reasonable therefore to assume that compliance measurements would also be comparable. In this study insufficient data were collected to verify this point.

It is pertinent to point out that the lung compliance is higher at the lower lung volumes studied (table 3). This occurred in both the supine and upright positions. From this one might conclude that the 'true' compliance is increased in recumbency when the lung volume is low. These studies, however, were made following hyperventilation and near maximal expansion of the lungs and are more representative of the deflation curve of expanded lungs. Therefore it may be that the 'true' lung compliance is decreased in recumbency, especially after a period of breathing with a small tidal volume.

The observation that patients with orthopnea have a decreased lung compliance in the supine position compared with the upright position (9, 10) might also be explained in a similar manner. Measurements of lung compliance on patients with orthopnea should be corrected for lung volume change; in addition, measurements in the horizontal and upright positions should be made so that any artifact associated with using esophageal pressure is minimal. Such a comparison has been made by other investigators (submitted for publication) and has shown that orthopneic patients have a decreased lung compliance in the prone position as compared with the upright position.

Some authors have investigated what happens to the pulmonary compliance when the intrathoracic blood volume is increased acutely as the result of submersion in water or during the use of G suits (11) or during acceleration (12). Changes similar to those reported here might possibly account in part for the decreased pulmonary compliance observed. With venous congestion and engorgement the great vessels might well alter the position of mediastinal contents and in so doing effect the esophageal pressures recorded. Certainly the effect of esophageal compression should be evaluated in these procedures.

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