THE VARIOUS FACTORS OF RESPIRATION IN PERSONS WITH PNEUMOTHORAX.

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Plates 44 and 45.

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In connection with the study of the respiration in experimental pneumonia, recently reported by Newburgh, Means, and Porter,[1] it became desirable to find out what effect a great reduction in the functioning lung surface would have on the various factors of respiration. Since pneumothorax presents this condition, the present research was undertaken. Our observations were made upon four cases in which pneumothorax was being produced for the treatment of pulmonary disease, and upon one case of spontaneous pneumothorax.[2]

The clinical data on the five cases are given below.

Case 1.—B. D., female, age 27 years. Artificial pneumothorax.

The first symptoms of pulmonary tuberculosis began 4 years ago. She lost ground rapidly for a year, in spite of rigid sanatarium treatment, and then injections of nitrogen were begun. She soon began to improve and the treatment has been continued ever since. There have been thirty-four injections in all. The dosage was about 1,000 cc. at first; now the average is 500 cc. In March, 1916, she had no symptoms of phthisis and was leading a normal life. Immediately after an injection she was somewhat short of breath, on exertion only.

Physical examination showed the usual signs of pneumothorax in the left chest. X-ray showed a nearly complete collapse of the left lung (Fig. 1).

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[1] Newburgh, L. H., Means, J. H., and Porter, W. T., *J. Exp. Med.*, 1916, xxiv, 583.

[2] Case 2 was a patient at the House of the Good Samaritan, Boston. We are indebted to the superintendent of that institution for making it possible for us to study the case and for furnishing much valuable information.

Case 2.—M. G., female, age 20 years. Artificial pneumothorax.

The first symptoms of pulmonary tuberculosis began 2½ years ago. She has had sanatarium treatment most of the time since. 3 months ago she had much cough and sputum and was running a high evening temperature. Physical examination at that time showed extensive involvement of the left lung with cavity formation, and very slight signs at the right apex. Collapse of the left lung was then begun. Twelve injections of nitrogen have been made in all. Marked improvement was at once apparent. In November, 1915, physical examination showed signs of pneumothorax over the left chest, and x-ray showed an extensive collapse of the left lung.

Case 3.—S. M. H., female, age 32 years. Spontaneous pneumothorax.

The past history is negative.

10 months ago while dancing she suddenly became short of breath. 2 weeks later a diagnosis of pneumothorax was made. The dyspnea gradually decreased, and in November, 1915, she had slight dyspnea on exertion only. She entered the hospital on November 4, 1915, at which time physical examination showed the signs of pneumothorax over the whole left chest, and x-ray showed an extensive left-sided pneumothorax with slight displacement of the heart toward the right. The right lung showed evidence of tuberculosis.

The Wassermann test was negative. The blood showed slight secondary anemia. The pulse, temperature, and respiration rate were all normal while she was in the hospital.

Case 4.—M. P., female, age 22 years. Artificial pneumothorax.

The patient was believed to have a lung abscess.

The family and past history are unimportant. She entered the Massachusetts General Hospital on June 5, 1916, having previously been a private patient of one of us. The history was that of a productive cough of 7 months' duration with considerable loss of strength, and occasional night sweats. The sputum was purulent and copious and was raised most abundantly in the morning. There had been hemoptysis on several occasions. Physical examination at the time of entry showed an area of dullness in the middle of the left back with crackling râles and dullness, with increased breath sounds at the left top posteriorly.

The Wassermann test on the blood was negative. She occasionally ran a slight fever while in the ward.

An x-ray plate taken April 30, 1916, showed an area of dullness between the second and fourth ribs on the right, which extended across the chest from the lung root to the axillary border. This dullness was of an even consistency except at the borders where there was some mottling. The apices were clear, but there was some thickening about the hilus of each lung.

It was thought that she probably had a lung abscess in the lower part of the right upper lobe, and treatment by artificial pneumothorax was undertaken. The following injections of nitrogen were made while she was in the ward.

	cc
June 8	600
" 9	500
" 12	650
" 18	900
" 24	300
July 3	700
" 6	800

A partial pneumothorax only was secured, as was shown by a series of x-ray plates (Figs. 2 and 3).

June 11. X-ray showed a small area of pneumothorax extending as high as the fifth rib in the axillary border on the right. Otherwise as previously described.

June 13. X-ray showed the lower lobe fairly well collapsed.

June 19. X-ray showed slightly more pneumothorax than at the last examination.

Case 5.—L. R., male, age 22 years. Artificial pneumothorax.

A case of bilateral pulmonary tuberculosis of 4 months' duration with active signs in the left upper lobe. Gradual loss of weight, fever, hemoptysis, and many tubercle bacilli in the sputum. As the disease was rapidly progressing and a brisk hemoptysis had set in, and since the patient was beginning to have an elevated temperature, it was decided to induce artificial pneumothorax and collapse the left lung (Fig. 4).

After the first two injections the patient raised about 8 ounces of blood during the succeeding 3 days, and it was feared the blood might come from the non-collapsed lung. As no signs of activity were noticeable in the non-collapsed lung, more nitrogen was introduced into the left pleural cavity, and soon after that the blood and sputum ceased.

At the present time the patient has a well collapsed left lung, is up and about every day, with no respiratory embarrassment, no cough or sputum, and has gained in weight.

The injections of nitrogen in the case were as follows:

	cc.
April 8	750
" 12	750
" 20	700
May 5	600
June 2	500
" 12	600

Observations with the Unit Apparatus.

Experiments with Benedict's Unit Apparatus (spirometer type, subjects breathing through a mouthpiece) were done with Cases 1, 2, and 3, in the fasting condition, lying prone, at complete rest. The data are given in Table I.

TABLE I.

Experiments with the Unit Apparatus.

Period.	Carbon dioxide per min.	Oxygen per min.	Respiratory quotient.	Ventilation per min. (reduced).	Respiration rate.	Volume per respiration (reduced).	Pulse.	Carbon dioxide in expired air (calculated).
	cc.	*cc.*		*liters*		*cc.*		*per cent*
Case 1. Weight 53.3 kg. Height 174.2 cm. Nov. 8, 1915.								
1	161	210	0.77	5.86	14.8	396	79	2.75
2	160	216	0.74	5.37	12.4	433	76	2.98
3	165	214	0.77	5.25	12.1	433	74	3.14
Average..	162	213	0.76					
Case 2. Weight 57.2 kg. Height 167.5 cm. Nov. 12, 1915.								
1	179	259	0.69	7.06	19.7	358	109	2.54
2	169	236	0.72	6.73	19.4	347	105	2.51
3	171	236	0.72	6.68	19.1	349	102	2.56
Average..	173	244	0.71					
Case 3. Weight 64.5 kg. Height 163.8 cm. Nov. 16, 1915.								
1	184	224	0.82	6.12	14.3	428	87	3.00
2	164	215	0.76	5.77	14.4	400	84	2.84
3	164	217	0.76	5.58	14.2	393	81	2.94
Average..	171	219	0.78					

Basal Metabolism.—This was calculated in each case from the average oxygen absorption and the calorific value of oxygen for the respiratory quotient obtained.[3]

The body surface of each subject was determined by the Du Bois height-weight chart,[4] and the metabolism expressed in terms of the area thus found, was as follows:

Case 1. 37.3 calories per sq. m. per hr.
" 2. 42.0 " " " " " "
" 3. 36.9 " " " " " "

[3] Williams, H. B., Riche, J. A., and Lusk, G., *J. Biol. Chem.*, 1912, xii, 357.
[4] Du Bois, D., and Du Bois, E. F., *Proc. Soc. Exp. Biol. and Med.*, 1916, xiii, 77.

Alveolar Carbon Dioxide Tension.—In three of the cases of artificial pneumothorax the alveolar carbon dioxide tension was determined by the Plesch-Higgins method. The results were:

	mm.
Case 1	44.3
" 2	39.0
" 5	41.5

Sensitivity of the Respiratory Center.—In three of the cases the sensitivity of the respiratory center was determined by obtaining the reaction to carbon dioxide. The experiment was carried out with the unit apparatus by replacing the absorbers with a large dead space, so that the carbon dioxide gradually accumulated. The curves shown in Tables II, III, and IV were obtained. In Case 4 one curve was secured before and two after the production of pneumothorax.

TABLE II.

Case 1. Reaction to Carbon Dioxide. Subject Lying on Back.

Carbon dioxide in inspired air.	Respiration rate.	Volume per respiration.	Total ventilation per min. (unreduced).	Ventilation coefficient. Increase in total ventilation. Start=100 per cent.
per cent		*cc.*	*liters*	*per cent*
		Feb. 5, 1916.		
0.00	12.0	460	5.51	100
1.42	14.3	481	6.90	125
3.06	13.0	605	7.88	143
3.63	15.3	611	9.36	170
4.66	15.7	765	12.00	217
5.30	15.8	870	13.75	250
5.81	17.0	876	14.90	270
6.50	18.2	975	17.75	322
		Mar. 27.		
0.00	15.5	403	6.25	100
2.58	15.8	536	8.49	136
3.71	16.0	596	9.55	153
4.66	17.5	667	11.69	187
5.70	19.0	741	14.10	226
6.41	19.3	920	17.75	284
7.14	20.0	910	18.20	292
7.60	21.0	1,017	21.35	341

TABLE III.

Case 4. Reaction to Carbon Dioxide. Subject Lying on Back.

Carbon dioxide in inspired air.	Respiration rate.	Volume per respiration.	Total ventilation per min. (unreduced).	Ventilation coefficient. Increase in total ventilation. Start = 100 per cent.
per cent		*cc.*	*liters*	*per cent*
June 6, 1916. Before nitrogen injections had been begun.				
0.00	25.0	336	8.40	100
1.43	25.8	389	10.03	119
3.00	28.3	410	11.60	138
4.40	24.8	556	13.80	164
5.15	24.5	641	15.70	187
5.80	30.5	778	23.73	283
6.60	30.8	1,050	32.35	385
June 14. Has had three injections of nitrogen since last experiment.				
0.00	34.0	284	9.65	100
1.92	35.5	336	11.90	123
3.53	37.0	420	15.2	161
4.52	39.0	525	20.55	212
5.43	39.0	630	24.40	254
6.20	41.0	735	30.615	312
June 30. Two more injections of nitrogen.				
0.00	20.2	420	8.49	100
2.21	25.0	441	11.10	132
4.56	32.5	630	20.50	242
5.21	41.0	630	25.80	304
5.95	44.0	735	32.40	382

TABLE IV.

Case 5. Reaction to Carbon Dioxide. Subject Lying on Back.

Carbon dioxide in inspired air.	Respiration rate.	Volume per respiration.	Total ventilation per min. (unreduced).	Ventilation coefficient. Increase in total ventilation. Start = 100 per cent.
per cent		*cc.*	*liters*	*per cent*
June 12, 1916.				
0.00	23.2	462	10.70	100
2.81	24.5	567	13.90	130
3.96	25.5	777	19.78	185
6.23	32.0	1,177	37.70	352
6.71	36.0	1,240	44.60	417

Vital Capacity.—The vital capacity was secured in Cases 1, 4, and 5. Case 1 fortunately had had some determinations made of her vital capacity while she was in college, which she was able to obtain for us. These determinations were as follows:

		liters
Oct. 1906	Vital capacity	2.6
" 1907	" "	2.5
	Weight 61 kg.	
" 1910	Vital capacity	2.1
	Weight 63 kg.	

The last was 2 years before the diagnosis of phthisis was made, and she says that she is sure she had tuberculosis at that time, as she distinctly remembers having a slight cough and tiring easily. This fact would explain the decrease in vital capacity.

On February 5, 1916, three determinations of her vital capacity, taken about 5 minutes apart, gave the following results:

	liters
Vital capacity	1.11
" "	1.11
" "	1.26

On March 27, 1916, the vital capacity was 1.5 liters.

The greater value obtained on March 27 is probably due to the fact that the last injection of nitrogen had been 4 weeks before, whereas on February 5, she had had one only 3 weeks before.

In Case 4 one determination was secured before any injections of nitrogen had been made, and two afterward.

On June 6 her vital capacity was 2.74 liters.

On June 14, after she had had three injections of nitrogen, it was 1.36, 1.40, average 1.38 liters.

On June 30, after five injections, it was 1.63 liters.

In other words, although by x-ray only a partial collapse of the right lung was present, yet functionally there was a reduction to one-half her original available ventilating space.

The vital capacity of Case 5 was observed but once. On June 12, it was 1.57 liters, which is less than half what we should expect in a man of medium weight and height.

DISCUSSION.

The observations on these five subjects show that all the factors of respiration are essentially normal in persons with one lung collapsed. The gaseous exchange is normal, for if we calculate the basal metabolism, we get normal values: 37.3 calories per sq. m. per hour for Case 1, 42.0 for Case 2, and 36.9 for Case 3 are all within 10 per cent of the normal average for women of their age. The respiratory quotients are perfectly reasonable except that that for Case 2, of 0.71, is somewhat low. She was, however, the subject with the most active tuberculosis and might easily have an increased catabolism and so reach a fasting respiratory quotient sooner than a normal subject.

The respiration rate, the volume per respiration, and the total ventilation of the lungs, in the three cases in which they were determined, are probably all within normal limits, though possibly the total ventilation in Case 2 is a little higher than is usually found.

The percentage of carbon dioxide in the expired air is within normal limits in Cases 1 and 3, but is somewhat low in Case 2.

The alveolar carbon dioxide by the Plesch method was normal in Case 1 (44.3 mm.) and Case 5 (41.5 mm.), but was somewhat low (39 mm.) in Case 2. This probably explains the low percentage of carbon dioxide in the expired air, and the higher ventilation in the case of the last subject. It may have been due to a very slight acidosis.

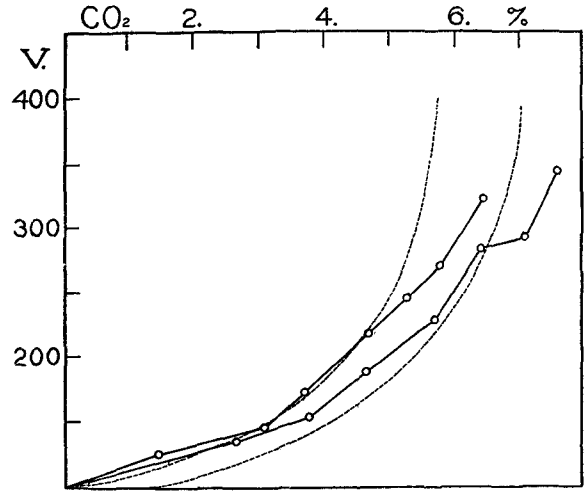
The reactions to increasing amounts of carbon dioxide in all the cases studied in this manner show that up to the point at which the respiration is trebled (at from 5.5 to 6.5 per cent of carbon dioxide in the inspired air) the increase in ventilation falls within the normal zone determined by Peabody,[5] as is shown in Table V. In this table the curves have been simplified by reducing the figures for ventilation increase to correspond to even percentages of carbon dioxide. This was done by plotting the actual observations and drawing the most probable curve through these points, then reading the values at the even percentages. The curves obtained with Case 1 are also shown graphically in Text-fig. 1.

[5] Peabody, F. W., *Arch. Int. Med.*, 1915, xvi, 851.

TABLE V.

Summary of Carbon Dioxide Reactions.

Subject.	Date.	Increase in ventilation to increasing amounts of carbon dioxide in the inspired air.						
		Carbon dioxide.						
		1 per cent.	2 per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Case 1.	Feb. 5	116	131	143	190	235	285	
	Mar. 27	112	126	140	162	200	243	305
Case 4.	June 6	110	125	138	157	190	305	
	" 14	110	125	145	177	225	300	
	" 30	115	130	170	215	285	390	
Case 5.	June 12	112	122	140	190	263	336	455
Reactions of normal persons, taken from Peabody's diagram.		0 to 112	105 to 130	122 to 150	148 to 185	180 to 250	237 to 450	350 and up.



TEXT-FIG. 1. Case 1. Reaction to carbon dioxide. The ordinates show the percentage of carbon dioxide in the inspired air, the abscissæ the ventilation coefficient. The subject's normal ventilation, breathing atmospheric air, is called 100 per cent. At 200 per cent the ventilation is doubled, etc. The dotted lines represent Peabody's group of reactions in normal subjects.

The reaction obtained on February 5 with Case 1 was discontinued at 6.5 per cent of carbon dioxide; that of March 27, however, was continued up to 7.6 per cent carbon dioxide. It is interesting to note that in the latter curve the last two points show a distinct decrease in reaction, a flattening of the curve, while in Peabody's normal cases this was the point at which the curve became steeper. We interpret this finding as meaning that the subject reaches her limit at this point. The normal respiratory apparatus can increase the normal resting ventilation from four- to eightfold without great discomfort. This patient, with one lung, has a lower limit, but up to her limit reacts normally.

In some experiments upon one of us, Newburgh and Means found that the ventilation was trebled when the subject was doing about 500 kg. m. of work per minute.[6] This would be the equivalent in Case 1 of going up about three flights of stairs in 1 minute. As a matter of fact, she can do more than that without urgent dyspnea. At the end of each reaction to carbon dioxide, her volume per respiration was from 65 to 80 per cent of her vital capacity, but the rate had only increased in one experiment 50 per cent, and in the other 35 per cent. It would seem as though a further increase in the ventilation might have been met by an increase in rate, but such was, actually, not the case.

With Cases 4 and 5 much the same thing was found. The curves are both normal as far as they go. Case 4, with only a partial pneumothorax but with a vital capacity reduced to half of what it had been before the injection of nitrogen, was almost able to quadruple her ventilation. Case 5, with a more complete collapse and a vital capacity less than one-half what it should be, was more than able to quadruple his breathing. These functional capacities compare favorably with those of some normal persons.

The vital capacity was definitely reduced in the three cases of artificial pneumothorax, when it was determined.

[6] Means, J. H., and Newburgh, L. H., *J. Pharm. and Exp. Therap.*, 1915, vii, 454.

CONCLUSION.

It may be said that at rest all the factors of respiration, gaseous exchange, carbon dioxide tension, and the mechanical factors, are normal in persons with a collapsed lung, that the reaction to carbon dioxide is normal up to the point at which the respiration is trebled, or sometimes quadrupled, but that beyond that point a limit may be reached.

The ventilation of the lungs can be accomplished in an entirely normal manner in spite of a greatly reduced vital capacity. The only difference between normal persons and persons with a collapsed lung is that the latter when called upon to increase their ventilation reach their limit a little sooner than the former.

From these findings we might deduce that there will be no dyspnea except after moderate exertion. And this deduction is borne out by the histories of the patients.

In other words, in the lungs, as in other organs, there is a large factor of safety, one lung being as efficient as two, except when the work done calls for more than a threefold increase in the normal ventilation.

EXPLANATION OF PLATES.

PLATE 44.

FIG. 1. Case 1. Artificial pneumothorax.

FIG. 2. Case 4. Before nitrogen injections were begun.

PLATE 45.

FIG. 3. Case 4. Artificial pneumothorax.

FIG. 4. Case 5. Artificial pneumothorax.

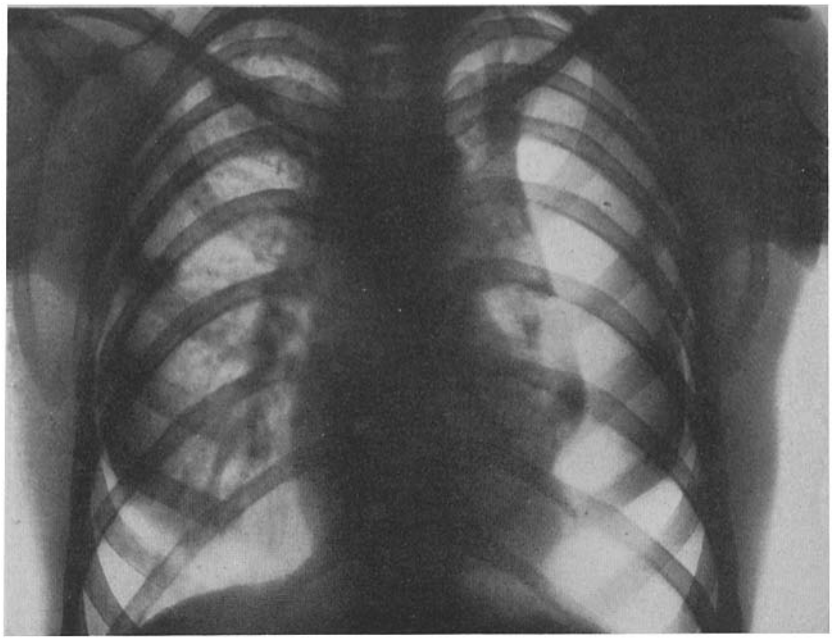


FIG. 1.

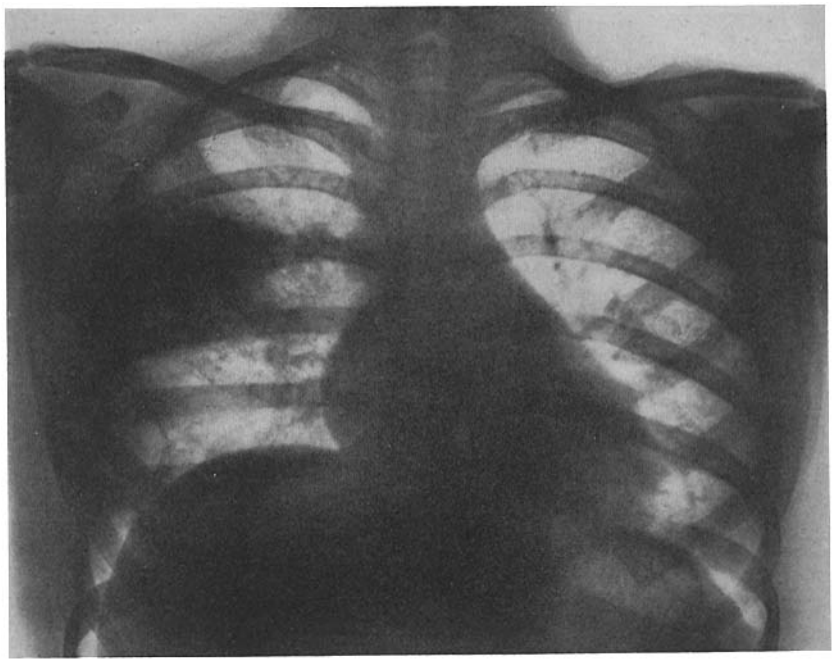


FIG. 2.

(Means and Balboni: Factors of Respiration in Pneumothorax.)

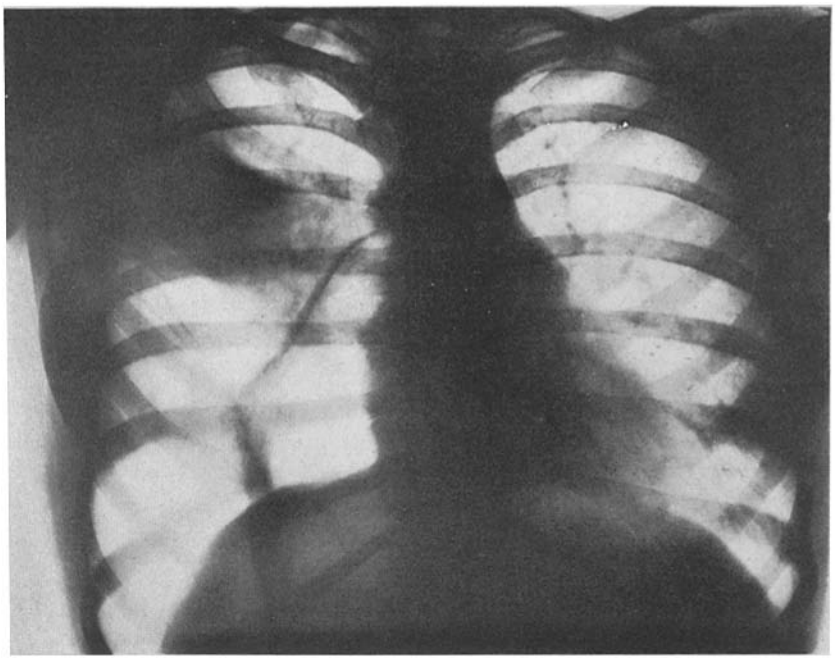


FIG. 3.

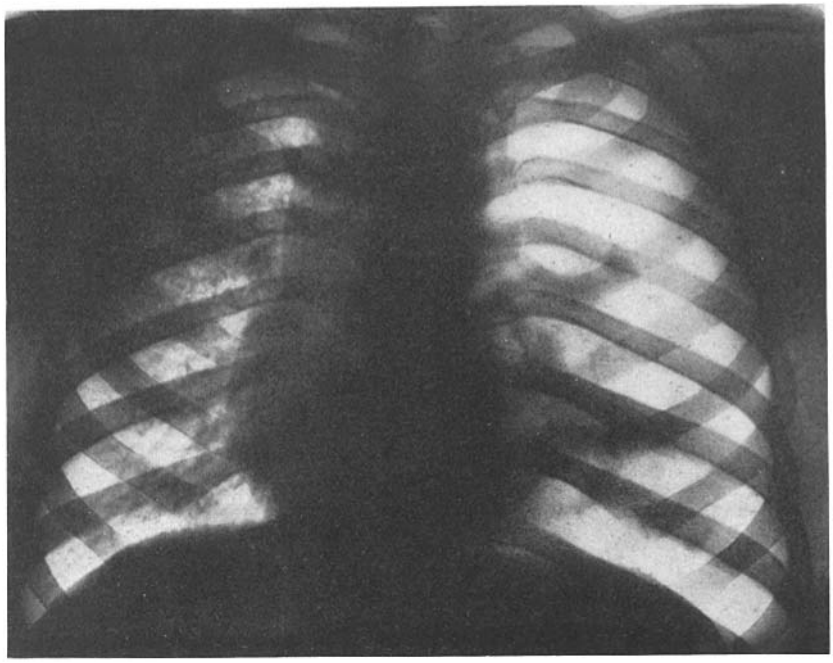


FIG. 4.

(Means and Balboni: Factors of Respiration in Pneumothorax.)