EFFECT OF LAPAROTOMY ON LUNG VOLUME. DEMONSTRATION OF A NEW TYPE OF PULMONARY COLLAPSE

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In a previous communication (1) it was shown that laparotomy produces characteristic changes in the function of respiration. These included marked reduction in tidal air, complemental air, supplemental air and in the vital capacity, together with increase in respiratory rate. No significant change occurred in minute volume.

The object of the present work was to carry this study further and, by adding the measurement of the residual air, to discover whether laparotomy causes any alteration in the actual volume of the lungs. It was hoped that such a study might throw light on the factors responsible for postoperative pulmonary complications.

· Terminology applied to the divisions of total lung volume is shown diagrammatically in Figure 1. In comparing the lung volume of one person with that of another or of the same person at different times it is obviously necessary to employ the same phase of respiration.

The measurement of the residual air, that is to say, the air remaining in the lungs at the end of a maximal expiration, can be measured even in sick patients, if cooperative, after operation by the method described below, and to the residual air thus determined may be added the vital capacity which gives the total or maximum lung volume. For the purpose of comparing the pulmonary volumes of patients before and after laparotomy, I have preferred, however, what I have called subtidal volume to all other volumes, partly because it does not require the degree of cooperation, possibly painful, necessary in residual air measurement and partly because for the reasons given below I look upon it as the most significant of all lung volumes.

METHODS

In measuring residual air and subtidal volume, I have used Christie's (2) method with slight modifications. This method measures the quantity
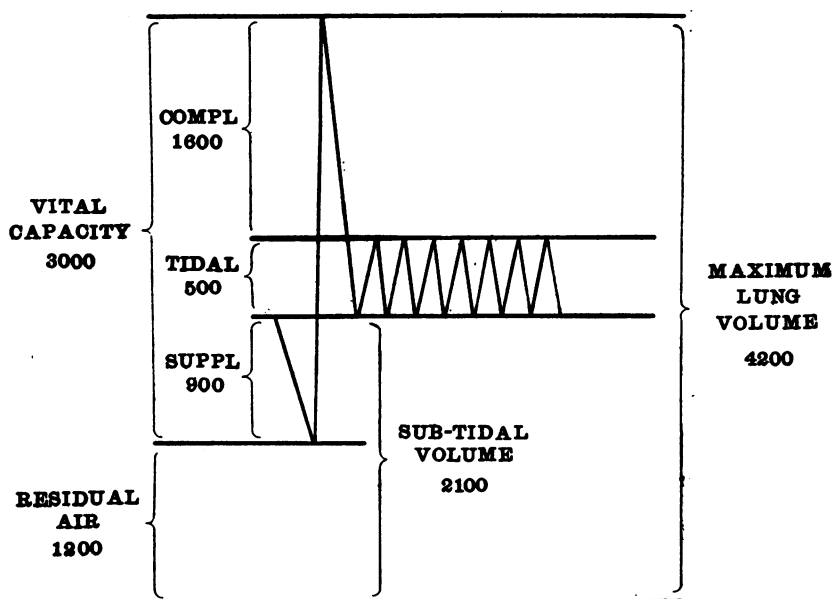

FIG. 1.   DIVISIONS OF LUNG VOLUME
Numbers represent cc.

of air in the lungs at the instant the patient's lungs and a spirometer be-
come parts of a closed system.   The nitrogen present in the lungs at the
instant of connection is diluted with a known quantity of oxygen.   The
lung volume can be calculated from the degree of the dilution by reference
to an equation which expresses the fact that the volume of nitrogen present
in the closed system at the start will be unchanged at the end of the period
of measurement, i.e.,

$$x\frac{y}{100} + d\frac{79.1}{100} = (x + d + a)\frac{y}{100}.$$

$x =$ lung volume in cc. at the instant the closed system was established.
$d =$ dead space of the system.
$v =$ alveolar nitrogen at the start of the analysis.
$a =$ oxygen added minus the oxygen consumed during the period of meas-
       urement.
$y =$ nitrogen percentage found in the system at the end of the period.

Simplifying,

$$x = \frac{(a + d)y - 79.1d}{v - y}.$$

The volume of alveolar nitrogen, v, for a given individual at rest does
not change.   Since the aim was to show the effect of laparotomy on lung

volume in a given individual, v may be used as a constant, provided it is not affected by the operation. That the operation has no effect on the alveolar nitrogen will be shown below in the section on data.

Christie's apparatus consists of a spirometer of standard type, used in measuring the basal metabolic rate. He removes the soda lime scrubber from the body of the spirometer and fills that space with paraffin which is pierced by the inspiratory and expiratory tubes. The soda lime scrubber must then be inserted in the expiratory circuit *outside* of the spirometer. This requires considerable alteration of the machine and tends to make the apparatus more cumbersome, less adapted to ward use. I have found it possible to avoid this alteration and thus to use an apparatus which is more compact than that described by Christie: The unaltered twelve-inch Benedict-Roth [2] metabolism spirometer met the requirements well, after the air trap around and beneath the soda lime container had been eliminated. Unless eliminated, this region contains a stagnant pool of air which does not come into equilibrium with that in the remainder of the circuit and will vitiate the results. The space beneath and around the sides of the soda lime scrubber was filled with paraffin. Before pouring in paraffin a small, stiff, rubber tube was connected with the oxygen tap. The tube extended to the top of the spirometer, being sealed in place by paraffin. Oxygen is added through this tube and samples for analysis removed by means of it.

A channel must be cut down through the paraffin wall to the outlet pipe of the spirometer. (The cross sectional area of this channel should be the same as that of the ventilation tube through which the patient breathes.) The inside of the closed system then contains a space, all parts of which are easily accessible to the diffusing gases, and pools of stagnant air are avoided, without the need of making Christie's extensive alterations of the spirometer. The apparatus remains compact.

<div align="center">DATA</div>

That the alveolar nitrogen is not affected by laparotomy is indicated in Table I; v, it appears, may be used as a constant in the above equation.

Thirty-five patients were studied before and after operation. In men, there were 5 gastric operations, 1 appendectomy, 1 abdomino-perineal resection because of carcinoma of the rectum, 1 cecostomy, 2 lower abdominal exploratory laparotomies, and 7 hernia repairs. In women, there were 8 cholecystectomies, 2 gastric operations, 6 lower abdominal exploratory laparotomies, and 2 uterine operations.

Data were obtained as described in the preceding paper, one to three days before and then from day to day following operation, and the changes in the volumes were studied. All of the values obtained were corrected for the difference between the temperature of the air in the lungs and that in the spirometer. The gas volumes were reduced to standard conditions.

[2] Warren Collins Co., Boston.

TABLE I

Alveolar nitrogen

Sex	Operation	Days post-operative	Alveolar N₂	Variation from average
			per cent	
M	Appendectomy.....................	5	79.87	− 0.37
F	Left oophorectomy.................	3	80.65	+ 0.41
F	Exploratory laparotomy and suspension of uterus...................	2	80.82	+ 0.58
F	Salpingectomy and suspension of uterus	7	79.84	− 0.40
F	Cholecystectomy...................	7	79.85	− 0.39
M	Exploratory laparotomy and cecostomy	1	80.63	+ 0.39
M	Appendectomy.....................	3	80.67	+ 0.43
M	Appendectomy.....................	6	79.78	− 0.46
F	Cholecystectomy...................	0	80.75	+ 0.51
F	Cholecystectomy...................	3	79.72	− 0.52
M	Cholecystectomy...................	7	79.63	− 0.61
M	Gastrectomy......................	1	80.62	+ 0.38
			80.24 Average	

The standard error of the mean $SE_M = (\sqrt{\Sigma D^2/N})$ is 0.13.

The extremes here produce a variation in typical results less than 3 per cent—if used in place of the mean.

As in the preceding paper, the values secured before operation were arbitrarily called 100 per cent, and the postoperative ones, fractions of these. Because of the practical difficulties in the way of obtaining an adequate series of data following operation in each case, all of the values obtained, based on 696 measurements, were combined and are presented in Figure 2.

To prove that the changes shown in Figure 2 are not only apparent but significant, the standard errors before and after operation have been calculated for each curve. The difference between the averages of the actual values, not per cents, must be more than twice the standard error if they are to be regarded as having significance. The data on which the three curves from 35 patients are based are given in Table II.

From a study of Figure 2, it can be seen that the residual air has undergone on the fourth day a decrease of 13.2 per cent. The greatest decrease, 33.0 per cent, in the maximum lung volume occurs on the second day. On the first day, the subtidal lung volume was 16.0 per cent smaller than it was before operation, on the second day 18.2 per cent, on the fourth day 19.8 per cent; there has been an absolute decrease in the volume of the lungs. In the two weeks after operation, the lungs gradually regained their original volume. Of thirty-five cases studied from this point of view, 29 cases (82.9 per cent) showed a reduction greater than 10 per cent in subtidal air, and 6 cases a less. Of the 6 (17.1 per cent), 4 were in women, all of whom had undergone cholecystectomies; 2 were in men both of whom had undergone hernia repair.
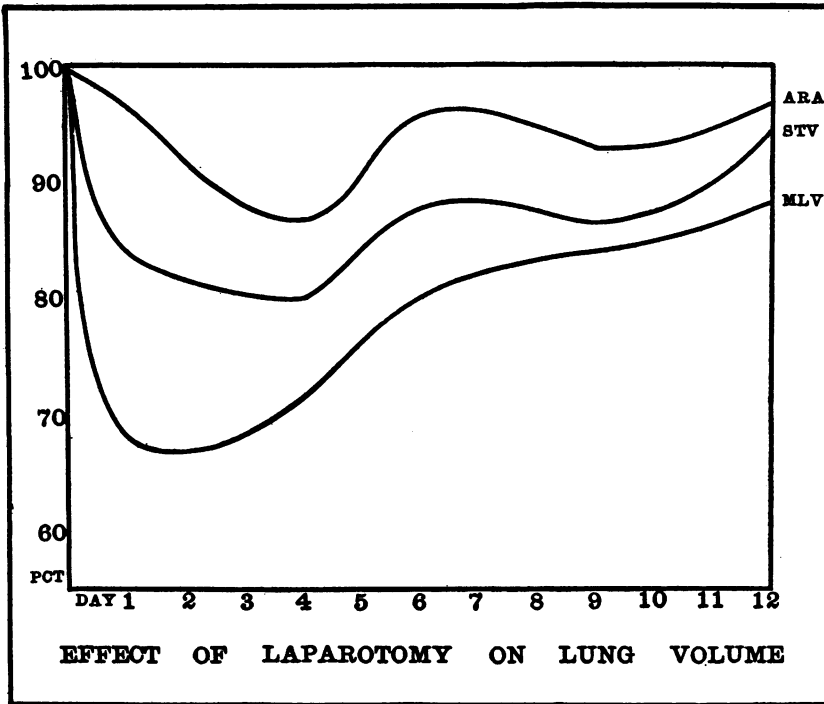
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FIG. 2

ARA = Absolute residual air
STV = Subtidal volume
MLV = Maximum lung volume
Abscissa = Days postoperative
Ordinate = Postoperative per cent of preoperative values.

TABLE II

Changes in lung volumes

Curve	A. Before operation		B. After operation		Differences between A and B		Change
	Pre-operative average volume control	Stand-ard error of control	Post-operative average volume contrast	Stand-ard error of con-trast	Difference between average volume control and contrast	Stand-ard error	
Residual air, *cc*	2075	176.3	1106	191.8	969 ±	260.5	Significant
Maximum lung volume, *cc*	5208	396.0	3492	238.0	1716 ±	462.0	Significant
Subtidal volume, *cc*	2796	235.4	2162	162.5	634 ±	286.0	Significant

The relation of the postoperative decrease in vital capacity to the decrease in subtidal volume (Figure 3) was measured in the same patients. The effect on vital capacity is based on 739 measurements. (Before operation the standard error was 134.0 and on the second day, 82.5. The difference is 1380 ± 157.3, the standard error; the curve of vital capacity shows, therefore, a significant change following operation.)
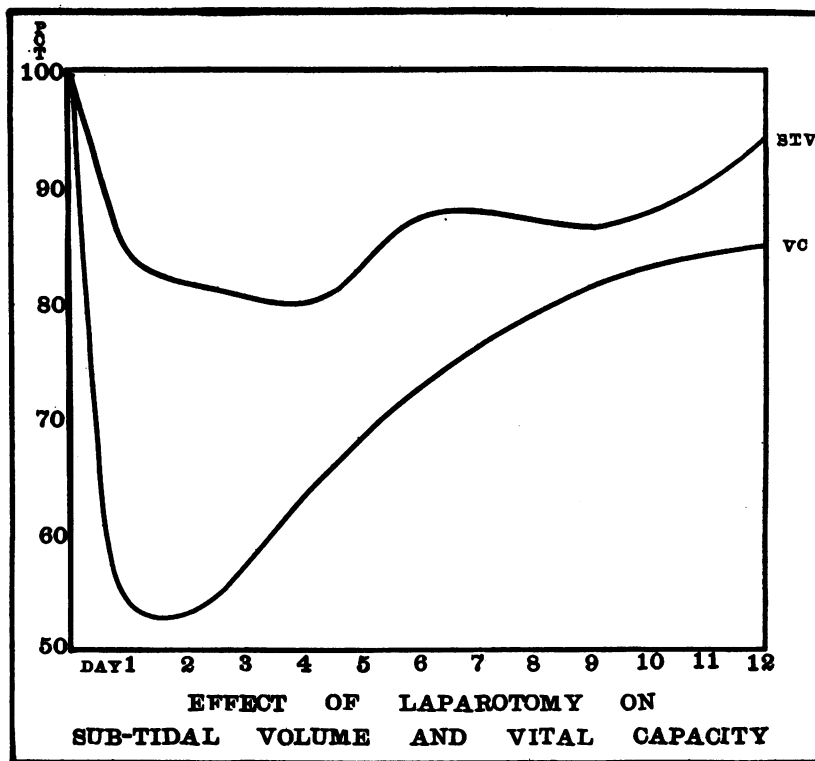

FIG. 3

STV = Subtidal volume
VC = Vital capacity
Abscissa = Days postoperative
Ordinate = Postoperative per cent of preoperative values.

DISCUSSION

The effect of laparotomy on lung volume at three phases of respiration is shown in Figure 2. Maximum lung volume requires for its determination the measurement of vital capacity and is therefore not reliable as a measure of lung volume. This is evident when one considers how vital capacity is obtained. It is not possible to say that crippling of vital capacity after operation means anything more than injury to, or painful

inhibition of, the respiratory mechanism. Residual air measurements in postoperative patients can be made with accuracy in the very cooperative patient; however, if such a patient expires only a fraction of that which he is able a false increase will be obtained when the volume of the residual air is calculated. The residual air may therefore appear to increase even though a small pulmonary collapse might have occurred.

There is a lung volume which can, on the other hand, be measured without requiring painful cooperation, which does not require any respiratory gymnastics, and which accurately reflects postoperative changes. This is the subtidal volume (Figures 1 and 2). When patients were too weak to seal the rubber mouthpiece with their lips, these were held tight for them. Occasionally patients slept during the procedure.

Measurement of the subtidal volume shows a consistent and significant decrease following laparotomy. This might be due merely to downward movement of the mid-position of tidal air or it might be due to decrease in the residual air from any cause. But this shrinkage cannot be due solely to this downward shift of mid-position because the decrease is actually as large as the entire volume of the supplemental air before operation. It is inconceivable that the postoperative, natural expiratory level could fall as low as the preoperative forced expiratory level. I believe that the results obtained must be interpreted, therefore, as signifying that some sort of actual pulmonary collapse has followed operation.

Several sorts of collapse are conceivable, for example, massive collapse of the whole lung, or atelectasis of smaller local areas of lung tissue may occur. There was no evidence of either of these on physical examination, and in six in which the examination was made, no evidence of them was found on x-ray photography. It is to be inferred that therefore the collapse observed was diffuse and partial, not local and complete; however, lobular total collapse may have occurred. This might be called collapse without symptoms; yet, since it occurred following 82.9 per cent of laparotomies, some of the "usual" postoperative manifestations may be due at least in part to its development, for example, the typical postoperative rise in pulse rate and the typical rapid and shallow respirations which were described in the preceding paper (1).

SUMMARY AND CONCLUSIONS

1. Christie's method for measuring residual air has been applied successfully to a clinical problem. It provides a means of studying the lungs of *sick* patients, and is superior to the measurement of the vital capacity.

2. Following laparotomy there is marked decrease in the lung volumes. The effect on residual air alone is quantitatively not significant. The same is true of maximum lung volume. The effect on subtidal volume is significant—it decreases one-fifth. Reasons are given for believing that this

shrinkage is due to a type of diffuse, partial collapse of the lungs not here-
tofore demonstrated, rather than to local total collapse.

3. Crippling of the respiratory mechanics indicated by decrease of vital
capacity precedes the development of this diffuse type of collapse.

The writer wishes to express his appreciation of the interest of Dr.
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them for many valuable suggestions made during the course of it.

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