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NORMAL STANDARDS FOR LUNG VOLUMES, INTRAPULMONARY GAS-MIXING, AND MAXIMUM BREATHING CAPACITY

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An objective assessment of respiratory function is important in the diagnosis and management of patients complaining of dyspnoea or suffering from disease involving the lungs. There are four main subdivisions, excluding blood composition, of the respiratory gas exchange process (ventilatory, distributive, diffusional, and circulatory), which are disturbed in various proportions in different diseases; therefore no single test of respiratory function can be adequate in all cases (Comroe, 1951; Gilson and Oldham, 1952). The ventilatory and distributive (intrapulmonary gas mixing) aspects of respiratory efficiency are commonly studied by measuring the total lung capacity (T.L.C.) and its subdivisions, the maximum breathing capacity (M.B.C.), the timed vital capacity (T.V.C.), and some form of "mixing efficiency" test.

It is perhaps rather generally assumed that reasonably adequate information is already available concerning these tests, which have been in use for some years. However, Comroe (1951), Fletcher (1953), and Donald (1953) all comment on the inadequacy of control data, and we find that a critical survey of the published reports upholds their opinion. We intend to make only a very brief survey of the literature, as there are already excellent reviews in this field (Comroe, 1950, 1951; Donald, 1953; Fowler, 1952).

Apart from vital capacity (V.C.), the normal values of which have been well studied (Hutchinson, 1846; West, 1920; Stewart, 1922; Kelly, 1933; Myers, 1925), we find there are a number of difficulties in determining the normal values for the other testing procedures.

Different workers have used various methods to obtain normal values for the several aspects of respiratory function, and the lack of standardized procedure makes the results not always comparable; this is particularly true for tests of mixing efficiency and maximum breathing capacity. Most of the reported series consist of only small numbers and the few larger groups cover only one or two testing procedures. Females of all ages are poorly represented, and comparatively few of the male subjects have been in the younger (age less than 18 years) or older (age more than 50 years) groups. There has been a tendency for selected types of subjects to be used, e.g., medical students and nurses in the younger age range and hospital patients and doctors in the older. The criteria of normality for selection of the subjects have not always been made clear, though the paper by Whitfield, Waterhouse, and Arnott (1950) is a notable exception. Furthermore, the interpretation of some of the results is made difficult by lack of information on body measurements, by the inclusion of rather large age ranges in single groups, or by incomplete analysis of the data obtained.

Estimation of total lung capacity (T.L.C.) has been carried out in very small numbers of subjects by early workers (Lundsgaard and Van Slyke, 1918; Lundsgaard and Schierbeck, 1923; Binger, 1923; Lindhard, 1925; Anthony, 1930; Christie, 1932), but Table I lists the more recent and larger groups studied. Prediction formulae, based on body measurements, have been calculated for T.L.C. by Hurtado and Fray (1933), by Kaltreider, Fray, and Hyde (1938), by Aslett, D'Arcy Hart, and McMichael (1939) and by Whitfield and others (1950); and for vital capacity (V.C.) by West (1920), Kelly (1933), and Baldwin, Cournand, and Richards (1948). Widely varying values have been given for the ratio of residual volume to total lung capacity (R.V./T.L.C. ratio) at different ages (Kaltreider and others, 1938; Robinson, 1938; Bates and Christie, 1950; Greifenstein, King, Latch, and Comroe, 1952). Regardless of this disagreement the ratio has been widely accepted, erroneously we think, as the key to the laboratory diagnosis of emphysema since it was first suggested by Hurtado, Fray, Kaltreider, and Brooks (1934).

TABLE I
TOTAL LUNG CAPACITY DETERMINATIONS

Author	Method	Subjects				
		Total	M	F	< 18 Yr.	> 50 Yr.
Hurtado and Boller (1933)	Uncorrected oxygen dilution	50	50	—	—	—
Hurtado and others (1934)	,, ,,	50	—	50	—	—
Kaltreider and others (1938)	,, ,,	50	50	—	—	18
Robinson(1938)	,, ,,	93	93	—	41	20
Lester and others (1942)	Open circuit	15	Not stated		15	—
Greifenstein and others (1952)	,, ,,	26	11	15	—	11 15
Aslett and others (1939)	Corrected oxygen dilution	64	64	—	—	8
Birath (1944)	Closed circuit hydrogen	35	16	19	—	—
Whitfield and others (1950)	Hydrogen or helium	96	64		10*	20*
	Closed circuit			32	5*	10*
Gilson and Hugh-Jones (1949)	Open circuit and helium closed circuit	4	4	—	—	—
Bates and Christie (1950)	Helium closed circuit	27	Not stated		1*	10*
Meneely and Kaltreider (1949)	,, ,,	10	7	3	1	—
Total ..		520	359	119	73	112

* Approximate numbers, extracted from the total number, age, range, and means, and scatter diagrams.

TABLE II
MIXING

Author	Method	Subjects			
		Total	M	F	Age (Years)
Roelsen (1939)	Single breath Fractional analysis	14	13	1	19–37
Cournand and others (1941)	7 minutes Nitrogen washout	17	Not stated		Not stated
Darling and others (1944)	7 minutes Nitrogen washout	21	18	3	21–65
Birath (1944)	Fractional analysis Closed circuit	35	16	19	18–39
Bates and Christie (1950)	Continuous analysis	17	Not stated		17–37
	Closed circuit	10			47–62
Briscoe and others (1951)	Continuous analysis		10		15–40
	Closed circuit	16	2	4	65–75 17–39
Comroe and Fowler (1951)	Single breath Continuous analysis	14	Not stated		18–38
Fowler (1949)	Single breath Continuous analysis	18	12	6	17–73
Greifenstein and others (1952)	7 minutes Nitrogen washout and single breath fractional analysis	26	11	15	50–75 50–77

The importance of the distributive aspect of ventilation (intrapulmonary mixing of inspired air) has been recognized for many years, and Fowler (1952) has published a valuable review of the extensive literature. Though much work has been done on this subject it has been largely devoted to the evolution of a multitude of different and not strictly comparable methods. Table II summarizes the reported work on normal subjects.

The maximum breathing capacity (M.B.C.) test devised by Hermannsen (1933) is generally accepted as very useful in assessing overall ventilatory ability. Table III summarizes the reported work on normal subjects. Prediction formulae have been calculated on the basis of sex, age, and body surface area (B.S.A.) by Baldwin, Cournand, and Richards (1948), and, in a purely male group, on age alone by Wright, Yee, Filley, and Stranahan (1949).

TABLE III
MAXIMUM BREATHING CAPACITY

Author	Method	Subjects			
		Total	M	F	Age (Years)
Hermannsen (1933)	Spirometer	23	Both		Not stated
Cournand and others (1939)	,,	40	20	20	Average 27
Wright and others (1949)	Douglas bag high velocity valve	250	250	—	Not stated
Gilson and Hugh-Jones (1949)	Spirometer	4	4	—	29–44
Gray and others (1950)	,,	323	283	40	Young adult
Gaensler (1951)	,,	35	" Equally divided "		Younger age group
Baldwin and others (1948)	,,	92	52	40	16–69 16–79
Greifenstein and others (1952)	Tissot spirometer	26	11	15	50–75 50–77
Bernstein and others (1952)	Spirometer with light bell	14	Not stated		Not stated
Turner and McLean (1951)	Spirometer	50	30	20	$5\frac{3}{4}$–14

Following criticism of the M.B.C. test as being too strenuous for really ill patients and too dependent upon co-operation by the subject there have been attempts to devise a simpler means of obtaining the same information. Tiffeneau, Bousser, and Drutel (1949), Gaensler (1951), and Kennedy (1953) all claim that a rather good estimate of the subject's actual (as opposed to predicted normal) M.B.C. can be obtained from the timed vital capacity (T.V.C.). This test is more rapidly performed and imposes much less strain on an ill patient. Gaensler began with a three-second test but later used the one-second test, and provided apparatus is available the shorter time is preferable as it yields a more accurate estimate of the M.B.C. He used an electrically controlled cut-out for measuring the one-second fraction, but a fast revolving kymographic method (Kennedy, 1953) is more useful as the shape of the whole inspiratory and expiratory curves can be seen.

It is the purpose of this communication to present and analyse further data on the normal values for these respiratory function measurements, i.e., total lung capacity (T.L.C.) and its subdivisions: intrapulmonary gas-mixing efficiency, maximum breathing capacity (M.B.C.), and timed vital capacity (T.V.C.).

MATERIAL

We studied 324 subjects, 183 men and 141 women. This included 150 aged 11–19 years (78 men, 72 women), 114 aged 20–49 years (72 men, 42 women), and 60 aged 50–77 years (33 men, 27 women).

The subjects of both sexes were distributed fairly evenly year by year in the age 11–19 group and by decades up to the age of 70 years.

We tried to arrange that subjects from the same age and sex groups should be drawn from more than one section of the community so that our results might be as representative as possible of the general population.

Subjects aged 11–19 years were obtained from a well-run orphanage, boy-scout and girl-guide companies, a secondary school, a pre-nursing school, laboratory technicians, nurses, a church youth group, medical students, and army recruits. Subjects aged 20 onwards consisted of nursing staff, hospital and university staff (graduates and others), factory workers (both men and women), members of a business women's association, personal friends, a few medical students, and hospital patients (suffering from disorders unrelated to the cardio-pulmonary system and not causing general debility).

CRITERIA FOR ACCEPTANCE AS NORMAL SUBJECTS

The decision whether or not to include a given subject was taken before function testing; none were subsequently rejected because of failure to come up to expectations on test procedures.

The following were the criteria adopted: (1) No history of (*a*) asthma, (*b*) frequent or habitual winter cough, (*c*) being subject to "colds always going to the chest," or (*d*) "smoker's cough" of more than a mild degree. (2) No exertional dyspnoea beyond that appropriate to their years: obviously there may be differing views on what ability for physical exertion may properly be expected of a person as age advances. Our view may be summarized by saying that we expected a person to be able to keep up without distress with apparently healthy people of his or her own sex and age. We tried to determine this by discussing with each subject his or her daily routine. This is not a very high standard, but we wished to sample a cross-section of an ordinary healthy, and not an exceptionally fit, community. (3) No obvious obesity. (4) No abnormal findings on clinical examination of the cardio-pulmonary system (though a mild hypertension less than 180/100 mm. Hg did not, by itself, disqualify). Full physical examination of the heart and lungs was not carried out on most of the subjects aged less than 20 years or on some of the older subjects. (5) Normal chest radiograph, but because of practical difficulties this was not carried out on most of the subjects aged less than 15 years or on a few of the others.

It was impossible to carry out full physical and radiological examinations on every subject, although this would have been desirable, but we considered that, in deciding whether to accept them as normal, the history of their actual exertional ability was of more importance. If any subjects were wrongly accepted, through lack of such examination, the effect would have been to lower our standards of "normal" performance, but there is no evidence of this in our results.

NOMENCLATURE

We have followed the nomenclatures recently adopted (Pappenheimer, 1950). Intrapulmonary mixing efficiency is designated "M.E.%." Timed vital capacity, which we measured over a two-second interval, is simply referred to as T.V.C., and maximum breathing capacity as M.B.C.

METHOD

Testing procedures were carried out in the morning, afternoon, or evening over the period June, 1952, to September, 1953. No difficulty was found in securing co-operation from the subjects, who were seated for all the tests and were in the non-basal state. The F.R.C. and M.E.% were determined by the closed circuit helium dilution method of Bates and Christie (1950), to whom we are indebted for the calculated normal data from which we constructed the theoretical mixing curves. We followed them in using oxygen rather than air in the circuit, as we wished to use our results for comparison with those obtained from patients, some of whom are more comfortable when breathing oxygen. We made some minor modifications in their method. (1) Rearrangement of the control switches enabled the entire operation to be carried out by a single observer. (2) A higher output (80 l. per min.) fan-type pump reduced the mixing time in the spirometer circuit so that our M.E.% values may be systematically slightly greater than theirs. (3) The fast kymograph speed (5 inches per minute) was used, as the 90% mixing point could then be more accurately read off the curve. (4) During the preliminary oxygen run, two V.C.s were obtained at the slow drum speed, then two on the fast drum when the subject was urged to breathe out as rapidly as possible. The largest of the four attempts was taken as the V.C., and the better of the two on the fast drum gave the T.V.C. The T.V.C. divided by the best V.C. gave the T.V.C./V.C. ratio. Even the fast speed of the standard Palmer kymograph does not enable accurate measurements of T.V.C. over less than a two-second interval, but this disadvantage is offset by the fact that other workers possessing this standard apparatus can use our normal values.

The M.B.C. was determined, using a standard Douglas double valve box and 100 litre Dougles bag, the air in the bag being measured through a water-filled gasometer. Although this method of determining the M.B.C. has the obvious disadvantages that no tracing is obtained and the level at which the breathing is carried out is not shown, yet the apparatus required can easily be duplicated for work in other laboratories. The subject was instructed to breathe as deeply and as quickly as possible, and several trials were given until it was obvious to a trained observer that a maximal effort was being obtained. On the actual run two to three seconds were allowed for starting, then the air was collected over a 15-second period, during which encouragement was given to maintain optimal rate and depth. After a five-minute rest a second measurement was made. The values thus obtained were usually within 8 litres of each other, but if not then a third attempt was allowed. The highest value obtained was taken as the M.B.C. No set respiratory rate was used, but every encouragement was given to keep this above 50 per minute. Co-operation by the subjects again presented no real difficulty, though certain nervous subjects and some of the older women required more preliminary instruction.

Height was recorded without shoes. Weight was taken in pyjamas or indoor clothes, with appropriate deduction. Body surface area (B.S.A.) was read off from a nomogram constructed from the Du Bois (1927) formula.

All gas volumes were measured at ambient pressure and room temperature, the observed range being 17–22° C.; the decision not to adjust gas volumes to B.T.P.S. was made for several reasons. It is unlikely that the large volume of air ventilated during an M.B.C. run will reach 37° C., fully saturated, and the same objection holds to some extent with a vital capacity determination. While a simple B.T.P.S. correction may properly be applied to the F.R.C., further investigation would be required to work out the different corrections for the other primary measurements, and the final result would be to add greatly to all routine work in this field. Since the conditions of testing do not vary very much, the errors introduced by omitting any correction will not in any case interfere with comparisons. The addition of 6% to our F.R.C. values would allow reasonably accurate comparisons to be made with data so corrected.

Table IV gives the analysis from duplicate experiments. All the duplicate M.B.C.s were done on different days. About half of the F.R.C. duplicate determinations were done on different days, but a separate analysis showed that this had no effect on repeatability. The number of duplicates is smaller for M.E.% than for F.R.C., because some of the latter were from other work not included in the main analysis.

TABLE IV

REPEATABILITY OF MEASUREMENTS

Measurement	F.R.C.	M.B.C.	M.E. %
No. of cases on which repeats were made	54	40	27
Mean values	2,866 ml.	106 l./min.	79·4
Maximum difference between repeats	260 „	16 „	13
Standard deviation of repeat measurements	94 „	4·6 „	4·1

F.R.C. = functional residual capacity, M.B.C. = maximum breathing capacity, M.E.% = mixing efficiency.

NOTES ON STATISTICAL METHODS

REGRESSION ANALYSES OF LUNG MEASUREMENTS ON PHYSICAL CHARACTERISTICS.—Multiple regression analyses were carried out for each of the lung measurements for each of the four groups of normal cases, taking age, height, weight, body surface area, and sitting height as the independent variables. The object was to obtain regression equations suitable for routine use in the prediction of normal values of the lung measurements. Partial regression coefficients have not been calculated for all of the five independent variables, since in every case it was possible to obtain the same accuracy of prediction from equations involving, at the most, three of the variables.

In the first of the alternative sets of regression equations given here, the most useful variables have been picked out progressively, for each separate equation, until these remaining could not account for a statistically significant proportion of the remaining variation in the lung measurement.

In the second set of regression equations more of the variables have been omitted. At the expense of a slight loss in predictive power, shown by increases in the residual standard deviations, there is a gain in simplicity. Not only have terms been eliminated, but changes have been made in the actual variables used in some of the equations so as to obtain the greatest possible homogeneity in this respect, which is of advantage in facilitating comparisons between the equations.

ASSUMPTIONS UNDERLYING REGRESSION ANALYSES.—The basic condition that must be satisfied to justify the regression analysis is that the discrepancies between the observed and predicted values of the lung measurements should be normally distributed, with a variability independent of the values of the physical characteristics involved. The standard deviation of these discrepancies is, of course, the value quoted under the heading of residual standard deviation.

Graphical checks have shown that this condition is at least approximately satisfied in each case, although there is a slight tendency in the non-adult groups for the variances to increase with increasing body size.

CORRELATION COEFFICIENTS.—We follow the practice in previous papers on this subject of giving total rather than partial correlation coefficients. This means, for example, that the correlation of vital capacity with height is that directly calculated from the pairs of values for each case, and is not adjusted to make it applicable to a population of uniform age, uniform weight, uniform body surface area, or uniform sitting height.

DISCUSSION

In the children up to 12–13 years there is little difference between boys and girls (though a study of a younger age group would be necessary to examine this properly), but from the age of puberty the boys' lung volumes and even more their M.B.C.s are greater than the girls' (Figs. 1 and 2). The women, however, appear to attain adult values about one year earlier than the men (17 years and 18 years respectively). This earlier maturation in girls was also shown in the very detailed vital capacity studies by Stewart (1922) and Kelly (1933), whose values, both for men and for women, are in close agreement with those of the present study. Male groups with mean age 11, 14, and 17½ years in the series studied by Robinson (1938) gave values comparable with ours for T.L.C., V.C., and F.R.C., allowance being made for their larger B.S.A., but the R.V./T.L.C.

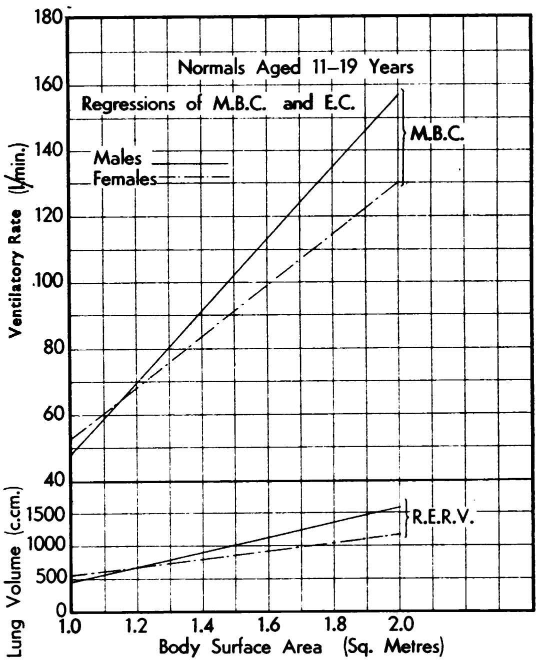

FIG. 2

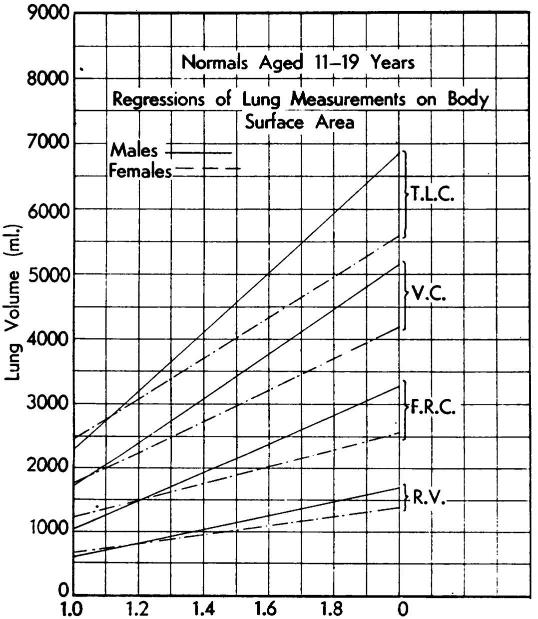

FIG. 1

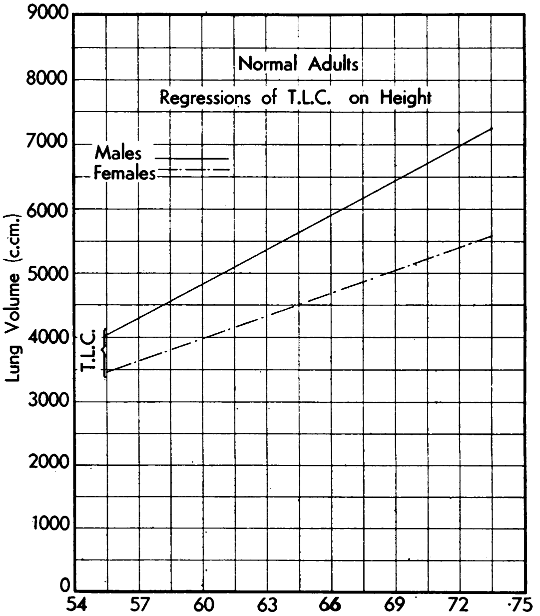

FIG. 3

and F.R.C./T.L.C. ratios are rather lower than ours. The values found by Turner and McLean (1951) for V.C. and M.B.C. in children from 11 to 14 years are similar to those obtained by us for the corresponding age groups. Applying their prediction formulae to our group gives a reasonable estimate of both V.C. and M.B.C., although we find B.S.A. to be better than height as a basis for prediction. The two groups each of five children of mean ages 12 and 14½ years reported by Lester, Cournand, and Riley (1942) gave values very like ours for V.C. and for M.B.C., but their T.L.C.s were calculated from an assumed R.V./T.L.C. ratio of 20.4%, which is appreciably lower than ours at any age.

In the adult group the M.B.C., the V.C., the T.V.C., and to a much smaller degree the T.L.C. are seen to decrease with advancing age whereas the F.R.C./T.L.C. ratio rises slightly and the R.V./T.L.C. ratio steeply. The M.E.% is unchanged by age in the men and shows a barely significant decrease in the older female groups up to the age of 70

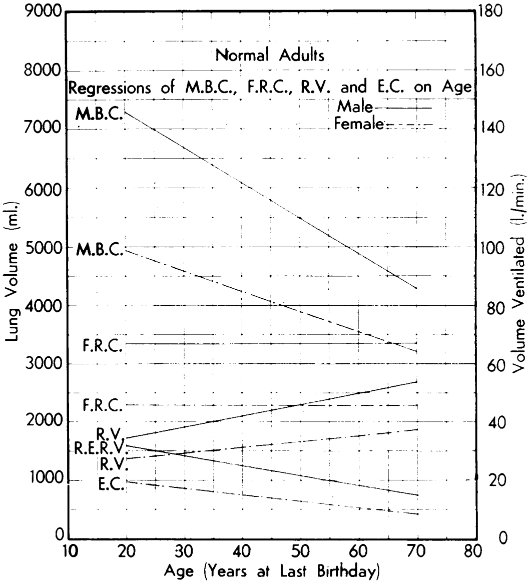

FIG. 4

TABLE V

OVERALL MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION

Measurement	Males			Females		
	Mean	S.D.	C.V.%	Mean	S.D.	C.V.%
Age group 11–19:						
No. of cases	78			72		
T.L.C. (ml.)	4,590	1,300	28	3,880	800	21
F.R.C. (ml.)	2,180	690	32	1,830	420	23
F.R.C./T.L.C. (%)	47·2	4·5	10	47·1	4·9	10
R.V. (ml.)	1,140	430	38	995	280	28
R.V./T.L.C. (%)	24·9	4·7	19	25·7	4·7	18
R.E.R.V. (ml.)	1,040	390	38	835	240	29
V.C. (ml.)	3,450	980	28	2,880	630	22
T.V.C. (2 sec.) (ml.)	3,440	980	28	2,870	620	22
M.B.C. (l./min.)	103	32	31	89	20	22
R.T.V. (ml.)	630	200	32	510	120	24
M.E. (%)	85·3	14·9	17	80·7	13·0	16
Age (yr.)	15·3	2·6	17	15·5	2·6	17
Height (in.)	63·2	5·7	9	61·9	4·1	7
Weight (lb.)	112·4	28·3	25	109·1	27·5	25
B.S.A. (sq.m.)	1·512	0·265	18	1·467	0·226	15
Sitting height (in.)	32·8	2·9	9	32·5	2·3	7
Age group 20–70:						
No. of cases	102			66		
T.L.C. (ml.)	6,230	830	13	4,330	620	14
F.R.C. (ml.)	3,330	680	20	2,300	490	21
F.R.C./T.L.C. (%)	53·4	7·1	13	53·0	7·5	14
R.V. (ml.)	2,100	520	25	1,570	380	24
R.V./T.L.C. (%)	33·8	7·4	22	36·4	7·2	20
R.E.R.V. (ml.)	1,240	410	33	730	300	41
V.C. (ml.)	4,130	750	18	2,760	540	20
T.V.C. (2 sec.) (ml.)	4,000	830	21	2,670	560	21
M.B.C. (l./min.)	121	24	20	84	16	19
R.T.V. (ml.)	660	230	35	550	160	29
M.E. (%)	78·7	11·4	14	78·7	11·1	14
Age (yr.)	41·2	13·2	32	42·1	14·4	34
Height (in.)	67·8	2·5	3·7	63·0	2·3	3·7
Weight (lb.)	151·2	20·0	13	128·7	21·3	17
B.S.A. (sq.m.)	1·807	0·140	8	1·597	0·140	9
Sitting height (in.)	34·9	1·6	4·6	33·1	1·5	4·5

T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume V.C. = vital capacity, T.V.C. = timed vital capacity, M.B.C. = maximum breathing capacity, R.T.V. = resting tidal volume, M.E. = mixing efficiency.

(i) In a normally distributed population approximately 95% of the individual values lie within the range (mean ± 2 × standard deviation).

(ii) The coefficient of variation is the standard deviation expressed as a percentage of the mean, and therefore gives an appreciation of the relative variability of the different measurements.

TABLE VI
PHYSICAL CHARACTERISTICS

Sex	Age (Years)	No.	Age (Years)			Height (in.)			Weight (lb.)			Body Surface Area (sq.m.)			Sitting Height (in.)		
			Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
M	11	8				54·8	52	58	77	61	96	1·12	1·00	1·25	29·0	27	31
	12	13				57·3	53	64	80	62	115	1·22	1·02	1·55	29·6	27	33
	13	8				59·6	54	67	96	80	120	1·38	1·25	1·62	31·2	29	34
	14	8				63·1	59	69	108	92	141	1·49	1·33	1·71	32·0	30	35
	15	8				65·4	62	68	121	100	132	1·60	1·43	1·70	33·6	30	35
	16	8				66·5	63	70	124	108	142	1·63	1·48	1·82	34·2	32	36
	17	9				66·7	62	69	130	116	145	1·69	1·54	1·86	35·1	33	37
	18	8				69·6	66	73	146	120	166	1·82	1·62	1·98	36·1	34	38
	19	8				69·1	67	72	146	130	168	1·81	1·68	2·02	35·9	35	39
M	20–30	27	25·2	20	29	69·1	66	72	155	124	195	1·86	1·62	2·10	35·8	33	38
	30–40	23	35·0	30	39	68·4	64	72	154	113	197	1·82	1·49	2·08	35·3	32	38
	40–50	22	44·9	40	48	67·8	63	72	152	118	175	1·81	1·59	2·00	35·1	32	38
	50–60	20	54·3	50	59	65·6	62	68	142	112	195	1·73	1·46	2·02	33·6	30	36
	60–70	10	64·2	60	68	67·6	64	72	150	124	182	1·79	1·62	2·05	34·2	33	37
M	>70	3	76·2	75	77	64·2	63	65	127	110	138	1·64	1·59	1·68	32·0	31	33
F	11	8				54·2	50	58	70	60	88	1·10	1·00	1·26	28·5	27	31
	12	8				58·2	56	62	82	65	101	1·24	1·09	1·42	30·5	29	32
	13	8				61·1	58	65	86	73	105	1·31	1·16	1·48	31·6	29	34
	14	8				61·8	59	65	106	94	122	1·45	1·34	1·60	32·6	31	35
	15	8				63·4	60	67	117	83	151	1·54	1·27	1·80	33·2	32	35
	16	8				64·9	61	70	127	114	153	1·62	1·52	1·80	34·1	32	36
	17	8				63·4	60	67	124	97	155	1·58	1·38	1·82	33·1	31	35
	18	8				64·8	62	67	140	118	172	1·70	1·54	1·91	34·5	33	37
	19	8				65·2	64	67	132	114	156	1·66	1·56	1·80	34·4	33	35
F	20–30	18	24·4	20	29	63·6	60	69	127	99	161	1·60	1·42	1·73	33·7	32	36
	30–40	13	34·3	30	39	63·5	58	69	121	90	156	1·57	1·32	1·88	33·7	32	37
	40–50	11	46·2	41	49	63·1	59	66	140	122	158	1·66	1·54	1·80	32·6	30	34
	50–60	16	54·1	50	59	62·1	56	65	124	94	170	1·56	1·30	1·84	32·5	30	34
	60–70	8	64·6	60	69	62·5	60	64	138	94	175	1·64	1·41	1·80	32·5	30	35
F	>70	3	75·5	74	77	57·0	55	60	105	86	119	1·37	1·22	1·44	29·0	28	30

(i) Tables VI, VII, and VIII are included as a summary of the observations carried out, since space does not permit a full list of values.

(ii) The values given should not be taken as establishing normal mean values or normal ranges for each age group. Split down to this extent, they are each dependent on comparatively few cases and so are subject to comparatively large sampling errors. The most outstanding example of such an effect occurs in the male 50–60 age group, where the sample has a small mean height compared with the other age groups, which results in the mean T.L.C., for example, being correspondingly depressed.

(iii) Values obtained from a few normals aged over 70 have been included in the tables for comparison, but no use has been made of these figures in any of the other calculations.

years. It is interesting to note how much more kindly the years treat the women than the men in respect of both V.C. and M.B.C.

Our values for lung volumes in men (Table VII, Figs. 3, 4, and 5) are rather lower than those found by Robinson (1938), even allowing for the B.T.P.S. correction, but they are somewhat higher than those found by Baldwin and others (1948). Our values for R.V./T.L.C. and F.R.C./T.L.C. ratios (Table VII, Figs. 6 and 7) are higher than those found by earlier workers (Kaltreider and others, 1938 ; Robinson, 1938), but are in close agreement with those found by Bates and Christie (1950), by Whitfield and others (1950), and by Greifenstein and others (1952). Like these more recent authors we found a marked increase in the R.V./T.L.C. ratio with advancing age, but the F.R.C./T.L.C. ratio is much less affected (Table X, Fig. 7). The former rises because of change in the absolute value of both R.V. (increase) and T.L.C. (decrease), whereas the much smaller rise in the F.R.C./T.L.C. is due to the decreasing T.L.C., the F.R.C. changing but little (Fig. 4). Our older subjects, while they showed a rather high R.V./T.L.C. ratio, certainly did not suffer from emphysema, as they showed no excess dyspnoea on exertion, gave high M.B.C. volumes, had normal mixing efficiency, and showed no evidence of air trapping on the spirometric record. An R.V./T.L.C. ratio above 36% has often been accepted in itself as evidence of emphysema (Baldwin and others, 1949 ; Motley, 1953 ; Galdston, Wolfe, and Steele, 1952 ; Greifenstein and others, 1952), but the present results and those of Bates and Christie (1950) and of Whitfield and others (1950) make this view difficult to maintain. It may be that an increase in the F.R.C./T.L.C. ratio will prove to be of more significance.

The absence of really significant deterioration in intrapulmonary gas-mixing up to the age of 70 years is in marked contrast with what is usually stated (Greifenstein and others, 1952 ; Bates and Christie,

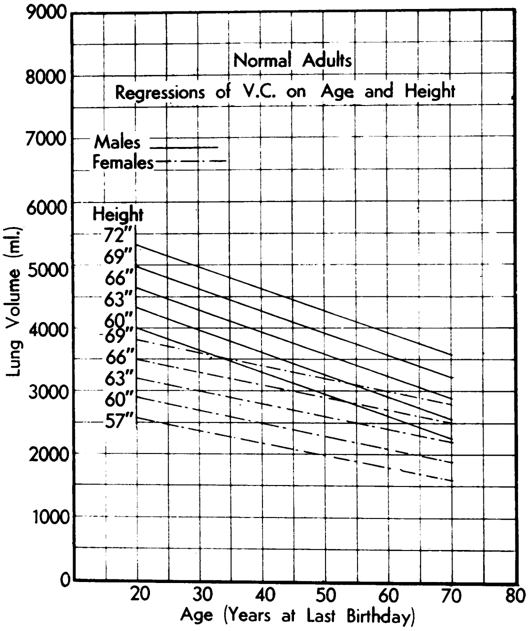

FIG. 5

1950 ; Fowler, 1952). In this laboratory an M.E. as low as 25% is commonly found in the presence of pulmonary disease (emphysema, communicating lung cysts, etc.), but a value below 60% is seldom found in normal subjects. In the first of these papers we notice that the mixing defect is more marked in the men than in the women, whereas we find no difference between our own male and female groups (Table VIII). The M.B.C. in their female group is nearly the same as in ours, but in their men it is lower (78 l./m. as against 95 l./m.), which makes it doubtful whether the men in their series were as good a normal sample as were the women. Comroe and Fowler (1951) reported a much greater range of M.E.% in old than in young subjects, whereas we found it unaffected by age. Fowler (1949) in a series of 18 subjects aged up to 73 years obtained normal mixing values, and Briscoe, Becklake, and Rose (1951) found M.E.% normal in one older man (aged 75) and only moderately reduced in the other (aged 65). Bates and Christie (1950) reported reduced mixing efficiency in 10 elderly

TABLE VII
LUNG MEASUREMENTS

Sex	Age	No.	T.L.C. (ml.)			F.R.C. (ml.)			F.R.C./T.L.C. (%)			R.V. (ml.)			R.V./T.L.C. (%)			R.E.R.V. (ml.)		
			Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
M	11	8	2,960	2,310	3,690	1,310	1,020	1,800	44·4	38	51	770	570	1,160	26·0	21	33	540	350	770
	12	13	3,210	2,600	3,930	1,550	1,170	1,850	48·3	40	54	810	570	1,150	25·1	18	33	750	410	900
	13	8	3,960	3,390	4,880	1,880	1.390	2,320	47·2	41	56	950	720	1,080	24·1	19	31	930	500	1,240
	14	8	4,140	3,240	5,920	1,920	1,250	2,610	46·1	38	52	980	750	1,390	24·0	15	29	950	500	1,700
	15	8	4,730	4,040	5,260	2,170	1,830	2,500	45·9	41	52	1,100	810	1,320	23·1	19	28	1,070	920	1,260
	16	8	5,160	3,850	6,730	2,460	1,460	3,460	47·0	38	54	1,290	760	1,970	24·6	17	35	1,170	700	1,900
	17	9	5,770	5,120	6,700	2,800	2,330	3,300	48·3	45	52	1,560	1,010	2,200	26·9	19	33	1,230	1,000	1,540
	18	8	6,130	5,140	7,320	2,980	2,560	3,660	48·9	44	55	1,610	1,120	2,100	26.2	19	35	1,370	700	2,000
	19	8	5,960	5,170	6,900	2,840	2,110	3,650	47·5	40	54	1,380	550	1,820	23·6	13	33	1,460	950	2,300
M	20–30	27	6,500	5,000	8,600	3,210	1,900	4,300	49·5	39	57	1,750	900	2,600	26·6	18	35	1,470	900	2,300
	30–40	23	6,630	5,700	8,300	3,550	2,600	4,800	53·6	40	60	2,110	1,500	3,000	32·0	23	41	1,430	800	1,900
	40–50	22	6,190	5,100	7,200	3,300	1,900	4,800	53·0	38	67	2,170	1,200	3,100	34·8	24	44	1,140	500	1,800
	50–60	20	5,610	3,800	7,100	3,160	1,800	4,400	56·2	36	67	2,200	1,300	2,900	39·0	26	49	980	500	1,800
	60–70	10	5,970	5,100	7,500	3,560	2,700	5,200	59·2	49	71	2,700	2,200	3,800	44·9	41	55	860	300	1,600
M	>70	3	4,730	4,290	5,150	3,120	2,830	3,270	66·0	63	69	2,420	2,370	2,470	51·3	48	55	710	480	860
F	11	8	2,570	2,320	2,860	1,170	1,000	1,320	45·6	39	53	630	480	890	24·5	17	34	540	400	670
	12	8	3,060	2,520	3,320	1,480	1,000	1,730	48·4	40	55	840	480	1,100	27·0	19	36	650	500	830
	13	8	3,530	2,610	4,280	1,760	1,320	2,480	49·5	44	58	950	750	1,480	27·1	22	34	810	500	1,100
	14	8	3,860	3,300	4,980	1,810	1,400	2,310	46·9	41	53	950	700	1,150	24·8	21	28	860	600	1,160
	15	8	4,040	3,050	4,850	1,920	1,590	2,320	47·8	42	53	1,040	850	1,230	26·1	20	32	880	620	1,350
	16	8	4,680	4,130	5,730	2,220	1,690	2,710	47·0	41	56	1,200	620	2,030	25·2	15	35	1,010	680	1,430
	17	8	4,330	3,740	5,380	2,020	1,520	2,350	46·9	33	53	1,070	840	1,320	25·0	20	31	950	620	1,300
	18	8	4,440	3,810	5,210	1,990	1,530	2,550	44·9	40	54	1,090	710	1,370	24·6	19	31	900	630	1,300
	19	8	4,420	4,040	4,940	2,080	1,680	2,520	47·0	41	54	1,190	910	1,490	27·0	22	33	920	510	1,270
F	20–30	18	4,560	3,500	5,600	2,340	1,700	3,500	51·6	43	63	1,460	1,000	2,200	31·9	22	39	900	600	1,300
	30–40	13	4,650	3,700	5,800	2,440	1,600	3,100	52·7	42	64	1,520	800	2,000	32·7	22	41	950	600	1,300
	40–50	11	4,140	3,400	5,200	2,070	1,500	2,900	49·7	43	57	1,500	1,000	2,500	35·6	30	49	570	200	900
	50–60	16	4,120	3,400	4,600	2,290	1,400	3,100	55·1	42	71	1,680	1,200	2,100	40·6	30	49	610	100	1,200
	60–70	8	4,000	2,900	4,700	2,340	1,600	3,300	57·5	42	70	1,820	1,000	2,700	45·1	32	60	490	000	1,100
F	>70	3	3,180	2,910	3,680	2,030	1,920	2,180	64·0	59	68	1,580	1,380	1,830	51·0	38	63	440	150	800

T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume.

male subjects. Our criteria of normality were not unduly strict and we are unable to explain the discrepancy in older subjects between our values and those of other workers.

Our M.B.C. values correspond fairly well with those reported by Wright and others (1949), but are rather lower than those found by valveless spirometric methods (Gray, Barnum, Matheson, and Spies, 1950; Bernstein, D'Silva, and Mendel, 1952). The spirometric method, however, does not always yield such high values, for like Gaensler (1951) we found values higher than those of Baldwin and others (1948), but this is probably due to the differences in the spirometers used. Donald (1953) pointed out the importance of standardizing the M.B.C. test, and it would seem that the Douglas bag method would achieve this. It is scarcely feasible for each laboratory to work out its own complete control series as suggested by Frost and Georg (1953). For the older female subjects our findings agree well with those of Greifenstein and others (1952), but our older male subjects gave significantly higher values. Wright and others (1949) predict M.B.C. for men purely on an age basis. We agree that age provides the most practicable basis for this prediction, although for the men a slight increase in accuracy is obtained by taking the B.S.A. into account as well (Gray and others, 1950).

The timed vital capacity (T.V.C.) gives more information than the V.C., which takes no account of the time taken to expel the air. The normality of the T.V.C. is judged by the absolute volume of air expelled (Tables VIII, XI, XII) in the given

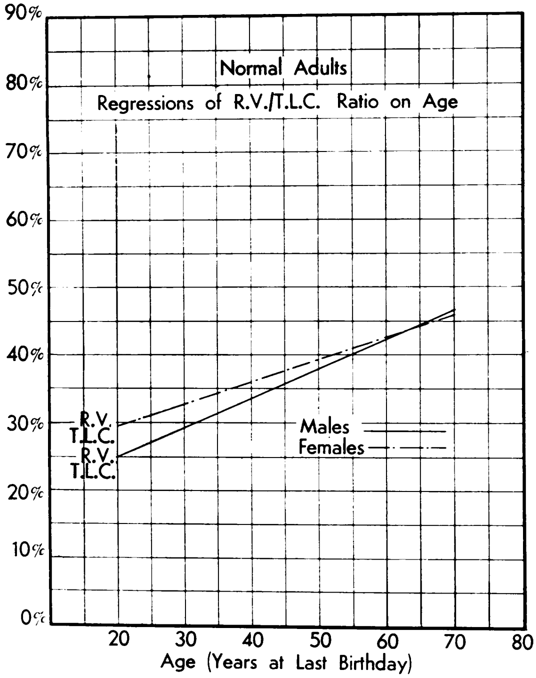

Fig. 6

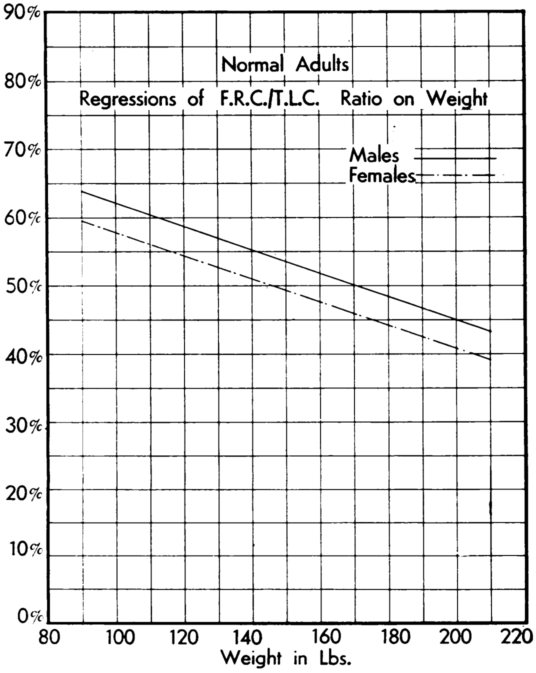

Fig. 7

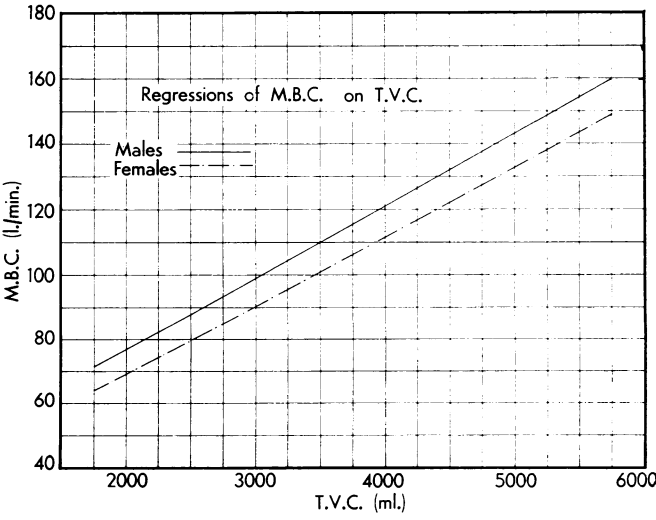

Fig. 8

TABLE VIII

LUNG MEASUREMENTS (CONTINUED)

Sex	Age	No.	V.C. (ml.)			T.V.C. (2 sec.) (ml.)			M.B.C. (l./min.)			R.T.V. (ml.)			M.E. (%)		
			Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
M	11	8	2,180	1,740	2,460	2,170	1,740	2,460	57	40	81	470	360	670	78·8	54	105
	12	13	2,420	2,000	3,100	2,410	2,000	3,100	72	49	90	540	400	750	85·9	62	112
	13	8	3,010	2,500	3,800	3,010	2,500	3,800	87	71	110	510	370	880	80·6	65	107
	14	8	3,160	2,480	5,010	3,160	2,480	5,010	98	59	121	625	400	900	77·2	60	96
	15	8	3,640	3,160	4,020	3,640	3,160	4,020	113	94	133	710	480	960	91·6	70	115
	16	8	3,860	3,090	5,170	3,860	3,090	5,170	114	88	138	770	520	1,160	84·8	65	120
	17	9	4,200	3,820	4,580	4,160	3,820	4,580	124	95	152	690	510	1,030	81·8	70	95
	18	8	4,520	3,800	5,400	4,520	3,800	5,400	137	105	165	710	560	1,200	94·9	72	105
	19	8	4,590	3,770	5,550	4,590	3,770	5,550	136	99	169	740	440	1,230	92·1	69	108
M	20–30	27	4,760	4,000	6,000	4,730	4,000	6,000	138	111	164	570	370	1,140	80·4	60	106
	30–40	23	4,510	3,600	5,400	4,460	3,600	5,400	129	99	171	660	520	1,180	77·4	61	94
	40–50	22	4,010	3,300	5,000	3,870	3,300	4,800	123	82	154	700	490	1,100	82·9	65	115
	50–60	20	3,400	2,000	4,400	3,160	1,900	4,200	104	72	146	710	390	1,100	74·7	56	101
	60–70	10	3,280	2,900	3,900	2,970	2,300	3,700	89	64	122	780	490	1,400	76·0	63	87
M	>70	3	2,320	1,920	2,680	2,130	1,580	2,600	68	40	95	550	430	780	59·0	44	71
F	11	8	1,940	1,540	2,380	1,940	1,540	2,380	53	43	61	500	360	640	73·9	62	88
	12	8	2,220	1,900	2,520	2,220	1,900	2 520	69	54	89	420	350	470	78·1	66	91
	13	8	2,560	1,790	2,930	2,560	1,790	2,930	83	51	97	580	410	800	77·2	56	104
	14	8	2,900	2,440	3,830	2,890	2,440	3,830	89	68	110	480	270	650	78·4	56	113
	15	8	3,000	2,200	3,900	3,000	2,200	3,900	90	74	102	560	450	670	77·1	63	100
	16	8	3,480	3,220	3,800	3,480	3,220	3,800	104	86	114	560	370	900	93·4	81	100
	17	8	3,260	2,800	4,330	3,230	2,800	4,330	110	91	142	460	340	570	87·8	68	100
	18	8	3,350	2,860	3,960	3,350	2,860	3,960	100	76	120	480	400	670	77·5	70	97
	19	8	3.200	2,880	3,720	3,200	2,880	3,720	103	90	120	550	450	690	81·6	60	91
F	20–30	18	3,090	2,500	4,200	3,080	2,500	4,200	96	68	122	570	390	930	82·8	64	96
	30–40	13	3,140	2,200	4,100	3,050	2,100	4,000	91	62	114	590	450	1,300	79·6	68	100
	40–50	11	2,640	2,300	3,600	2,510	1,900	3,500	80	62	106	490	310	750	76·6	58	100
	50–60	16	2,440	2,100	2,800	2,310	1,900	2,700	75	53	99	530	280	820	76·0	61	107
	60–70	8	2,180	1,800	2,700	2,040	1,600	2,500	66	54	78	570	400	860	76·2	58	89
F	>70	3	1,600	1,080	2,300	1,490	1,080	2,000	63	48	78	590	320	750	64·0	48	81

TABLE IX

LUNG MEASUREMENTS AND PHYSICAL CHARACTERISTICS: TOTAL CORRELATION COEFFICIENTS

Age Group (Years)	Physical Characteristic	Lung Measurement											
		Sex	T.L.C.	F.R.C.	F.R.C./ T.L.C.	R.V.	R.V./ T.L.C.	R.E.R.V.	V.C.	T.V.C. (2 sec.)	M.B.C.	R.T.V.	M.E. (%)
11–19	Age	M	0·86	0.81	0·14	0·66	0·00	0·71	0·86	0·86	0 83	0·45	0·24
		F	0·75	0·62	−0·09	0·54	−0·01	0·48	0·72	0·72	0·75	0·07	0·21
	Height . .	M	0·88	0·82	0·10	0·62	−0·09	0·76	0·89	0·89	0·84	0·57	0·32
		F	0·88	0·80	0·03	0·65	0·01	0·66	0·84	0·84	0·84	0·24	0·30
	Weight . .	M	0·91	0·83	0·06	0·67	−0·05	0·74	0·91	0·92	0·89	0·59	0·31
		F	0·84	0·64	−0·22	0·50	−0·17	0·55	0·86	0·86	0·80	0·04	0·25
	B.S.A. . .	M	0·93	0·85	0·08	0·68	−0·06	0·76	0·93	0·93	0·90	0·59	0·30
		F	0·88	0·71	−0·15	0·56	−0·12	0·61	0·88	0·88	0·83	0·10	0·27
	Sitting height	M	0·92	0·86	0·09	0·73	0·02	0·71	0·91	0·91	0·88	0·63	0·32
		F	0·86	0·76	0 01	0·62	−0·01	0·62	0·82	0·82	0·87	0·23	0·28
20–70	Age	M	−0·36	0·03	0·39	0·49	0·77	−0·56	−0·74	−0·78	−0·66	0·37	−0·16
		F	−0·33	−0·03	0·27	0·34	0·66	−0·51	−0·63	−0·67	−0·62	0·06	−0·25
	Height . .	M	0·55	0·28	−0·14	0·05	−0·28	0·38	0·58	0·55	0·41	0·19	0·14
		F	0·47	0·18	−0·18	0·00	−0·30	0·31	0·54	0·50	0·30	0·10	0·16
	Weight . .	M	0·22	−0·17	−0·48	−0·17	−0·34	−0·06	0·36	0·35	0·28	0·10	0·06
		F	0·07	−0·26	−0·49	−0·08	−0·13	−0·33	0·14	0·10	0·00	0·14	0·03
	B.S.A. . .	M	0·37	−0·03	−0·42	−0·10	−0·35	0·07	0·48	0·46	0·37	0·14	0·10
		F	0·21	−0·15	−0·45	−0·06	−0·20	−0·16	0·30	0·24	0·10	0·14	0·08
	Sitting height	M	0·46	0·18	−0·18	−0·03	−0·32	0·33	0·53	0·54	0·46	0·19	0·16
		F	0·47	0·17	−0·16	−0·06	−0·37	0·38	0·58	0·56	0·38	0·27	0·23

T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume, V.C. = vital capacity, T.V.C. = timed vital capacity, M.B.C. = maximum breathing capacity, R.T.V. = resting tidal volume, M.E. = mixing efficiency, B.S.A. = body surface area.

For the number of cases from which these correlations have been calculated, the coefficient must be at least 0·2 in magnitude to establish a significant association.

TABLE X
BEST REGRESSION EQUATIONS FOR EACH LUNG MEASUREMENT

Lung Measurement		Regression Coefficients (with Standard Errors)							
		× Age (Completed Years)	× Height (in.)	× Weight (lb.)	× B.S.A. (sq. m.)	× Sitting Height (in.)	Constant in Equation	Residual Standard Deviation	Coefficient of Variation (%)
T.L.C. (ml.)	A*	100 (±40)				200 (±60)	−6,480	460	10
	B		90 (±30)		2,000 (±800)		−3,900	360	9
	C	−10 (±5)	160 (±30)		1,500 (±500)		−4,210	680	11
	D	−10 (±5)	110 (±30)				−2,180	540	12
F.R.C. (ml.)	A	80 (±30)				140 (±30)	−3,600	340	16
	B		85 (±7)				−3,430	260	14
	C	10 (±5)	180 (±30)	−18 (±4)			−6,560	590	18
	D			−40 (±10)	5,000 (±1,400)		−530	450	20
F.R.C./ T.L.C. (%)	A						+47·2	4·5	10
	B						+47·1	4·9	10
	C	0·24 (±0·05)	1·2 (±0·3)	−0·23 (±0·04)			−3·0	5·5	10
	D	0·17 (±0·05)		−0·19 (±0·04)			+70·4	6·1	11
R.V. (ml.)	A					110 (±12)	−2,460	300	26
	B		45 (±6)				−1,790	210	21
	C	24 (±3)	100 (±20)	−10 (±3)			−4,150	410	19
	D	9 (±3)					+1,200	360	23
R.V./ T.L.C. (%)	A						+24·9	4·7	19
	B						+25·7	4·7	18
	C	0·45 (±0·04)	0·6 (±0·2)	−0·12 (±0·03)			−7·1	4·4	13
	D	0·34 (±0·05)		−0·07 (±0·03)			+31·3	5·4	15
R.E.R.V. (ml.)	A				1,100 (±130)		−630	250	24
	B		40 (±5)				−1,640	190	22
	C	−14 (±3)	80 (±20)	−8 (±2)			−2,410	310	25
	D	−7 (±2)		−26 (±5)	3,500 (±800)		−1,220	220	30
V.C. (ml.)	A				3,400 (±150)		−1,690	360	10
	B				2,400 (±160)		−640	300	10
	C	−35 (±4)	110 (±20)				−1,910	440	11
	D	−20 (±3)	100 (±20)				−2,710	360	13
T.V.C. (ml.)	A				3,400 (±150)		−1,700	360	10
	B				2,400 (±160)		−650	300	11
	C	−42 (±4)	100 (±20)				−1,070	460	11
	D	−23 (±3)	90 (±20)				−2,040	370	14
M.B.C. (l./min.)	A				108 (±6)		−60	14	14
	B	2 (±0·7)				6·4 (±0·8)	−149	10	11
	C	−1·1 (±0·2)			40 (±13)		+94	18	14
	D	−0·7 (±0·1)					+113	13	16
R.T.V. (ml.)	A					44 (±6)	−810	160	25
	B		30 (±9)		−500 (±200)		−610	110	22
	C	10 (±2)				66 (±14)	−2,050	200	30
	D					28 (±12)	−370	154	28
M.E. (%)	A		0·8 (±0·3)				+34·7	14	17
	B		1·0 (±0·4)				+18·8	13	16
	C						+78·7	11	14
	D	−0·2 (±0·1)					+87·0	11	14

* A = Males 11–19. B = Females 11–19. C = Males 20–70. D = Females 20–70.

B.S.A. = body surface area, T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume, V.C. = vital capacity, T.V.C. = timed vital capacity, M.B.C. = maximum breathing capacity, R.T.V. = resting tidal volume, M.E. = mixing efficiency.

(i) As an example of how the equations should be read from the table we give the M.B.C. equation for normal adult males, as follows: M.B.C. = (−1·1 × age) + (40 × B.S.A.) + 94, where the units are as given in the table.

(ii) Roughly speaking, the error in prediction should be less than the residual standard deviation in two cases out of three, and less than twice the residual standard deviation in 19 cases out of 20.

(iii) The regression coefficients are not all significantly different between males and females, as may be seen from their standard errors, but since some of them are, no attempt has been made to combine the pairs of values.

Similar remarks apply to the table of simplified regression equations (Tables XI, XII, XIII).

time, by the proportion which this volume represents of the total V.C. (Table XIV), and also by the shape of the expiratory tracing.

Using even the fast speed of the standard Palmer kymograph we were unable to measure T.V.C. accurately over less than a two-second period. A one-second T.V.C. would have the advantage of discriminating between those normal subjects with very fast expiratory rate (complete in one second) and those with medium expiratory rate (requiring one to two seconds). However, the two-second T.V.C. is usually adequate for clinical purposes, as patients may take more than 10 seconds to expel the entire V.C. The actual M.B.C. can be fairly well predicted in normal subjects from the two-second T.V.C. (Table XV, Fig. 8). Kennedy (1953) obtained a closer prediction of the M.B.C. by measuring the 0.75 second T.V.C. on a special fast kymograph, but he examined a mixed group of normal subjects and patients. It is possible that even the two-second T.V.C. would correlate better with the M.B.C. in patients with prolonged expiratory time than it does in normal subjects many of whom expel all, or nearly all, their V.C. in one second. It may be unnecessary to predict M.B.C. from T.V.C. because there seems to be no good

TABLE XI

SIMPLIFIED REGRESSION EQUATIONS FOR EACH LUNG MEASUREMENT IN AGE GROUP 11–19 YEARS: REGRESSIONS ON BODY SURFACE AREA ALONE

Lung Measurement		Regression		Residual Standard Deviation	Coefficient of Variation
		× B.S.A. (sq.m.)	Constant in Equation		
T.L.C. (ml.) ..	A	4,500 (±200)	−2,220	500	11
	B	3,100 (±200)	−670	380	10
F.R.C. (ml.)	A	2,200 (±200)	−1,150	360	17
	B	1,300 (±140)	−80	300	16
F.R.C./T.L.C. (%) ..	A		+47·2	4·5	10
	B		+47·1	4·9	10
R.V. (ml.) ..	A	1,100 (±130)	−520	320	28
	B	700 (±110)	−30	230	23
R.V./T.L.C. (%) ..	A		+24·9	4·7	19
	B		+25·7	4·7	18
R.E.R.V. (ml.)	A	1,100 (±100)	−630	250	24
	B	650 (±100)	−120	190	23
V.C. (ml.) ..	A	3,400 (±150)	−1,690	360	10
	B	2,400 (±160)	−640	300	10
T.V.C. (ml.)	A	3,400 (±150)	−1,700	360	10
	B	2,400 (±160)	−650	300	11
M.B.C. (l./min.)	A	108 (±6)	−60	14	14
	B	77 (±5)	−24	12	13
R.T.V. (ml.)	A	450 (±70)	−50	170	27
	B		+510	120	24
M.E. (%) ..	A		+85·3	15	18
	B		+80·7	13	16

A = Males. B = Females.

B.S.A. = body surface area, T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume, V.C. = vital capacity, T.V.C. = timed vital capacity, M.B.C. = maximum breathing capacity. R.T.V. = resting tidal volume, M.E. = mixing efficiency.

TABLE XII

SIMPLIFIED REGRESSION EQUATIONS FOR EACH LUNG MEASUREMENT IN AGE GROUP 20–70 YEARS: (a) REGRESSIONS ON AGE AND/OR HEIGHT

Lung Measurement		Regression			Residual Standard Deviation	Coefficient of Variation
		× Age (Completed Years)	× Height (in.)	Constant in Equation		
T.L.C. (ml.)	C		180 (±30)	−5,980	690	11
	D		120 (±30)	−3,220	550	13
F.R.C. (ml.)	C			+3,330	680	20
	D			+2,300	490	21
R.V. (ml.)	C	19 (±3)		+1,330	450	21
	D	9 (±3)		+1,200	360	23
R.V./T.L.C.%	C	0·43 (±0·04)		+16·3	4·8	14
	D	0·33 (±0·05)		+22·7	5·5	15
R.E.R.V. (ml.)	C	−17 (±3)		+1,930	340	27
	D	−11 (±2)		+1,190	260	36
V.C. (ml.)	C	−35 (±4)	110 (±20)	−1,910	440	11
	D	−20 (±3)	100 (±20)	−2,710	360	13
T.V.C. (ml.)	C	−42 (±4)	100 (±20)	−1,070	460	11
	D	−23 (±3)	90 (±20)	−2,040	370	14
M.B.C. (l./min.)	C	−1·2 (±0·1)		+170	18	15
	D	−0·7 (±0·1)		+113	13	16
R.T.V. (ml.)	C	6 (±1·5)		+420	220	33
	D			+550	160	29
M.E.(%)	C			+78·7	11·4	14
	D			+78·7	11·1	14

C = Males. D = Females.

TABLE XIII

SIMPLIFIED REGRESSION EQUATIONS FOR F.R.C. T.L.C. FOR AGE GROUP 20–70 YEARS: (b) REGRESSION ON WEIGHT

Lung Measurement		Regression		Residual Standard Deviation	Coefficient of Variation
		× Weight (lb.)	Constant in Equation		
F.R.C./T.L.C. (%)	C	−0·17 (±0·03)	+79·1	6·3	12
	D	−0·17 (±0·04)	+74·9	6·6	12

C = Males. D = Females.

TABLE XIV

NORMAL VALUES OF (T.V.C./V.C. × 100): DISTRIBUTION BY AGE AND SEX

Age Group (Years)	Distributions of Values of T.V.C./V.C. × 100							
	<85	85–95	>95	Total No.	<85	85–95	>95	Total No.
	No. of Males				No. of Females			
11–19 ..	0	1	77	78	0	1	71	72
20–30 ..	0	1	26	27	0	0	18	18
30–40 ..	0	1	22	23	0	3	10	13
40–50 ..	0	7	15	22	2	3	6	11
50–60 ..	3	9	8	20	0	9	7	16
60–70 ..	2	7	1	10	0	4	4	8
>70 ..	1	1	1	3	0	1	2	3
Total	6	27	150	183	2	21	118	141

T.L.C. = total lung capacity, F.R.C. = functional residual capacity, R.V. = residual volume, R.E.R.V. = resting expiratory reserve volume, V.C. = vital capacity, T.V.C. = timed vital capacity, M.B.C. = maximum breathing capacity, R.T.V. = resting tidal volume, M.E. = mixing efficiency.

TABLE XV

PREDICTION OF M.B.C. FROM T.V.C. (2 SEC.)

Group of Cases	Regression Equation (M.B.C. in l./min.: T.V.C. in ml.)	Residual Standard Deviation	Coefficient of Variation (%)
Males, 11–19 years	M.B.C. $= (0{\cdot}028 \times \text{T.V.C.}) + 6{\cdot}3$ $\pm 0{\cdot}002$	16	15
Females, 11–19 years	M.B.C. $= (0{\cdot}028 \times \text{T.V.C.}) + 8{\cdot}4$ $\pm 0{\cdot}002$	12	13
Males, 20–70 years	M.B.C. $= (0{\cdot}022 \times \text{T.V.C.}) + 33{\cdot}2$ $\pm 0{\cdot}002$	16	13
Females, 20–70 years	M.B.C. $= (0{\cdot}021 \times \text{T.V.C.}) + 27{\cdot}6$ $\pm 0{\cdot}002$	11	14

M.B.C. = maximum breathing capacity, T.V.C. = timed vital capacity.

(i) Four equations are given, one for each group of cases. These could not properly be combined, since the residual variation is significantly higher for males than for females, and the regression coefficients themselves are significantly higher for the adults than for the 11–19 age group.

(ii) It will be noted that in the cases of the adults, these equations give better predictions than do the regressions on physical characteristics, but this is not true of the 11–19 age group.

reason why the T.V.C. absolute value itself should not be used as a valid measure of ventilatory capacity. This would not be quite the same thing as the M.B.C., because it takes no account of the exhaustion factor, but, as this is chiefly prominent in patients who are unsuitable for the M.B.C. test, it is not a very weighty objection.

SUMMARY

Comment is made on the inadequacy of present standards for the ventilatory and distributive aspects of pulmonary function.

Lung volumes, intrapulmonary gas-mixing efficiency, timed vital capacity, and maximum breathing capacity have been measured in a total of 324 normal male and female subjects of whom 150 were under 20 years and 60 were over 50 years of age.

The results have been subjected to statistical analysis. The interrelations of the functions with age and body measurements have been studied, and regression equations have been evolved to allow prediction of expected normal values. A number of the equations are also presented in graphical form.

The findings in the present study are briefly discussed in relation to those previously reported.

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