COMPLIANCE OF THE RESPIRATORY SYSTEM AND ITS COMPONENTS IN HEALTH AND OBESITY.

by

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Introduction

It has been noted that marked obesity may be associated with hypoxia and hypercapnia in the absence of demonstrable intrinsic pulmonary disease and that this is associated with an increased oxygen cost of breathing (1-5). The latter may be due to either an increased mechanical work being performed on the respiratory apparatus or a reduced efficiency of the respiratory muscles. The lack of abnormalities in the physical properties of the lungs in obese individuals has led those inclined to the former view to postulate that any increase in total work done is due to an increased resistance offered by the chest wall (5). However, evidence to support this hypothesis has not yet been advanced.

The purpose of this paper is to report studies on the elastic properties of the total respiratory system and its components in a group of obese subjects and to compare them to those of a group of normal individuals.

Method

Twenty-three subjects were studied (Table I). Fourteen of these were normal individuals whose mean age was 29 years, mean weight 76 Kg. and mean height and body surface area 176 cm. and 1.94 M^2 respectively. Nine obese individuals, whose mean age was 47 years, mean weight 116 Kg. and mean height and surface area 170 cm. and 2.13 M^2, were also studied. All were more than 25% heavier than their ideal weight. None of the obese subjects gave a history of pulmonary, cardiac or neuromuscular disease and they were asymptomatic aside from somnolence and exertional dyspnea which were present in a few.

Ventilatory function was assessed in 22 subjects. Vital capacity, inspiratory capacity, maximum expiratory mid-flow rates and maximum breathing capacity were measured using a Collins respirometer with the valves and CO_2 absorber removed and a high speed rotating drum incorporated. The maximum of at least three trials was recorded. Predicted values were determined from the data of Baldwin, Cournand, and Richards (6).

The intrapulmonary mixing of inspired gas was assessed by determining the breath to breath washout of nitrogen from the lungs while breathing oxygen, and by measuring the concentration of nitrogen remaining in the alveolar gas after seven minutes by means of an instantaneously recording nitrogen meter (7). The functional residual capacity (FRC) was determined by measuring the volume and nitrogen concentration of the expired gas at the end of the seven minute period. Total lung capacity was derived by adding the inspiratory capacity to the FRC.

Arterial blood gas analysis was performed in seven of the nine obese subjects by the method of Riley et al (8) as modified by Brinkman et al (9). All had low oxygen tensions at rest and in two, these were associated with hypercapnia.

In five of the nine obese subjects the oxygen cost of breathing was determined and found to be elevated. These patients formed part of a series reported elsewhere (5).

All subjects reported to the laboratory without special preparation and were asked to remove any restrictive garments. A latex balloon was positioned in the oesophagus and a nose clip fitted tightly. The subject then entered an air-tight body plethysmograph and breathed through a tube into and out of an oxygen filled spirometer containing a CO_2 absorber situated outside the plethysmograph.

The oesophageal-mouth pressure differential was used as an index of transpulmonary pressure. A pneumotachometer was incorporated into the airway in order to record air flow. Recordings of plethysmograph pressure, transpulmonary pressure and air flow were obtained by means of strain guages leading to three channels of a Sanborn Polyviso recorder while simultaneous changes in lung volume were obtained from the spirometer tracing.

Following a period of tidal breathing at the resting level, from eight to twenty different continuous pressures ranging between plus 20 and minus 25 cm. H_2O were applied around the body by means of a motor blower attached to the plethysmograph. The resultant changes in lung volume and end-expiratory transpulmonary pressure were noted for each pressure applied, after the breathing became steady at the new lung volume. The mean of five to ten breaths was used; the end-expiratory point being determined by the point of zero flow on the pneumotachogram. The subject was allowed to return to the resting lung level after each application of pressure.

In 12 of the 14 normal subjects and in seven of the nine obese subjects, studies were performed both in the seated and supine positions.

An example of the type of records obtained and the method of their analysis is shown in Figure 1. It can be seen that a change in plethysmograph pressure of minus 15 cm. H_2O resulted in an increase in lung volume of 1500 ml. and a simultaneous change in transpulmonary pressure of 8 cm. H_2O. The change in pressure across the chest wall was therefore 7 cm. H_2O. Since compliance represents the volume change (in liters) associated with a static pressure change of 1 cm. H_2O the compliance of the total respiratory system was .100 l./cm. H_2O; the compliance of the lung was .187 l./cm. H_2O and that of the chest wall was .214 l.cm. H_2O.

For each subject static volume changes were plotted against the simultaneous pressure changes across the total respiratory system, the lung and the chest wall separately, in the sitting and supine positions. In order to compare the normal and the obese subjects lung volume at various pressures was expressed as a percentage of the total lung capacity. A typical example of the pressure-volume curves obtained in normal subjects is shown in Figure 2. In addition, compliance was calculated by determining the pressure required to increase lung volume by 10% of the total lung capacity from the resting level and expressed as liters per cm. H_2O.

Four normal and two obese subjects were each studied on two separate occasions. Compliance values determined on the second occasion did not differ from the initial study by more than 15%. No consistent direction of change was noted.

Results

Normal Subjects

The pressure-volume curves for the total respiratory system, the lung and the chest wall are shown separately for all the normal subjects in Figure 3. It can be seen that the curves for the total respiratory system, the lung and the chest wall are roughly sigmoid in shape. Since the "slopes" of the curves are an expression of compliance it is evident that the compliance of the lung and chest wall are nearly equal. It can also be noted that in some of the normal subjects the pressure-volume curve of the chest wall had an increasing slope over the range of volume achieved. In two other subjects this type of curve was obtained only when they were supine.

The calculated compliance values obtained in normal subjects in both the seated and supine positions are shown in Table IIA. In the seated position the mean compliance of the total respiratory system was .120 (S.D. .044) l./cm. H_2O; the compliance of the lung was .304 (S.D. .094) l./cm. H_2O and that of the chest wall was .209 (S.D. .083)

1./cm. H_2O.

Obese Subjects

The results of the ventilatory function studies are listed on Table I. It will be seen that some of the obese subjects had fairly marked reduction in vital capacity and maximum breathing capacity. However, maximal mid-flow rates revealed no evidence of bronchiolar obstruction. The concentration of nitrogen in the alveolar gas after seven minutes of oxygen breathing was within normal limits in the obese subjects.

The pressure-volume curves derived for the obese subjects are shown in Figure 4. It is apparent that the pressure-volume curves for the total respiratory system are flatter in the obese than in the normal individuals. The curves for the chest wall are more obviously flattened than those obtained in the normals. On the other hand, the curves for the lung are not different in slope than those obtained in the normal subjects.

The calculated compliance values obtained in the obese subjects are shown in Table IIB. In the seated position the mean compliance of the total respiratory system was .058 (S.D. .024) 1./cm. H_2O; the compliance of the lung was .177 (S.D. .086) 1./cm. H_2O and that of the chest wall was .089 (S.D. .039) l./cm. H_2O. While the compliance of the lung did not differ from the normals, the compliance of the total respiratory system and the chest wall were significantly lower than the normal ($p < .01$) in the seated position.

The Effect of Posture on Compliance

The effect of recumbency on the pressure-volume diagrams of a normal and an obese subject is shown in Figure 5. It will be noted both in the normal and the obese subject there was a decrease in the resting level in the supine position. In the normal subject during recumbency the slope of the pressure-volume curves of the total respiratory system was unaltered and the slope of the curve for the lung was decreased while the slope of the pressure-volume curve of the chest wall was actually increased. On the other hand, in the obese subject during recumbency the slopes of the pressure-volume curves of the total respiratory system and of the chest wall were appreciably reduced, while that of the lung was unaltered.

The effect of posture on the derived compliance values in the normal and obese subjects is shown in Table IIA and B. It can be seen that the compliance values in the supine position were no different than those obtained in the seated position in the normal subjects. On the other hand, the reduction in the compliance of the total respiratory system and the chest wall indicated in Figure 5 was observed in six of the seven obese subjects studied in the supine position. This reduction in compliance of the chest wall on assumption of the supine position was significant ($p < .05$).

The effect of recumbency on the distension pressure required to increase lung volume by 10% of the total lung capacity starting from a lung volume equal to the resting lung volume in the seated position, in normal and obese subjects, is shown in Table III. It can be seen that distension pressures were unchanged in the supine position in the normal subjects. In the obese subjects, on the other hand, the distension pressure for the total respiratory system and that for the chest wall were increased an average of 60% in the supine position while that for the lung was unchanged.

Discussion

While the compliance of the lung may be studied with relative ease in the spontaneously breathing subject, that of the chest wall (i.e. those extrapulmonary structures which are deformed or displaced during breathing) is more difficult to measure. It has been estimated in the "relaxed" normal subject (10) ventilated by a respirator and in anesthetized subjects under the influence of muscle relaxants (11) by subtracting the compliance of the lung from that of the total respiratory system.

The disadvantages of these methods are the necessity for expert co-operation from the subject, or special conditions such as anesthesia and muscular paralysis and that they may not reflect the elastic resistance actually encountered during spontaneous breathing.

Studies of the compliance of the respiratory system reported in this study have been carried out in spontaneously breathing unanesthetized subjects. Our results are similar to those of Heaf and Prime who have provided the only other estimate of the compliance of the chest wall in the spontaneously breathing unanesthetized subject (12). They have pointed out that the measurement of chest wall compliance by the technique used in the present study is based on the assumption that the volume change produced by the application of pressure around the thorax is dependent only on the passive resistance to distension offered by the chest wall and lung. This implies that no active resistance by the respiratory musculature must be overcome. The extent to which such active resistance was operative in the studies reported in this paper is unknown. Our results also agree closely with those of Butler and Smith (11) who studied subjects under the influence of anesthesia and muscle relaxants. This supports the assumption that our subjects were indeed "relaxed".

The finding that the pressure-volume curve for the chest wall in some of the normal subjects was not sigmoid but had an increasing slope over the range of lung volume obtained is of considerable interest. This phenomenon has been reported by other workers (11). Since the subjects in whom this was observed were breathing at a low percentage of their total lung volume at rest, this phenomenon may in some way be related to resting lung volume. This is supported by the finding that this phenomenon appeared in two subjects only when they assumed the recumbent position, in which the resting level is also reduced.

The data presented indicate that the compliance of the total respiratory system is reduced in obese individuals. This reduction in compliance is almost entirely due to a reduction in compliance of the chest wall. Thus, there is an increase in elastic resistance to distension in obese individuals. The resistance to distension offered by the chest wall is increased an average of 60% in the obese individual. These findings support the hypothesis of other investigators that the increased oxygen cost of breathing in obesity is at least in part due to an increased mechanical work done to overcome the elastic resistance of the chest wall. Non-elastic resistances of the chest wall and a reduced muscular efficiency may also contribute to the increased oxygen cost of breathing.

It is noteworthy that in these obese individuals the compliance of the total respiratory system is reduced even further in the recumbent position. The increase in resistance to distension during recumbency is entirely due to an increased resistance offered by the chest wall in this position. Thus, while the resistance of the chest wall is an average of over 70% of the total resistance to distension in the obese subject in the seated position this is increased to over 80% in the supine position, and is almost four times as great as the resistance in the normal individuals in the same position.

Summary and Conclusions

1. The compliance of the total respiratory system and its components was studied in 14 normal and nine obese spontaneously breath-

ing unanesthetized subjects.

2. The mean compliance of the total respiratory system was .120 l./cm. H_2O in normal individuals but was reduced to .058 l./cm. H_2O in obese subjects indicating an increased elastic resistance to distension.

3. The compliance of the lung was not different in obese individuals compared to normals.

4. The compliance of the chest wall was .209 l./cm. H_2O in normal subjects but was reduced to .089 l./cm. H_2O in obese individuals.

5. In contrast to normal subjects total respiratory compliance was markedly reduced by recumbency in obese individuals. This was entirely due to a further increase in the resistance of the chest wall.

6. Evidence has been provided which supports the contention that the increased oxygen cost of breathing in obesity may be due to an increased work of breathing required to overcome the elastic resistance of the chest wall.

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TABLE I

PHYSICAL CHARACTERISTICS AND PULMONARY FUNCTION OF SUBJECTS STUDIED

CONDITION	SUBJ. (No.)	SEX	AGE (yr.)	HEIGHT (cm.)	WEIGHT (Kg.)	B.S.A. (M^2)	VITAL CAPACITY (ml.)	VITAL CAPACITY (%Pred.)	MAXIMUM BREATHING CAPACITY (l/min.)	MAXIMUM BREATHING CAPACITY (%Pred.)	ALVEOLAR N_2 AFTER 7 MIN. O_2 (%)	TOTAL LUNG CAPACITY (ml.)
NORMAL	1	M	31	174	79	1.94	5750	113	135	118	0.6	5900
	2	M	27	178	77	1.95	5500	110	143	120	0.5	6640
	3	F	19	163	66	1.71	3835	119	125	130	0.8	4800
	4	F	27	165	69	1.76	4445	136	162	164	1.4	6464
	5	M	24	184	85	2.08	5362	138	198	143	0.7	6260
	6	M	25	180	73	1.98	4950	113	139	105	0.8	5284
	7	M	26	180	73	1.98	5444	121	173	128	2.4	6130
	8	M	42	179	86	2.05	4700	113	133	113	1.1	5540
	9	M	21	193	93	2.27	7070	142	228	155	1.2	8320
	10	M	23	170	82	1.94	5750	154	180	125	1.0	7750
	11	M	25	173	67	1.80	5080	122	170	134	1.1	7510
	12	M	21	178	77	1.95	7320	162	205	152	0.6	7950
	13	M	22	180	73	1.91	5400	121	286	214	0.8	7300
	14	M	46	171	68	1.80	4790	123	159	145	0.8	5090
OBESE	A	M	34	173	167	2.65	2970	74	55	47	0.7	5030
	B	M	60	161	105	2.06	4095	117	110	120	1.2	4120
	C	M	70	178	130	2.43	4070	112	111	126	0.4	5190
	D	F	32	163	91	1.96	3480	113	54	58	0.4	5250
	E	F	58	170	116	2.24	2386	86	49	58	0.9	4130
	F	F	50	155	88	1.87	2260	91	73	95	1.2	3350
	G	F	53	165	89.5	1.97					1.8	5385
	H	F	17	165	95	2.01	4115	123	48	48	0.6	4840
	J	F	48	156	103	2.00	2650	105	71	91	0.4	5015

TABLE II

RESPIRATORY COMPLIANCE IN NORMAL AND OBESE SUBJECTS

	SUBJECT	TOTAL (l/cm. H_2O) Seated	Supine	LUNG (l/cm. H_2O) Seated	Supine	CHEST WALL (l/cm. H_2O) Seated	Supine
A. NORMAL	1	.075	.088	.369	.316	.094	.121
	2	.141	.186	.368	.442	.279	.320
	3	.087	.089	.267	.216	.130	.152
	4	.072	.050	.154	.107	.135	.092
	5	.099	.156	.216	.375	.184	.268
	6	.143		.393		.224	
	7	.085	.130	.198	.329	.150	.214
	8	.168	.143	.395	.397	.291	.222
	9	.173	.140	.362	.293	.333	.269
	10	.138	.097	.323	.293	.242	.149
	11	.107	.143	.268	.291	.179	.274
	12	.215	.141	.441	.234	.346	.370
	13	.074	.104	.252	.173	.104	.261
	14	.104		.250		.284	
	Mean	.120	.122	.304	.289	.209	.226
	S.D.	.044	.037	.086	.095	.083	.084
B. OBESE	A	.059	.035	.140	.136	.103	.047
	B	.077	.056	.246	.246	.111	.072
	C	.107	.037	.367	.412	.151	.042
	D	.077	.057	.175	.164	.138	.085
	E	.034		.103		.052	
	F	.028		.084		.042	
	G	.038	.031	.148	.151	.051	.039
	H	.047	.045	.138	.123	.071	.071
	J	.059	.052	.193	.129	.080	.068
	Mean	.058	.045	.177	.194	.194	.061
	S.D.	.024	.011	.086	.105	.039	.018

TABLE III

DISTENSION PRESSURE* IN NORMAL AND OBESE SUBJECTS

	SUBJECT	TOTAL (cm. H_2O/10% TLC)		LUNG (cm. H_2O/10% TLC)		CHEST WALL (cm. H_2O/10% TLC)	
		Seated	Supine	Seated	Supine	Seated	Supine
A. NORMAL	1	7.9	6.5	1.6	1.9	6.3	4.6
	2	4.7	3.5	1.8	1.5	2.9	2.0
	3	5.5	5.5	1.8	2.1	3.7	3.4
	4	9.0	16.7	4.2	6.7	4.8	10.0
	5	6.3	4.2	2.9	1.8	3.4	2.4
	6	4.4		1.6		2.8	
	7	7.2	5.7	3.1	2.7	4.1	3.0
	8	3.3	3.9	1.4	1.5	1.9	2.4
	9	4.8	5.6	2.3	2.6	2.5	3.0
	10	5.6	8.0	2.4	3.0	3.2	5.0
	11	7.0	4.6	2.8	2.6	4.2	2.0
	12	3.7	5.8	1.8	4.2	2.3	1.6
	13	9.9	5.7	2.9	4.4	7.0	1.3
	14	5.0		2.0		3.0	
	Mean	6.0	6.3	2.4	2.9	3.6	3.4
B. OBESE	A	8.5	21.0	3.6	3.6	4.9	17.4
	B	6.4	9.0	2.0	2.6	4.4	6.4
	C	4.8	17.3	1.4	1.3	3.4	16.0
	D	6.8	9.2	3.0	3.2	3.8	6.2
	E	12.0		4.0		8.0	
	F	12.0		4.0		8.0	
	G	14.3	20.1	3.7	4.1	10.6	16.0
	H	10.3	12.7	3.5	3.6	6.8	9.1
	J	7.2	14.0	2.1	2.3	5.1	11.7
	Mean	9.1	14.8	3.0	3.0	6.1	11.8

* Pressure required to increase lung volume by ten percent of the total lung capacity. In the seated position the initial level was the resting lung volume. An equal lung volume was used as the initial level in the supine position.

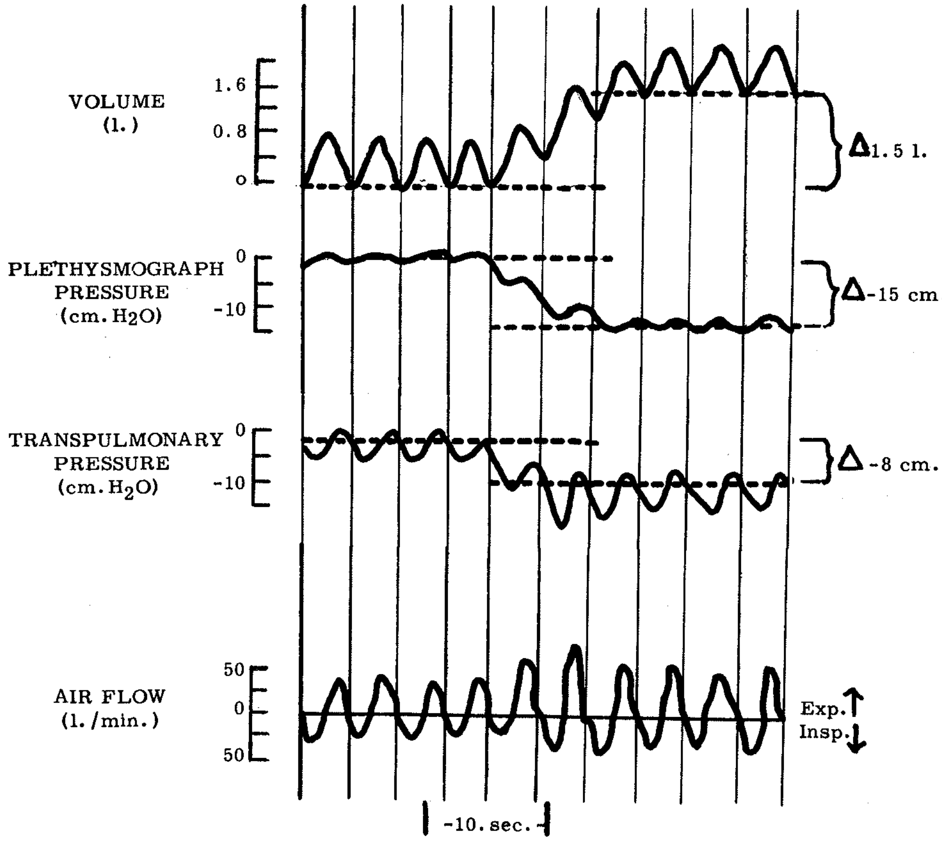

Figure 1. Simultaneous recordings of air flow, transpulmonary pressure, plethysmograph pressure and volume obtained while breathing at ambient pressure and during application of a negative pressure around the body in a plethysmograph.

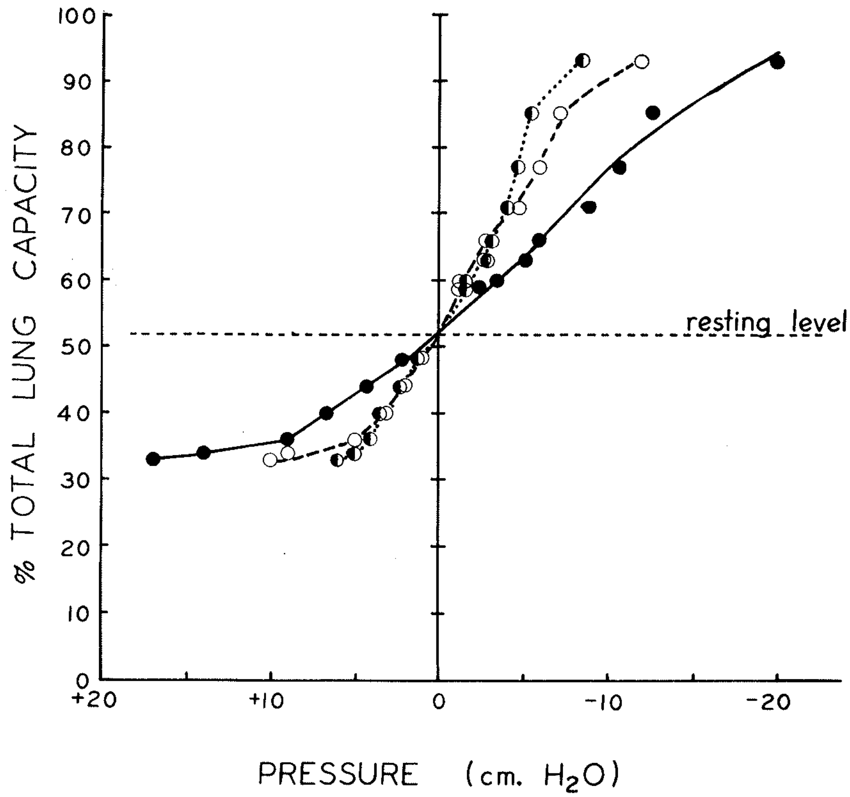

Figure 2. Pressure-volume relationships of the total respiratory system (closed circles), the lung (open circles) and chest wall (half open circles) in a normal subject (14). Plethysmograph pressure represented the pressure across the total respiratory system; oesophageal-mouth pressure, the pressure across the lung and the difference between plethysmograph pressure and the oesophageal-mouth pressure, the pressure across the chest wall.

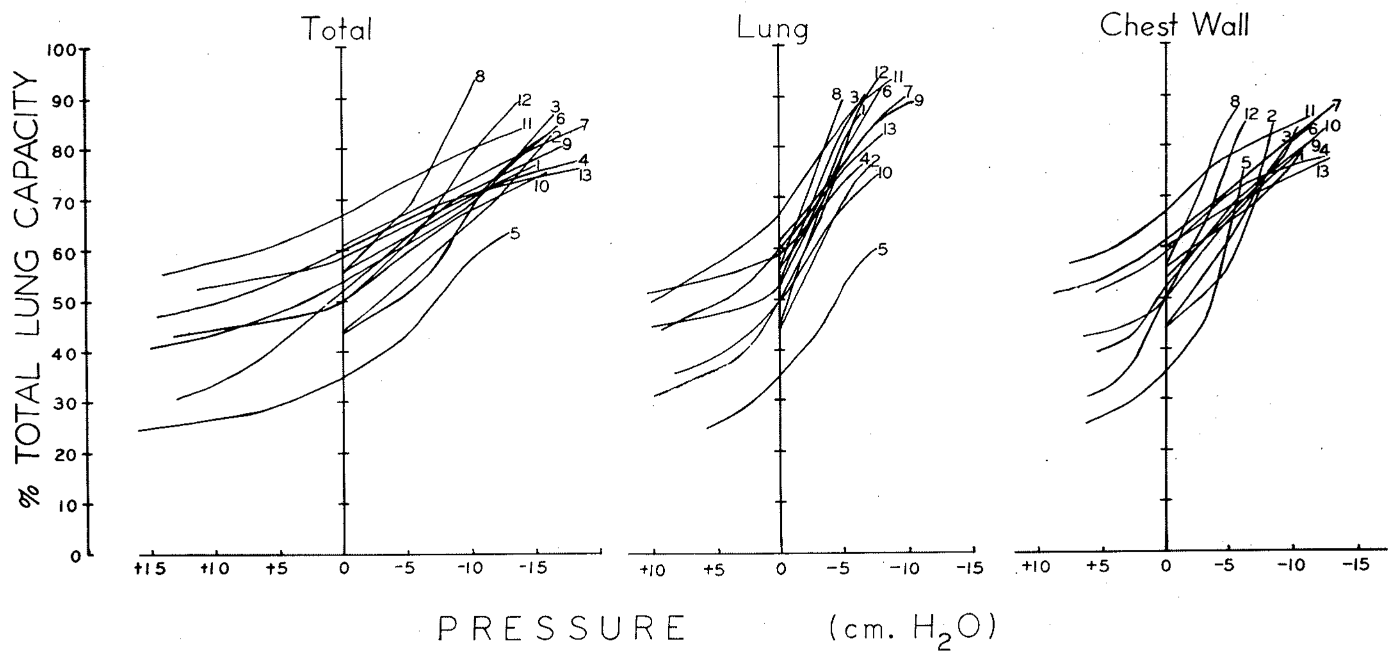

Figure 3. The pressure-volume relationships of the total respiratory system, the lung and the chest wall in a group of normal subjects.

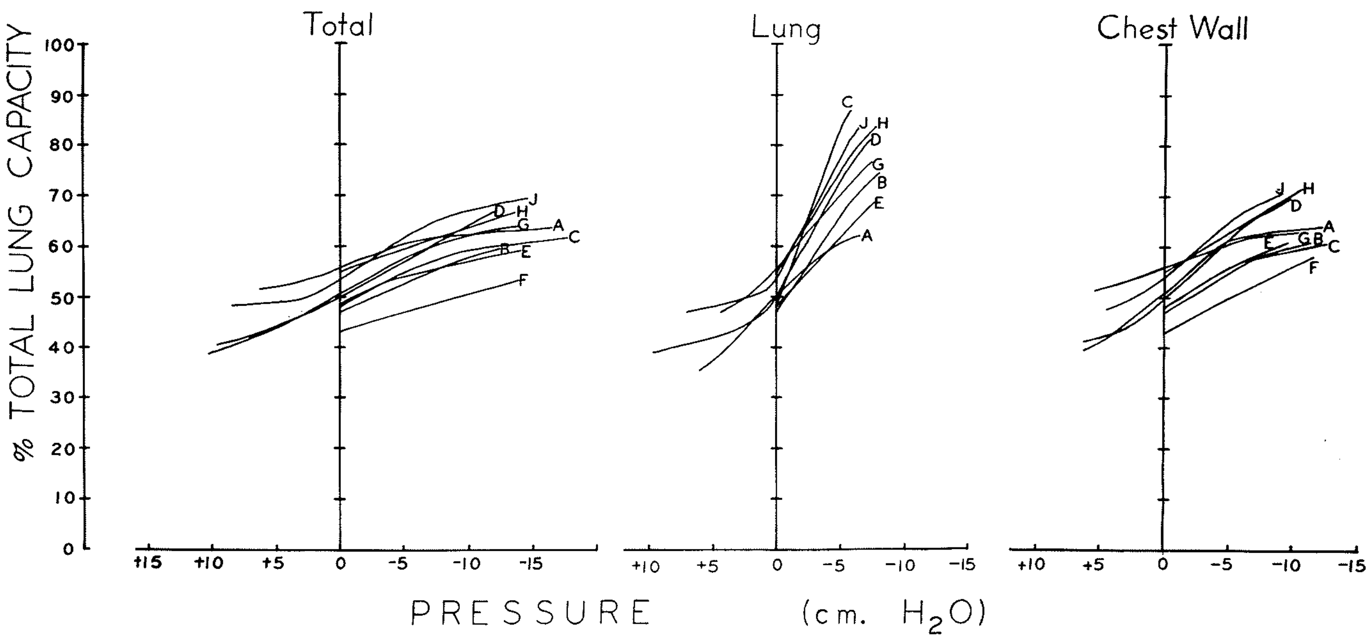

Figure 4. The pressure-volume relationships of the total respiratory system, the lung and the chest wall in a group of obese subjects.

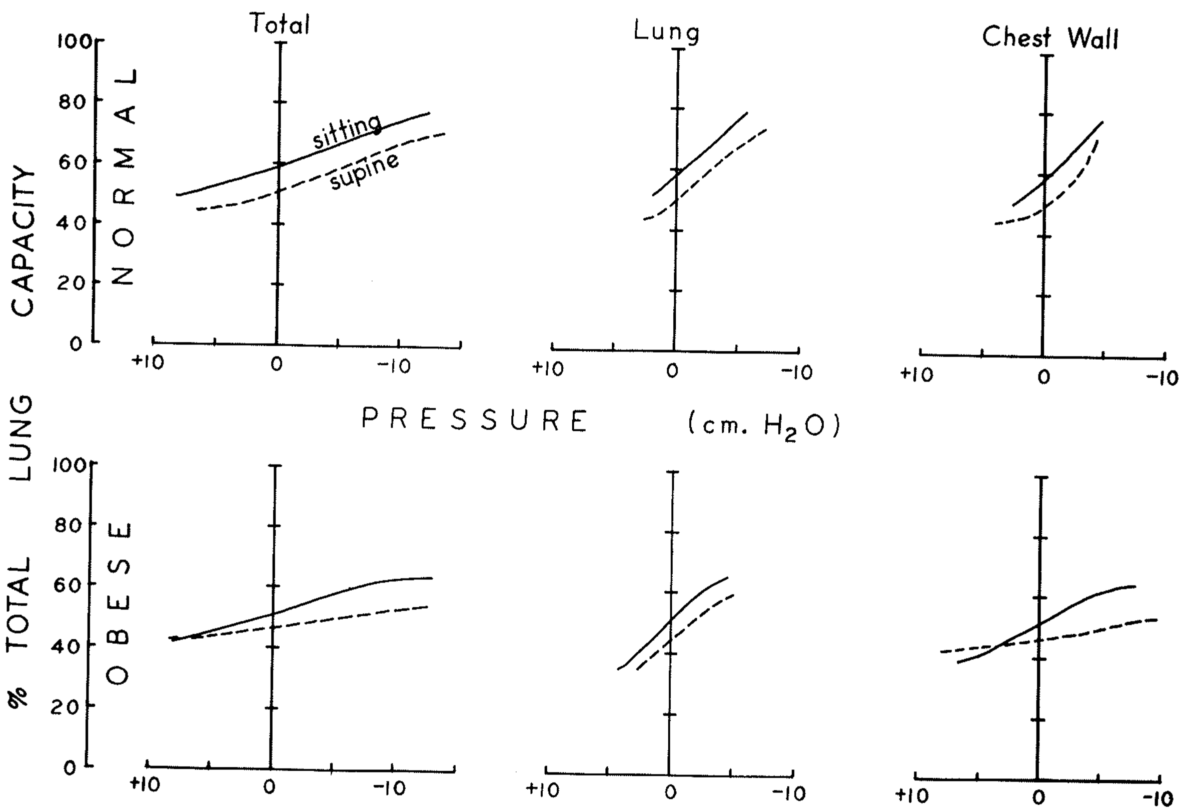

Figure 5. The effect of recumbency on the pressure-volume relationships of the total respiratory system, the lung and the chest wall in a normal and an obese individual.