STUDIES OF TOTAL PULMONARY CAPACITY AND ITS SUB-DIVISIONS. I. NORMAL, ABSOLUTE AND RELATIVE VALUES

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In the investigation of the symptom, dyspnea, by physiological methods studies of the pulmonary mechanisms have lagged behind those of other mechanisms involved. In most clinics the measurement of the vital capacity is frequently made, but rarely in conjunction with measurements of total pulmonary air and its subdivisions. No complete understanding of the problem can be attained without a complete study of the functions of the lungs in addition to those of the blood and the circulatory organs. The studies to be reported here were commenced as a preliminary to an investigation of the functional disability caused by various types of fibrosis of the lungs, particularly the pneumonoconioses. At the outset it was discovered that data regarding lung capacity were available in only a small number of normal individuals, so small that no standards of normality could be established for comparison with measurements to be made in pathological conditions.

We will not attempt to make a historical review of the methods used in the determination of the lung volume and its subdivisions. A complete presentation of the subject, from this point of view, has been published very recently by Christie (4). We may mention that probably three factors have largely been responsible for hesitancy in accepting this procedure as a useful tool in clinical medicine: unreliability of the methods used; difficulty of using complicated methods in dealing with very sick patients, and finally lack of normal standards for comparative purposes. The first two drawbacks have been solved by the methods described by Van Slyke and Binger (12), and lately by Christie (4). The present study was undertaken in an attempt to furnish some information regarding the normal values of the pulmonary air and its subdivisions, to appreciate the character of its variations, to establish a method which will permit the prediction of normal values in a given case, and finally to apply the information gained from the normal observations to the study of cases of

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chronic pulmonary pathology. In this and subsequent papers we will present our results, together with a consideration of the related literature.

NOMENCLATURE

A serious drawback to the proper comparison of different series of observations has been the use of different terms, and even different meanings for the same term. It is therefore essential to adopt a single nomenclature in order to have a clear understanding of the subject. We have adopted for our studies the classification proposed by Christie (4) with the exception of the replacement of the term " functional residual air " by mid capacity. The classification may be briefly summarized as follows:

Residual air is the amount of air remaining in the lungs after fullest possible expiration.

Mid capacity is the amount of air remaining in the lungs after a normal expiration. The term " functional residual air " introduced by Lundsgaard and Schierbeck (6), and used by Binger and Brow (3), is synonymous with this term. It appears to be more convenient, however, to use the term mid capacity as being more descriptive and more commonly used. The term " functional residual air " may be easily confused with residual air, or it may suggest that it is a subdivision of the latter. Mid capacity represents the sum of the residual and reserve airs.

Vital capacity is the amount of air expired in the fullest possible expiration following the deepest possible inspiration. Vital capacity is the sum of the complementary and reserve volumes.

Total capacity of the lungs is the sum of the residual air and the vital capacity.

Complementary air is the volume of air inspired from the position of mid capacity to that of the maximum possible inflation. It includes the tidal air.

Reserve air is the amount of air expired from the mid capacity position to the maximum possible deflation.

The character of this classification may be appreciated more readily in the diagram of Figure 1. Other classifications differ mainly in the definition of the mid capacity. Panum (9), in 1868, regarded this as the volume of air in the lungs at a point mid-way between normal expiration and inspiration. Most investigators have adopted his definition. It seems better, however, to define mid capacity as proposed by Siebeck (11), who took into consideration the commonly accepted finding that the most constant level in any graphic respiratory tracing is found at the end of a normal expiration. (Christie calls this level the " resting respiratory level.") The level at which the mid capacity is placed in the different classifications changes the values given to the complementary and reserve volumes. It will be noted that in the nomenclature adopted for this study the complementary air is the volume of air from the level of normal expiration up to the limits of complete inspiration (consequently it includes the *tidal air* which is the amount of air moving in and out during quiet breathing). The reserve air is the volume of air between the level of normal expiration and the limits of complete expiration.

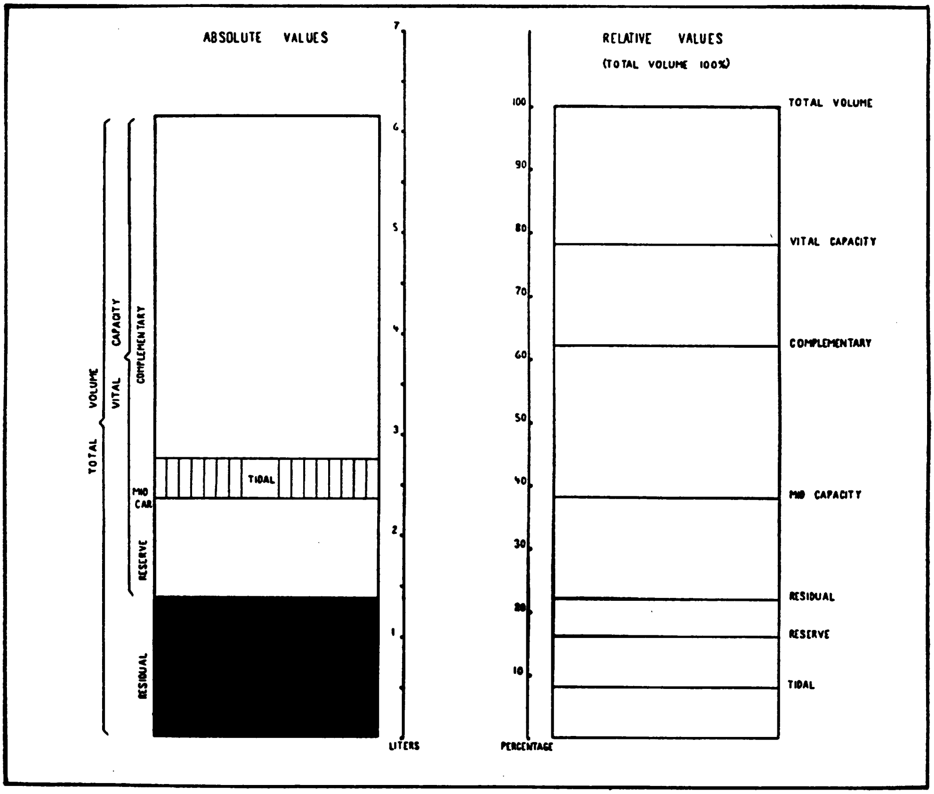

FIG. 1. MEAN ABSOLUTE AND RELATIVE VALUES OF PULMONARY AIR IN 50 NORMAL MALES

METHODS

We have used Christie's method (4) of oxygen dilution without forced breathing. The details of this method have been fully described in this author's original description, so we will omit a detailed account. The spirometer employed was of the type described by Van Slyke and Binger (12) of nine liters capacity, provided with a solid core to decrease the dead space, with a graduated millimeter scale and a recording pen (each millimeter on the scale being equivalent to a volume of 20 cc.). A five way valve permitted easy and quick communication of the patient with the desired connection. The dead space of the spirometer, including rubber tubing, soda lime container, etc., was calculated according to the instructions given by Christie, and found to be 2600 cc. Care was taken to keep the same level of water in the spirometer by means of a small syphon mounted on a graduated scale. The oxygen used was analyzed to discover inert gases acting as impurities. Five liters were admitted to the spirometer for each determination. The respiratory tracings were recorded on paper with millimeter rulings, mounted on a kymograph drum. From the tracings (the patient being under basal conditions) the basal metabolic rate may be calculated, if desired. All our results have been corrected to the volume corresponding to a temperature of 37° C., and complete saturation with water vapor. The main defect of this method, as pointed out by Christie, is the difficulty in making an accurate measurement of the oxygen consumption. Although in most cases a satisfactory base line is secured, there are cases in which breathing is somewhat irregular, and in consequence only an approximate determination of the oxygen consumption may be obtained. The error under these conditions may be considerable. In such cases we have used the following procedure for the determination of the *residual air*. A second spirometer containing about three or four liters of atmospheric air, and provided with a recording pen, is connected by means of a wide and short rubber tube to one of the outlets of the five way valve. The kymograph is placed so that a graphic tracing may be obtained from the excursions of this spirometer. The subject breathes through the five-way valve to the outside air for one or two minutes. Then he is rapidly connected with this spirometer. After three or four breaths, at the beginning of a normal expiration, he is suddenly asked to continue to expire as completely as possible to the level of the maximum deflation, and to hold his breath at this level for just the time (about a second) necessary to turn the valve connection to the regular mixing spirometer containing the measured amount of oxygen. Quiet breathing is continued for seven or eight minutes and respirations are recorded on the kymograph to which the recording pen of this spirometer is adjusted as soon as possible after the connection is made. At the end of this period the subject is again suddenly asked to continue as full an expiration as possible and to hold the breath at this level while the connection to the spirometer is quickly closed off. The oxygen consumption is calculated directly from the graduated scale of the spirometer (from the difference between the level after the known amount of oxygen was added and the level at the end of the determination). The respiratory tracing serves chiefly to detect any possible leakage or gross irregularity. It also gives a graphic record of the reserve air when the subject was asked to expire to the residual level at the beginning and end of the determination. The degree of the subject's cooperation can thus be readily determined by comparing these tracings, and proper corrections may be introduced, obviating, at least in part, the main error in the direct determination of the residual air. A third determination of the reserve air a few minutes later was sometimes used as a further check. A preliminary explanation usually suffices to obtain the desired cooperation. The rest of the calculation is made exactly as described by Christie, but of course the result obtained represents the residual air. This added to the reserve air will give the mid capacity.

Our gas analyses have been made in the Van Slyke manometric apparatus (10). This procedure is less time consuming than the use of the Haldane gas analysis apparatus. It has been found to give close agreement in duplicate analyses. All the determinations have been made with subjects in the recumbent position in bed, with two flat pillows for a head rest. In each case two determinations were made: one of mid capacity, following strictly Christie's method, and the other by the alternate method of determining the residual air according to the procedure just described. In most cases, when the base line for measurement of the oxygen consumption was satisfactory, a close agreement was found between the volume of the residual air obtained directly and the one calculated by subtracting the reserve volume from that of the mid capacity. The vital capacity, reserve and complementary airs were determined immediately afterward in the same spirometer without change in the subject's position. After connection was again established with the spirometer, the subject was asked to breathe normally for one or two minutes, and then while watching the graphic registration of his breathing he was asked to continue an expiration down to the maximum point of deflation to measure the reserve air. After quiet breathing was again resumed for a short time he was asked to continue an inspiration up to the maximum level of inflation thus measuring the complementary air. Finally after a short interval, we obtained a graphic tracing of the fullest possible inspiration followed by the maximum possible expiration (vital capacity). In normal people this vital capacity ought to be equal to the sum of the reserve and complementary volumes determined separately. Not infrequently small differences are found, possibly due to lack of cooperation.

MATERIAL

Determination of the total pulmonary air and its subdivisions has been made in 50 normal males, varying in age from 18 to 30 years and with a mean age of 23 years. The physical characteristics of these subjects are summarized in Table 1, from which it can readily be appreciated that no

TABLE 1

Physical characteristics of the subjects examined

	Mean	Standard deviation	Coefficient of variation	Variations
			per cent	
Age, *years*	22.9 ±0.31*	3.3 ±0.22*	14.4	18–30
Body height, *cm*	176.2 ±0.49	5.1 ±0.35	2.9	157.6 –186.5
Body weight, *kgm*	72.5 ±1.07	11.2 ±0.76	15.5	52.8 –104.0
Body surface area, *cm.*²	187.8 ±1.19	12.5 ±0.84	6.6	1.52– 2.19
Chest circumference, *cm*	85.4 ±0.60	6.3 ±0.43	7.3	74–110
Chest volume, *liters*	10.00±0.19	2.03±0.14	20.3	7.00– 18.33
Chest index $\frac{Depth}{Width} \times 100$	68.5 ±0.55	5.8 ±0.39	8.4	58.3 - 84.4
Chest index $\frac{Height}{Width} \times 100$	70.8 ±0.71	7.3 ±0.49	10.3	50–84
Costal angle °	71.8 ±1.18	12.4 ±0.84	17.2	50–104

* Probable error.

selective criteria were used in regard to the bodily appearance. The chest size, as judged from external measurements, also varies within wide limits, as well as its shape (as indicated by the variations in the indices of Depth/Width and Height/Width and in the costal angle). This group of normal males, although not very large in number, is accordingly representative and may be considered as a fair sample of this age period. The subjects were students of the School of Medicine and the College for Men of the University of Rochester. In all cases a brief history of previous diseases and athletic activities was recorded, and the chest examined clinically and radiologically. The vast majority of the subjects were in non-fasting condition at the time of the determination, but all of them had a preliminary resting period of at least twenty minutes. The total number of observations was fifty-two. We have excluded from this report only two cases: in one the value for residual air was found to be a negative quantity for some unknown reason, and in the other case satisfactory co-operation could not be obtained.

TABLE 2

Values of pulmonary capacity from the literature *

Absolute values

Pulmonary capacity	Mean	Standard deviation	Coefficient of variation	Variations
	liters	*liters*	*per cent*	*liters*
Total capacity	5.98	1.12	18.7	3.25–8.22
Vital capacity	4.46	0.87	19.5	2.31–5.95
Complementary air	2.60	0.63	24.2	1.61–3.95
Reserve air	1.98	0.51	25.7	0.70–2.92
Mid capacity †	3.70	0.66	17.8	2.23–5.08
Residual air	1.50	0.33	22.0	0.87–2.48
Relative values (Total capacity = 100 per cent)				
	per cent	*per cent*	*per cent*	*per cent*
Vital capacity	75.1	4.2	5.6	60–84
Complementary air	40.6	4.9	12.0	26–48
Reserve air	30.0	6.2	20.6	15–40
Mid capacity	60.7	4.0	6.6	52–69
Residual air	25.3	4.3	17.0	16–40
Relative values (Vital capacity = 100 per cent)				
	per cent	*per cent*	*per cent*	*per cent*
Complementary air	56.7	5.9	10.4	44–69
Reserve air	44.0	5.9	13.4	31–56
Mid capacity	81.2	8.7	10.7	63–97
Residual air	34.2	11.0	32.1	19–66

* Summary of 46 determinations made on male subjects collected from Lundsgaard and Van Slyke (7); Lundsgaard and Schierbeck (6); Binger (2) and Anthony (1).

† Volume of air in the lungs mid-way between a normal expiration and inspiration.

Normal values given in the literature

Records of normal values for the total capacity and its subdivisions are few, and it is difficult to evaluate them since the observations were made with different techniques and under varying conditions. Information about the age and physical characteristics of the people examined was usually meager. Frequently values obtained in males and females have been combined so that it is difficult to separate the results according to sex. We have summarized in Table 2 all the determinations made on normal *males* since Lundsgaard and Van Slyke (7) reported 11 observations in 1918. No attempt has been made to include earlier data, since the methods used are open to question. We have included 11 cases of Lundsgaard and Van Slyke, 19 cases of Lundsgaard and Schierbeck (6), the largest series in the literature, 7 cases reported by Binger (2) and finally 9 cases from Anthony's report (1), making a total of 46 cases. The determinations have been made either standing or sitting up, and the classification used by the authors quoted places the mid capacity halfway between normal expiration and inspiration. In 11 cases, of the 19 reported by Lundsgaard and Schierbeck, we have found that the reported value of mid capacity is equal to the sum of the residual air and half the vital capacity, evidence that different criteria have been used in the calculation of that subdivision. From the series of Anthony we have included only the values reported for residual air. Table 2 has been arranged to present the summary of these data in absolute values for the different components of the total capacity, as well as their proportional relationship to the total volume and vital capacity. Comparison of results obtained from the literature with our findings is made elsewhere in this paper.

RESULTS

In Table 3 are summarized the determinations of the total pulmonary air and its subdivisions, indicating the mean values, the deviations from the mean and the extreme variations. The observed values are given, and relative values are expressed as percentages of the total volume and vital capacity.

Absolute values observed. The mean value of the *total capacity* in this series is 6.13 ± 0.08 liters, a figure very close to that of 5.98 liters, which is the corresponding mean of all the observations collected from the literature. There are wide variations from this mean. The standard deviation is 0.82 liter, with a coefficient of variation of 13.3 per cent, indicating that in our series there is a total range of variability of about 27 per cent from the mean value. Similar, and even higher, variability becomes evident from the study of the reported observations in the literature.

When we come to the *vital capacity* we also find, as others have found, a wide variation in the absolute values. With a mean value of 4.78 ± 0.06 liters it varies between 3.40 and 5.85 liters, with a total variation of about 25 per cent from the mean. The fact that all our subjects were young males possibly explains the higher mean value we obtained as compared with the one calculated from the observations of other investigators.

TABLE 3

Determinations of pulmonary capacity in 50 healthy males

Absolute values

Pulmonary capacity	Mean	Standard deviation	Coefficient of variation	Variations
	liters	*liters*	*per cent*	*liters*
Total capacity	6.13±0.08*	0.82±0.06	13.3	4.42–7.86
Vital capacity	4.78±0.06	0.59±0.04	12.3	3.40–5.85
Complementary air	3.79±0.05	0.52±0.04	13.7	2.41–4.93
Reserve air	0.98±0.02	0.26±0.02	26.5	0.26–1.58
Mid capacity	2.34±0.05	0.49±0.03	20.9	1.09–3.38
Residual air	1.36±0.04	0.38±0.03	27.9	0.81–2.16
Relative values (Total capacity = 100 per cent)				
	per cent	*per cent*	*per cent*	*per cent*
Vital capacity	78.0±0.41	4.3±0.29	5.5	68.4–85.5
Complementary air	61.9±0.51	5.3±0.36	8.5	51.7–78.9
Reserve air	16.2±0.39	4.1±0.28	25.3	5.0–30.3
Mid capacity	37.9±0.75	7.9±0.53	20.6	21.0–50.3
Residual air	22.0±0.41	4.3±0.29	19.5	14.5–31.6
Relative values (Vital capacity = 100 per cent)				
	per cent	*per cent*	*per cent*	*per cent*
Complementary air	79.4±0.50	5.2±0.35	6.5	63.1–94.1
Reserve air	20.6±0.52	5.4±0.36	26.2	5.9–36.9
Mid capacity	49.1±0.85	8.9±0.60	18.1	25.0–70.4
Residual air	28.2±0.70	7.3±0.49	25.8	16.9–46.0

* Probable error.

The *mid capacity* also shows wide fluctuations. It varies between 1.09 and 3.38 liters, with a mean value of 2.34 ± 0.05 liters. It shows a total variation of about 42 per cent from the mean. Our results cannot be compared with those reported by other investigators on account of the difference in classification used. Binger and Brow (3) in nine determinations of the mid capacity (called "functional residual air" in their report), which was measured in a manner analogous to ours, obtained, however, an average value of 2.43 liters in very close agreement with the mean value of this series.

The volume of *residual air* varies markedly. Its lowest and highest values in our series are 0.81 and 2.16 liters and the mean value is 1.36 ± 0.04 liter, a figure slightly lower than 1.50 liter which is the mean value of the cases previously reported.

The *complementary* and *reserve volumes* show marked deviations from the corresponding mean values, especially the latter. The diagram of Figure 1 illustrates graphically the mean values obtained for the total capacity and its subdivisions.

Relative values. It has been customary to express the values of the lung volume subdivisions as percentages of the total capacity. This is the more valuable method of expressing the results, as one may readily see from an inspection of the diagram of Figure 2. The vital capacity, mid

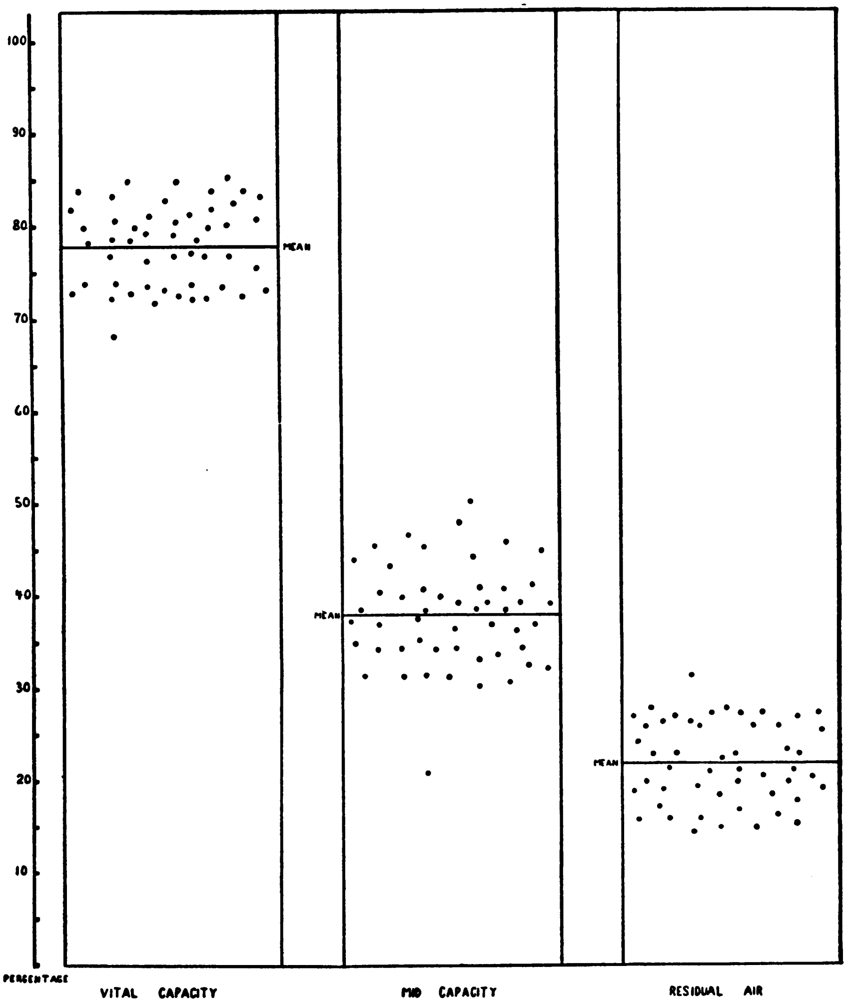

FIG. 2. VITAL CAPACITY, MID CAPACITY AND RESIDUAL AIR EXPRESSED IN PERCENTAGE OF THE TOTAL CAPACITY

The dots indicate 50 individual observations grouped about the mean values.

capacity and residual air constitute more or less constant fractions of the total capacity in normal people, giving a sound basis for comparison with the possible variations of these ratios in pathological subjects. In the case of the vital capacity we find that it has a mean value representing 78.0

± 0.41 per cent of the total volume. The standard deviation is only 4.3 per cent, so all variations actually come within 12 per cent of that mean value. It appears to indicate a rather constant relationship of vital capacity to residual air in constituting the total lung capacity. It is significant to find that the same ratio (Vital capacity/Total capacity) × 100 calculated from the cases reported in the literature has a mean value of 75.1 per cent, with a standard deviation of 4.2 per cent, that is a similar range of variability as found in our series. There is only one case (from the series of Lundsgaard and Van Slyke) in which this ratio was lower than 69 per cent.

The residual air, expressed in percentage of the total capacity, varied in our series from 14 to 31 per cent, with a mean value of 22.0 ± 0.41 per cent. In 96 per cent of the cases it formed from 15 to 30 per cent of the total volume. The data in Table 4 show that the residual air varies more

TABLE 4

Comparison of residual air, vital capacity and total capacity

Ratio $\frac{\text{Residual air}}{\text{Total capacity}} \times 100$	Residual air	Vital capacity	Total capacity
per cent	*liters*	*liters*	*liters*
14–16	0.90	4.80	5.71
17	1.13	4.79	5.91
20	1.28	4.74	6.02
23	1.53	4.92	6.45
26	1.68	4.68	6.36
29	1.96	4.26	6.22

Correlation coefficients

Ratio $\frac{\text{Residual air}}{\text{Total capacity}}$ and residual air	+0.8740±0.0229*
Idem and vital capacity	+0.0164±0.0971
Idem and total capacity	+0.3898±0.0823

* Probable error.

than the vital capacity. From the cases reported in the literature we obtained a mean value of 25.3 per cent in the ratio (Residual air/Total capacity) × 100, and in the recent series of Anthony (1) the average of eight determinations (also made in the recumbent position) was 23.2 per cent.

The ratio (Mid capacity/Total capacity) × 100 has a mean value of 37.9 ± 0.75 per cent and a standard deviation of 7.9 per cent. In 96 per cent of the cases a ratio was between 30 and 50 per cent. The complementary and reserve airs, expressed as percentage of the total volume, show moderate variations in the case of the former, and very wide fluctuations in the percentage of the latter. The close correlation of the total capacity with the vital capacity, mid capacity and residual air may also be appreciated from the high and significant correlation coefficients calculated in our series and presented in Table 5.

TABLE 5

Correlation between the different subdivisions

Capacities correlated	Correlation coefficient
Total capacity and vital capacity	+0.8950±0.0188*
Total capacity and complementary air	+0.7889±0.0361
Total capacity and reserve air	+0.4171±0.0782
Total capacity and mid capacity	+0.8020±0.0337
Total capacity and residual air	+0.7721±0.0384
Vital capacity and complementary air	+0.8836±0.0209
Vital capacity and reserve air	+0.4347±0.0769
Vital capacity and mid capacity	+0.5748±0.0634
Vital capacity and residual air	+0.4571±0.0748
Complementary air and mid capacity	+0.3296±0.0850
Complementary air and reserve air	+0.0195±0.0951
Complementary air and residual air	+0.4731±0.0735
Mid capacity and reserve air	+0.6191±0.0587
Mid capacity and residual air	+0.8202±0.0310
Residual air and reserve air	+0.1491±0.0931

* Probable error.

Few investigators have expressed the values of the subdivisions of the pulmonary air as a percentage of the vital capacity. There appears to be no special advantage in doing so, and perhaps it will be more convenient and simpler to use the total capacity as a basis for percentage estimations, rather than the vital capacity. It is interesting to notice the rather constant relationship between complementary air and vital capacity, the former constituting about 80 per cent of the latter.

Oxygen consumption and its relationship with ventilation per minute and vital capacity. Efforts have been made by different investigators to correlate the oxygen consumption of the body with the ventilation in a given period of time, in the hope of finding fixed ratios for normal people and possible deviations in pathological conditions. Knipping and Moncrieff (5) have investigated the so-called "ventilation equivalent for oxygen" which may be calculated according to the formula (Minute volume respiration/O_2 used per minute) $\times$ 100. They report observations in 54 normal subjects (31 males and 23 females), and obtained an average value of 2.44 liters for this ratio, with variations ranging between 1.68 and 3.70 liters. In 19 cases of heart disease the results varied between 2.1 and 8.61 liters. Close examination of their findings does not indicate any value in such a ratio as a measure of respiratory efficiency. In 15 of our subjects in whom the determination of total capacity was done under basal conditions (rest and fasting) the calculation of that ratio gives an average of 2.66 with variations between 1.47 and 4.04. The coefficient of variation is very high and the correlation coefficient between oxygen consumption and ventilation per minute is not significant. Anthony (1) has found in normal subjects a close correlation between the vital capacity and the calories utilized per 24 hours. In the 15 cases already mentioned we obtained a very high coefficient of variation in the ratio (Vital capacity/O_2 consump-

TABLE 6

Relation of oxygen consumption to vital capacity and ventilation per minute (observations on 15 cases)

Ratios	Mean	Standard deviation	Coefficient of variation	Variations
			per cent	
$\frac{\text{Vital capacity}}{O_2 \text{ consumption per minute}} \times 100$	1.95	0.33	16.9	1.26–2.40
$\frac{\text{Ventilation per minute}}{O_2 \text{ consumption per minute}} \times 100$	2.66	0.73	27.4	1.47–4.04

Correlation coefficients

Vital capacity and O_2 consumption per minute............	$+0.3468 \pm 0.1645$*
Ventilation per minute and O_2 consumption per minute....	$+0.1787 \pm 0.1811$

* Probable error.

tion per minute) × 100. Again the coefficient between these two characteristics is valueless. Table 6 summarized the findings in the calculation of the ratios which have just been discussed.

DISCUSSION

From the presentation of our results, and from the review of the literature, it is evident that a knowledge of the absolute values of the lung volume and its subdivisions would find very limited, if any, clinical application. The wide variations from the mean values makes it almost impossible to appreciate moderate, but perhaps important, deviations in a given case. It will be necessary to find in normal people a correlation between such values and physical or radiological characteristics which will permit the prediction of the normal capacity of the lungs in a given case. That this correlation exists and that it may be used advantageously will be shown in a subsequent paper. The absolute values found on repeated determinations of some of the subdivisions in the same individuals have exhibited great constancy. This fact has been found to be very valuable in following the course of a given case, and from this point of view a knowledge of the variations in the absolute values will be, of course, useful. In isolated observations the absolute values have little significance.

When we come to a consideration of the relative values which are expressed as percentage of the total volume, we find definite and significant relationships. We have seen that the vital capacity, mid capacity and residual air vary within narrow limits as components of the total volume. The constancy of these findings is striking in our normal series. That this relationship may be important has already been indicated. Meakins and Christie (8) write, " The efficiency of the pulmonary ventilation would appear to rest upon the relationship between the residual air and the total capacity." To arrive at a definite conclusion in this matter it will be necessary, of course, to make observations in a large number of patients with definite limitation in the respiratory adaptation to physical activity, and determine whether any relationship exists between the degree of respiratory inefficiency and the alteration in those ratios. Such an investigation is being carried out at the present time. From our preliminary studies it seems that a correlation exists, and that a knowledge of the relative values is useful. From our results, and the review of the literature, we may say that if the vital capacity is less than 65 per cent of the total volume, or correspondingly if the residual air is higher than 35 per cent, an impairment in the alveolar ventilation must be considered probably to be present. It is quite possible that the normal values found in young males cannot be used for comparative purposes in females or in older males. It is a common observation that as age increases the vital capacity decreases. Whether this is accompanied by corresponding changes in the residual air or mid capacity is unknown. We are collecting data on this point at the present time.

SUMMARY AND CONCLUSIONS

Determinations of the total pulmonary capacity and its subdivisions have been made in 50 normal young males. The age and physical characteristics of these subjects are fully presented. Christie's method of oxygen dilution without forced breathing has been used and his classification adopted. All determinations have been made with the subject in the recumbent position after a preliminary period of rest. Normal values gathered from the literature have been summarized.

The results obtained suggest the following conclusions:

1. There are wide variations in the absolute values of the total pulmonary capacity and its subdivisions.

2. The vital capacity, residual air and mid capacity fluctuate within well defined limits if expressed as a percentage of the total volume.

3. If the vital capacity is less than 65 per cent of the total volume, or if similarly the residual air is higher than 35 per cent, an impairment in the alveolar ventilation must be suspected.

4. The constant normal ratios found between the total pulmonary capacity and its main subdivisions (vital capacity, residual air and mid capacity) suggest that alterations in these ratios may give a quantitative estimation of the degree of functional respiratory efficiency, from the point of view of alveolar ventilation.

BIBLIOGRAPHY

1. Anthony, A. J., Deutsches Arch. f. klin. Med., 1930, clxvii, 129. Untersuchungen über Lungenvolumina und Lungenventilation.
2. Binger, C. A. L., J. Exper. Med., 1923, xxxviii, 445. The Lung Volume in Heart Disease.

3. Binger, C. A. L., and Brow, G. R., J. Exper. Med., 1924, xxxix, 677. Studies on the Respiratory Mechanism in Lobar Pneumonia. A Study of Lung Volume in Relation to the Clinical Course of the Disease.
4. Christie, R. V., J. Clin. Invest., 1932, xi, 1099. The Lung Volume and its Subdivisions. I. Methods of Measurement.
5. Knipping, H. W., and Moncrieff, A., Quart. J. Med., 1932, i, 17. The Ventilation Equivalent for Oxygen.
6. Lundsgaard, C., and Schierbeck, K., Acta med. Scandinav., 1923, lviii, 541. Untersuchungen über die volumina der Lungen. IV. Die Verhältnisse bei Patienten mit Lungenemphysem.
7. Lundsgaard, C., and Van Slyke, D., J. Exper. Med., 1918, xxvii, 65. Studies of Lung Volume. I. Relation between Thorax Size and Lung Volume in Normal Adults.
8. Meakins, J. C., and Christie, R. V., Ann. Int. Med., 1929–30, iii, 423. Lung Volume and its Variations.
9. Panum, P. L., Arch. f. d. ges. Physiol., 1868, i, 125. Untersuchungen über die physiologischen Wirkungen der comprimirten Luft.
10. Peters, J. P., and Van Slyke, D. D., Quantitative Clinical Chemistry. II. Methods. Williams & Wilkins, Baltimore, 1932.
11. Siebeck, R., Deutsches Arch. f. klin. Med., 1910, c, 204. Über die Beeinflussung der Atemmechanik durch krankhafte Zustände des Respirations- und Kreislaufapparates.
12. Van Slyke, D. D., and Binger, C. A. L., J. Exper. Med., 1923, xxxvii, 457. The Determination of Lung Volume without Forced Breathing.