Brit. J. soc. Med. (1950), **4,** 113-136.

THE TOTAL LUNG VOLUME AND ITS SUBDIVISIONS. A STUDY IN PHYSIOLOGICAL NORMS

III.—CORRELATION WITH OTHER ANTHROPOMETRIC DATA

BY

A. G. W. WHITFIELD, J. A. H. WATERHOUSE, and W. MELVILLE ARNOTT

From the Departments of Medicine and Medical Statistics, Queen Elizabeth Hospital, University of Birmingham

Numerous attempts have been made to correlate the vital capacity of normal subjects with other physical measurements. As long ago as 1846, Hutchinson examined its relationship with age, height, weight, and chest circumference in males. Though he found no uniform correlation between vital capacity and bodyweight and no correlation whatever with chest circumference, he stated that the vital capacity increased by eight cu. in. for every inch of height from five to six feet, and decreased by about one cu. in. per year after the age of thirty-five. Peabody and Wentworth (1917) examined 96 males and 44 females and found that, if each sex was divided into three groups according to height, 84 per cent. of the males and 68 per cent. of the females had vital capacities within 10 per cent. of the mean for their group. They also pointed out that nearly all of the subjects whose vital capacity fell outside this range had very large vital capacities, apparently as a result of athletic habit.

Dreyer (1919), however, found that in sixteen normal males the vital capacity showed an approximately equal correlation with weight, standing height, stem height, and chest circumference but a much closer correlation with surface area. His findings were confirmed in a much larger group of both sexes by West (1920).

Cripps, Greenwood, and Newbold (1923) examined 950 males passed as fit for service in the Royal Air Force and obtained a correlation coefficient of 0·59 between vital capacity and standing height. Correlation coefficients of vital capacity with stem height, weight, chest circumference, and age were all lower (at 0·54, 0·50, 0·39, and —0·1 respectively), while a multiple correlation between vital capacity and all five variables was 0·64.

Cripps (1924) found a different order of correlations in 481 normal females in whom chest circumference showed the highest correlation with vital capacity at 0·47, while the correlation coefficients of vital capacity with weight, standing height, and stem height were 0·44, 0·40, and 0·36 respectively. Baldwin, Cournand, and Richards (1948) determined the vital capacity in a group of 52 normal males with ages ranging from 16 to 69, and obtained correlation coefficients of +0·485, +0·436, +0·227, and —0·432 with height, body surface, weight, and age respectively, while in a group of forty normal females with an age range of 16 to 79 they found correlation coefficients of +0·501 with height, +0·263 with body surface, +0·067 with weight, and —0·589 with age.

Lundsgaard and Van Slyke (1918) appear to have been the first to extend the investigation of such correlations to other divisions of lung volume. They measured the total lung volume and all its subdivisions in eleven normal males and seven normal females and also determined their " chest volumes " as the product of the height, width, and depth of their chests. They concluded that the various divisions of lung volume could be expressed as functions of the " chest volume " and this view was later confirmed by Lundsgaard and Schierbeck (1922-23). Binger and Brow (1924), however, in a group of nine normal males and four normal females, found no correlation between functional residual air and chest volume, nor between functional residual air and height, weight, or surface area.

Binger (1923) had earlier published the results he obtained by first predicting and then measuring the total lung volume and its subdivisions in seven normal subjects of each sex. The difference between the predicted and observed figures was remarkably small in every instance, and again suggested that there was a close correlation between lung volume and surface area, as his prediction figures for vital capacity were obtained from West's formula (Vital Capacity=Surface Area ×2·5) and the predicted figures for the total lung volume and the remaining lung volume divisions were calculated from the predicted vital capacity by using " normal " percentage figures.

Robinson (1938), using Christie's method (Christie, 1932), determined the total lung volume and all its subdivisions in recumbency in 94 male subjects with ages ranging from 5 to 91 years. He found that the total lung volume increased rapidly from boyhood to the third decade and then gradually decreased with advancing years. The absolute and percentage values of vital capacity and reserve air showed similar changes, but the functional residual air and residual air showed a definite though somewhat uneven increase both in their absolute and percentage values from boyhood to old age.

The first comprehensive large-scale investigation of the correlation of the total lung volume and its divisions with other physical measurements was published by Hurtado and Fray (1933) who found that in fifty males aged from 18 to 30 years the total lung volume, vital capacity, functional residual air, and residual air were all more closely related to the " radiological chest volume " than they were to height, weight, surface area, chest circumference, or " chest volume ". They obtained the " radiological chest volume " by multiplying the area occupied by the heart and lungs on an anteroposterior chest *x*-ray film by the depth of the chest measured with a pelvimeter.

Kaltreider, Fray, and Hyde (1938) confirmed these findings in respect of total lung volume and vital capacity in a series of fifty older males. However, Hurtado, Fray, Kaltreider, and Brooks (1934) in an examination of fifty females with ages ranging from 18 to 34 years found that the total lung volume showed a higher correlation with standing height than it did with radiological chest volume though vital capacity, as in the males studied by the other Rochester workers, showed a maximal correlation with radiological chest volume. Conversely, Aslett, d'Arcy Hart, and McMichael (1939) found in a group of over sixty South Wales coalminers maximal correlations between total lung volume and radiological chest volume, and between vital capacity and stem height.

All workers who have studied any large series of normal subjects have found that the total lung volume and its subdivisions vary within very wide limits, and it is obviously desirable to find some means of narrowing this wide range of variability, so as to differentiate more clearly the victims of cardio-respiratory dysfunction and to assess more accurately the extent of their disability. It is not disputed that the total lung volume and its subdivisions are to some extent correlated with sex, age, and other physical measurements, and it is obvious that it is in this direction that a means of narrowing the normal range must be looked for. The results of previous investigations directed to this end have been conflicting, probably, it is thought, as a result of restriction (by age, sex, or numbers) of the subjects examined, and the object of this investigation has been to examine a significant number of subjects of all ages and both sexes and to endeavour to assess to what extent their divisions of lung volume are correlated with their other physical measurements.

METHOD

The terminology used, the method employed for the determination of the total lung volume and its subdivisions, the positioning of the subjects, and their criteria of normality were exactly the same as described previously (Whitfield, Waterhouse, and Arnott, 1950a).

Measurements.—The radiological and other physical measurements were carried out as follows:

1. *Height.*—This measurement was made in ordinary walking shoes and was approximated to the nearest quarter of an inch.
2. *Weight.*—Subjects were weighed in their night attire to the nearest half pound.
3. *Chest Expansion.*—This was measured to the nearest quarter of an inch at the level of the fifth costal cartilage in the recumbent position with the arms to the sides.
4. *Radiological Chest Volume.*—All subjects had their chests x-rayed in the erect posture in full inspiration at a distance of six feet. The area on the film occupied by the heart and lungs was measured with a planimeter and was multiplied by the antero-posterior depth of the chest measured on the subject with calipers at the level of the fifth costal cartilage. Planimetry was always carried out at least twice on each film to ensure accuracy.

Scope of the Investigation.—Fifty-eight males and 31 females were examined in the sitting posture, and 38 of the male subjects and sixteen of the female subjects were also examined in recumbency. An approximately equal number of subjects were drawn from each decennium from ten to seventy.

RESULTS

A statistical analysis of the age, height, weight, chest expansion, and radiological chest volume of the subjects examined is shown in Table I (overleaf), and a

TABLE I

STATISTICAL ANALYSIS OF SUBJECTS EXAMINED

Sex	Posture	Number of subjects examined	Statistical Observation	Age (years)	Height (inches)	Weight (pounds)	Chest expansion (inches)	Radiological chest volume (ml.)
MALE	SITTING	58	Mean	39·1	66·8	135·2	3·1	13,996
			Standard deviation	16·8	3·0	20·9	0·8	2,266
			Coefficient of variation (%) ..	43	4·6	15·5	24·8	16
			Range	13–69	59–73	83–192	1·50–5·00	5,856–18,325
	LYING	38	Mean	33·9	66·7	136·7	3·1	13,671
			Standard deviation	14·6	3·1	21·1	0·7	2,241
			Coefficient of variation (%) ..	43	4·7	15·5	23·4	16
			Range	13–65	59–73	83–192	2·0–5·0	5,856–17,428
FEMALE	SITTING	31	Mean	38·2	63·1	116·9	2·9	10,552
			Standard deviation	17	3·3	19·6	0·5	1,638
			Coefficient of variation (%) ..	44·6	5·2	16·8	16·9	16
			Range	12–68	53–68	70–173	2·0–4·0	5,564–13,191
	LYING	16	Mean	33·2	64·3	116·7	3	10,625
			Standard deviation	15·4	2·4	22·9	1	1,508
			Coefficient of variation (%) ..	46·4	3·7	19·6	18·3	14
			Range	12–62	59–68	70–173	2·0–4·0	7,670–12,840

similar analysis of their total lung volume and its subdivisions in Table II (opposite).

It will be seen from Table II that the means, standard deviations, coefficients of variation, and ranges of the total lung volume and its subdivisions for both sexes in both postures are virtually the same as those we have previously published (Whitfield, Waterhouse, and Arnott, 1950a). This is due to the fact that the same group of subjects were used for both investigations, but a few had to be omitted from the present study as for various reasons full details of their physical and radiological measurements were not available.

In Table III (pp. 118 and 119) are given the correlation coefficients between the total lung volume and each of its subdivisions on the one hand, and age, height, weight, chest expansion, and radiological chest volume on the other. It will be seen

TABLE II

Statistical Analysis of Lung Volume of Subjects Examined

Sex	Posture	Number of subjects examined	Statistical Observation	Total Lung Volume	Vital Capacity	Complemental Air	Reserve Air	Functional Residual Air	Residual Air
Male	Sitting	58	Mean	5·65	3·91	2·68	1·23	2·97	1·74
			Standard deviation	0·976	0·810	0·605	0·458	0·756	0·577
			Coefficient of variation (%) ..	17·3	20·7	22·5	37·3	25·5	50·5
			Range	2·53–7·29	1·66–5·58	1·26–4·53	0·27–2·54	1·27–4·78	0·57–2·99
	Lying	38	Mean	5·43	3·98	2·99	0·98	2·44	1·46
			Standard deviation	0·743	0·983	0·671	0·313	0·673	0·509
			Coefficient of variation (%) ..	18·1	18·7	14·5	19·5	34·9	27·6
			Range	2·31–7·24	1·78–5·68	1·58–4·53	0·20–2·60	0·73–4·39	0·53–2·58
Female	Sitting	31	Mean	4·31	2·88	1·99	0·90	2·32	1·43
			Standard deviation	0·715	0·561	0·361	0·350	0·487	0·462
			Coefficient of variation (%) ..	16·6	19·5	18·2	39·0	21·0	32·4
			Range	2·65–5·52	1·72–3·98	1·42–2·70	0·30–1·58	0·98–3·21	0·48–2·38
	Lying	16	Mean	4·32	3·13	2·46	0·66	1·86	1·19
			Standard deviation	0·553	0·517	0·383	0·242	0·431	0·478
			Coefficient of variation (%) ..	12·8	16·5	15·5	41·3	20·6	40·0
			Range	3·20–5·31	2·23–4·12	1·96–3·10	0·17–1·12	1·24–2·64	0·53–2·08

that the vital capacity shows a negative correlation coefficient with age, of the order of 0·4 in males and females whether sitting or recumbent. This accords with the results obtained by previous workers (Robinson, 1938; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy Hart, and McMichael, 1939; Baldwin, Cournand, and Richards, 1948) who all found that the vital capacity decreased with age. This change appears to be due to a diminution in mobility of the thoracic cage and a loss of elasticity in the lung parenchyma with advancing years. As in normal subjects the vital capacity is usually the same as the sum of the complemental air and

TAB

Posture	Sex and No. of Subjects	Independent Variable	Total Lung Volume			Vital Capacity			Com
			r	*β*	*b*	*r*	*β*	*b*	*r*
SITTING	Males (58)	Age	−·146	−·257	−·015	−·423	−·476	−·023	−·392
		Height	·621	·251	·081	·629	·169	·045	·594
		Weight	·323	−·411	−·019	·373	−·131	−·005	·393
		Chest expansion	·510	·271	·340	·700	·388	·405	·675
		Radiological chest volume	·622	·829	·357	·514	·640	·229	·497
		R^2	·7141			·8594			·7771
		R	·845			·927			·882
		Constant			−2·608			−1·983	
	Females (31)	Age	−·117	−·156	−·006	−·366	−·385	−·012	−·298
		Height	·525	·459	·100	·336	·093	·016	·372
		Weight	·262	−·270	−·010	·286	·038	·001	·301
		Chest expansion	·267	·208	·301	·528	·381	·433	·434
		Radiological chest volume	·552	·537	·234	·363	·423	·145	·305
		R^2	·5399			·5376			·4149
		R	·735			·733			·644
		Constant			−3·955			−0·566	
LYING	Males (38)	Age	−·221	−·107	−·007	−·398	−·224	−·011	−·458
		Height	·626	·386	·122	·702	·365	·087	·667
		Weight	·397	−·483	−·023	·467	−·193	−·007	·437
		Chest expansion	·584	·193	·258	·722	·326	·331	·711
		Radiological chest volume	·703	·764	·335	·629	·447	·148	·496
		R^2	·3735			·7711			·6893
		R	·611			·878			·830
		Constant			−4·744			−3·580	
	Females (16)	Age	−·368	−·444	−·016	−·435	−·580	−·019	−·409
		Height	·596	·162	·038	·269	−·220	−·048	·411
		Weight	·608	·364	·009	·507	·640	·014	·670
		Chest expansion	·213	−·071	−·075	·381	·075	·074	·507
		Radiological chest volume	·778	·575	·211	·445	·210	·072	·479
		R^2	·9131			·6388			·8351
		R	·956			·800			·914
		Constant			−·642			4·206	

r = Correlation Coefficient.
R = Multiple Correlation Coefficient.

reserve air, and as it usually comprises some two-thirds to four-fifths of the total lung volume, one would expect also to find negative correlations between age and total lung volume, complemental air, and reserve air respectively. This is seen to be so, but it will be noted that in male subjects the negative correlation of complemental air with age is greater, and that of reserve air with age less in recumbency than in the sitting posture. This postural difference no doubt results from the fact that complemental air becomes larger and reserve air less on lying down. As we have pointed out previously (Whitfield, Waterhouse, and Arnott, 1950b), this change results from the rise in the level of the diaphragm and the increase in the

LE III

plemental Air		Reserve Air			Functional Residual Air			Residual Air		
β	*b*	*r*	*β*	*b*	*r*	*β*	*b*	*r*	*β*	*b*
−·438	−·016	−·231	−·263	−·007	·125	·019	·001	·346	·233	·008
·116	·023	·327	·146	·022	·326	·231	·057	·168	·187	·035
−·039	−·001	·140	−·180	−·004	·103	−·499	−·018	·024	−·511	−·014
·394	·307	·348	·167	·098	·119	·035	·034	−·120	−·087	−·065
·576	·154	·252	·371	·075	·405	·608	·203	·332	·504	·128
		·2344			·2769			·2772		
		·484			·526			·527		
	−1·201			−0·787			−1·402			−0·619
−·278	−·006	−·280	−·329	−·007	·050	−·022	−·001	·239	·204	·006
·188	·021	·154	−·045	−·005	·494	·534	·079	·366	·540	·084
·051	·001	·147	·009	·000	·161	−·435	−·011	·053	−·420	−·011
·323	·237	·399	·278	·197	·070	·065	·065	−·206	−·128	−·132
·288	·064	·267	·380	·081	·584	·574	·171	·374	·286	·089
		·2988			·5330			·3574		
		·547			·730			·598		
	−0·564			−0·003			−3·380			−3·389
−·245	−·011	·040	·001	·000	·140	·091	·004	·154	·120	·004
·355	·077	·169	·075	·010	·239	·204	·044	·183	·211	·034
−·046	−·002	·130	−·281	−·005	·138	−·659	−·021	·080	−·650	−·016
·372	·346	·130	−·028	−·016	·133	−·096	−·088	·073	−·104	−·073
·193	·059	·324	·501	·090	·524	·920	·276	·438	·821	·187
		·1348			·4398			·3567		
		·367			·663			·597		
	−3·462			−0·111			−1·267			−1·157
−·528	−·013	−·282	−·399	−·006	−·102	−·094	−·003	·045	·112	·004
−·100	−·016	−·076	−·311	−·032	·376	·280	·054	·399	·425	·086
·728	·012	·023	·215	·002	·174	−·169	−·003	·155	−·271	−·006
·205	·150	·013	−·163	−·075	−·167	−·257	−·224	−·166	−·163	−·149
·143	·036	·085	·192	·036	·539	·575	·174	·418	·438	·139
		·1817			·7087			·3248		
		·426			·842			·570		
	1·688			2·499			—2·330			0·325

β = Standardized Regression Coefficient.
b = Final Unstandardized Regression Coefficient.

volume of blood in the lungs which follow the assumption of the recumbent posture. Though the functional residual air shows no appreciable correlation with age Table III shows that the residual air increases with years, especially in the sitting position. The tendency for the residual air to increase with age has been pointed out by previous workers (Robinson, 1938; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy Hart, and McMichael, 1939); it appears to result from the same degenerative processes that lead to a diminution in vital capacity. The higher positive correlation coefficients between age and residual air in the sitting position as compared with those obtained in recumbency are probably in part due to the fact that the volume of the residual air decreases on lying down.

The total lung volume and all its subdivisions show a positive correlation with height. The highest correlation coefficients are with total lung volume, vital capacity, and complemental air, in which they are of the order of 0·6 to 0·7 in males. The relationship between height and vital capacity was first recognized by Hutchinson (1846) and has since been confirmed by other workers (West, 1920; Cripps, Greenwood, and Newbold, 1923; Hurtado and Fray, 1933; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy Hart, and McMichael, 1939; Baldwin, Cournand, and Richards, 1948); it inevitably reflects itself in the complemental air and total lung volume.

Bodyweight likewise shows a positive correlation with the total lung volume and all its subdivisions, but in the case of the reserve air, functional residual air, and residual air the degree of correlation is negligible, and the correlation coefficients of total lung volume, vital capacity, and complemental air with weight are (except in the small series of females examined in recumbency) all much lower than those obtained with height. Again this is in accordance with previous publications (Hurtado and Fray, 1933; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy Hart, and McMichael, 1939; Baldwin, Cournand, and Richards, 1948).

As would be expected, the vital capacity shows a high positive correlation with chest expansion, correlation coefficients of over 0·7 being obtained in male subjects whether sitting or lying. Dependent as they are on vital capacity, the total lung volume and complemental air naturally show similar trends. The reserve air, however, while showing positive correlation coefficients with chest expansion of 0·35 to 0·4 in the sitting position, has no significant correlation in recumbency. This postural shift again appears to be largely attributable to the diminution in reserve air that occurs on lying down. The functional residual air and residual air are seen to be unrelated to chest expansion.

The functional residual air and residual air show a consistently higher positive correlationship with radiological chest volume than they do with age, height, weight, or chest expansion, correlation coefficients of from 0·33 to 0·44 being obtained for residual air and of 0·40 to 0·58 for functional residual air. This is what one would expect, having regard to the nature of the respective measurements. Total lung volume, vital capacity, complemental air, and reserve air also all show a very considerable correlation with radiological chest volume, correlation coefficients of over 0·7 being obtained for the total lung volume in females.

The correlations between the various divisions of lung volume and age, height, weight, chest expansion, and radiological chest volume are of course well shown in scatter diagrams but space does not permit the inclusion of all of the eighty such diagrams that have been made. Six of them are, however, reproduced (Figs 1 to 6).

It has of course been of interest to compare the correlation coefficients obtained in the present series with those published by other workers. Unfortunately only five of the previously published series (Hurtado and Fray, 1933; Hurtado, Fray, Kaltreider, and Brooks, 1934; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy

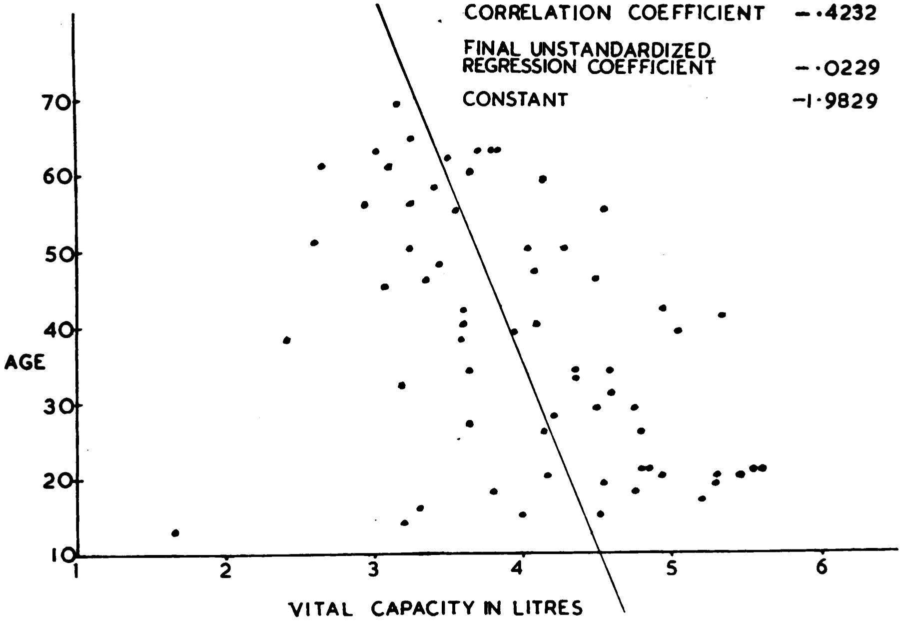

FIG. 1.—Males (sitting).

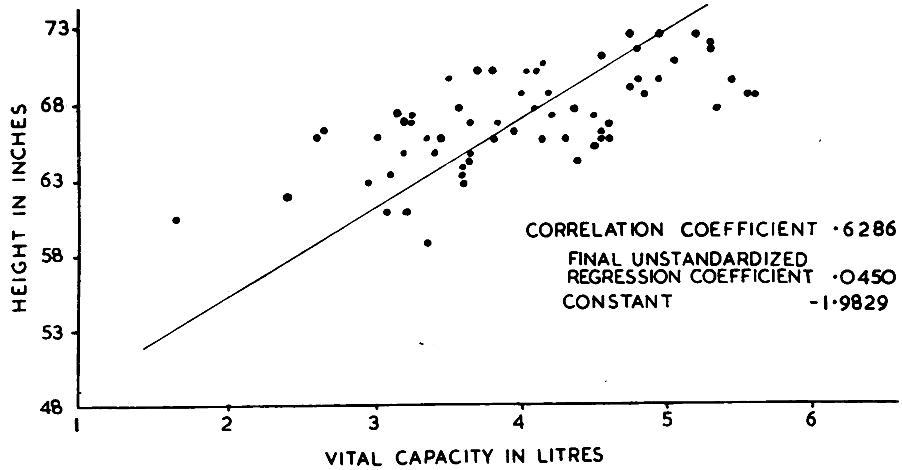

FIG. 2.—Males (sitting).

Hart, and McMichael, 1939; and Baldwin, Cournand, and Richards, 1948) permit of such a comparison. In the remainder correlation coefficients are not included and insufficient data is given to allow them to be worked out. Though Cripps, Greenwood, and Newbold (1923) and Cripps (1924) in their work on vital capacity give details of the correlation coefficients obtained, they do not state the posture of

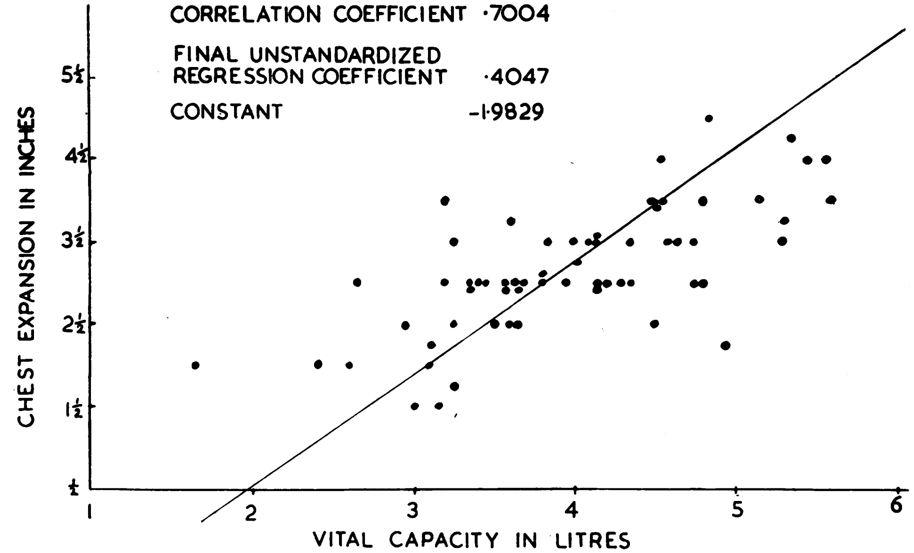

FIG. 3.—Males (sitting).

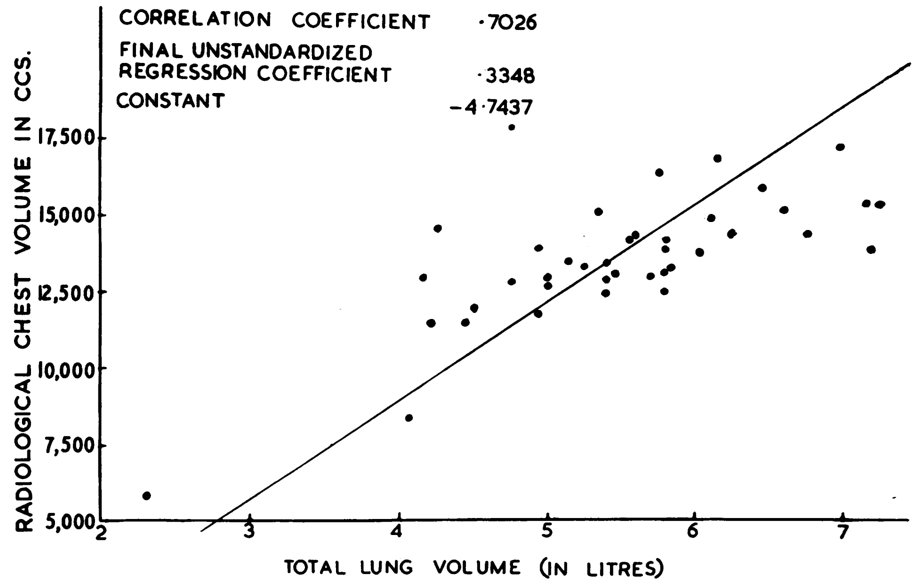

FIG. 4.—Males (lying).

their subjects so that their results cannot be compared accurately with our own.

Table IV (p. 124) gives details of all comparable published correlation coefficients. From this it will be seen that the results obtained in the present series agree very

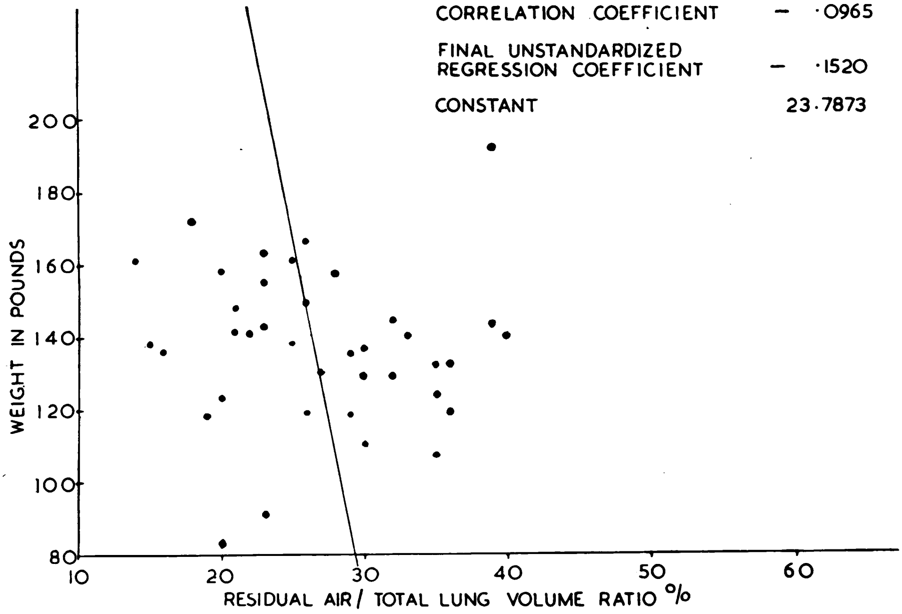

FIG. 5.—Males (lying).

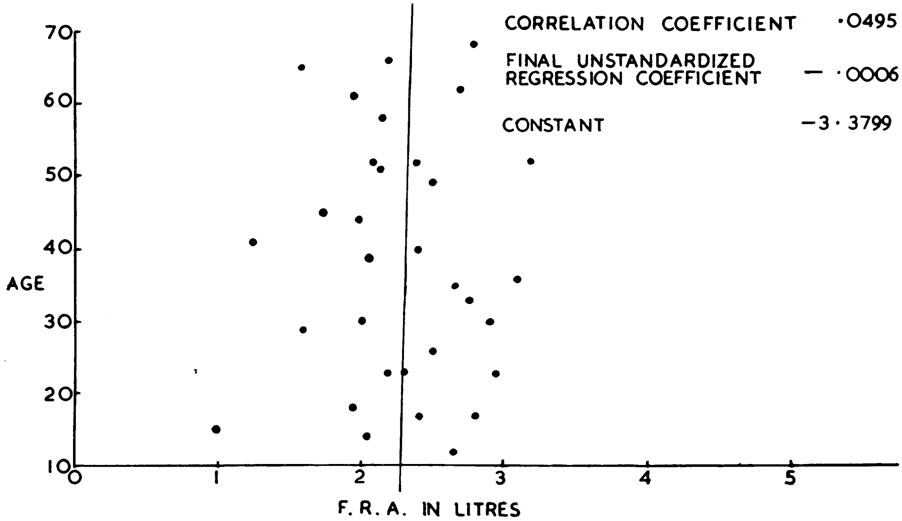

FIG. 6.—Females (sitting).

closely with those previously published. There are only two striking dissimilarities. Firstly Aslett, d'Arcy Hart, and McMichael found negligible correlations between chest expansion and total lung volume, and between chest expansion and vital capacity, while in the present series correlation coefficients of 0·57 and 0·70 were obtained. The mean age, height, weight, and radiological chest volume of Aslett,

TABLE IV

COMPARISON OF AUTHORS' CORRELATION COEFFICIENTS WITH THOSE OBTAINED BY OTHER WORKERS

Posture	Characteristics Correlated	Males				Females		
		Hurtado and Fray 50 subjects (age 10–30)	Kaltreider, Fray, and Hyde 50 subjects (age 38–63)	Baldwin, Cournand, and Richards 52 subjects (age 16–69)	Authors' series 38 subjects (age 13–65)	Hurtado, Kaltreider, Fray, and Brooks 50 subjects (age 18–34)	Baldwin, Cournand, and Richards 40 subjects (age 16–79)	Authors' series 16 subjects (age 12–62)
LYING	Vital Capacity with Age			−·432	−·398		−·589	−·435
	Total Lung Volume with Height	+·551	+·616		+·626	+·662		+·596
	Vital Capacity with Height	+·545	+·636	+·485	+·702	+·513	+·501	+·269
	Total Lung Volume with Weight ..	−·127	+·357		+·397	+·181		+·608
	Vital Capacity with Weight	+·138	+·309	+·227	+·467	+·260	+·067	+·507
	Total Lung Volume with Radiological chest volume ..	+·634	+·850		+·703	+·625		+·778
	Vital Capacity with Radiological chest volume	+·717	+·728		+·629	+·707		+·445
	Functional Residual Air with Radiological chest volume ..	+·444			+·524			+·539
	Residual Air with Radiological chest volume	+·383			+·438			+·418

Posture	Characteristics Correlated	Aslett, d'Arcy Hart, and McMichael 64 subjects (age 18–63)	Authors' series 58 subjects (age 13–69)	Females
SITTING	Total Lung Volume with Height	+·66	+·621	No comparable figures published
	Vital Capacity with Height	+·70	+·629	
	Total Lung Volume with Weight ..	+·55	+·323	
	Vital Capacity with Weight	+·57	+·373	
	Total Lung Volume with Chest expansion	+·14	+·570	
	Vital Capacity with Chest expansion ..	+·28	+·700	
	Total Lung Volume with Radiological chest volume ..	+·80	+·622	
	Vital Capacity with Radiological chest volume	+·63	+·514	

d'Arcy Hart, and McMichael's series were virtually the same as those in the group that we have examined, but the mean chest expansion of their subjects was only 1·94 inches while in our own series it was 3·14 inches. Therein lies the probable explanation of the different results obtained, though why there should be such a wide discrepancy between the chest expansion of two otherwise similar groups is not known. Secondly in both male and female subjects examined in recumbency we have obtained higher correlation coefficients between weight and total lung volume, and weight and vital capacity, than have been obtained by other workers. This may be due to the fact that the mean weight of the subjects examined by the Rochester workers and by Baldwin, Cournand, and Richards was appreciably greater than in our series.

From Table III and the discussion which follows it, it is clear that, though there is in many instances a considerable simple correlation between the various divisions of lung volume and age, height, weight, chest expansion, or radiological chest volume, the correlation coefficient is nowhere high enough to allow the normal total lung volume or any of its subdivisions to be predicted from any one of these independent variables with sufficient accuracy to indicate whether observed volumes fall within or without the normal range.

Multiple correlation coefficients between age, height, weight, chest expansion, and radiological chest volume on the one hand, and the total lung volume and each of its subdivisions on the other hand, have therefore been calculated in order to ascertain whether, when all the independent variables are considered together, a sufficiently high correlation is obtained with the total lung volume or any of its subdivisions to allow of their accurate prediction. The results obtained are shown in Table III, from which it will be seen that in all but two instances the multiple correlation coefficients are much higher than any of the simple correlation coefficients. The highest multiple correlation coefficients are, as in the case of the simple correlation coefficients, with total lung volume, vital capacity, and complemental air, in which in many instances they approach unity. However, reserve air, functional residual air, and residual air also show very much more useful multiple than single correlation coefficients from the point of view of prediction, only three being less than 0·50, and one being as high as 0·84. It is clear, therefore, that though it is not possible to predict with any useful degree of accuracy the total lung volume or any of its subdivisions from either age, height, weight, chest expansion, or radiological chest volume alone, a very accurate prediction can be made when these variables are considered as a whole.

In Table V (pp. 126 and 127) is shown the contribution of each of the independent variables considered towards the total variance in the total lung volume and each of its subdivisions which they explain when considered together. Their contribution is also shown as a percentage of the variance that they " explain ". From this table it will be seen that the contributions afforded by each of the independent variables show considerable sex and postural difference. Nevertheless, certain definite trends appear. As far as the total lung volume is concerned, radiological

TAB

Posture	Sex and No. of Subjects	Independent Variable	Total Lung Volume		Vital Capacity	
			100 βr	%R^2	100 βr	%R^2
SITTING	Males (58)	Age	3·76	5·27	20·14	23·44
		Height	15·57	21·80	10·62	12·36
		Weight	−13·28	−18·60	−4·87	−5·67
		Chest expansion	13·80	19·33	27·19	31·64
		Radiological chest volume	51·55	72·19	32·86	38·24
		R^2	71·40		85·94	
	Females (31)	Age	1·82	3·37	14·08	26·19
		Height	24·08	44·60	3·11	5·78
		Weight	−7·07	−13·10	1·09	2·03
		Chest expansion	5·55	10·28	20·13	37·44
		Radiological chest volume	29·62	54·86	15·35	28·55
		R^2	54·00		53·76	
LYING	Males (38)	Age	2·37	3·28	8·90	11·54
		Height	24·13	33·74	25·65	33·26
		Weight	−19·16	−26·79	−9·07	−11·76
		Chest expansion	11·24	15·56	23·51	30·49
		Radiological chest volume	53·66	74·27	28·13	36·48
		R^2	72·23		77·12	
	Females (16)	Age	16·31	17·86	25·14	39·36
		Height	9·67	10·59	−5·90	−9·24
		Weight	22·15	24·26	32·46	50·82
		Chest expansion	−1·51	−1·65	2·86	4·48
		Radiological chest volume	44·70	48·95	9·32	14·59
		R^2	91·31		63·87	

100 βr=Percentage contribution (i.e. " explanation ") to total variance.

chest volume is the dominant factor, though height and chest expansion offer significant contributions. As regards the vital capacity and complemental air, the radiological chest volume and chest expansion offer approximately equal contributions, but age and height are seen to play a considerable part. The explanation of the variance in reserve air shows remarkable sex and postural differences for which no reason is apparent, but radiological chest volume again appears to be the most important factor. The variance of the functional residual air and residual air is also shown to be very largely attributable to the radiological chest volume with height playing a relatively minor part.

Table III also shows the standardized regression coefficients, the final unstandardized regression coefficients, and the constants for each division of lung volume when related to age, height, weight, chest expansion, and radiological chest volume together. From these the predicted values for the total lung volume and each of its subdivisions has been calculated for six males and six females in the sitting posture and for a similar number from each sex in recumbency. The results are shown graphically (Figs 7 to 10). No gross discrepancy is apparent.

The Rochester workers (Hurtado and Boller, 1933; Hurtado, Fray, Kaltreider, LE V

Complemental Air		Reserve Air		Functional Residual Air		Residual Air	
100 βr	%R^2	100 βr	%R^2	100 βr	% R^2	100 βr	%R^2
17·17	22·09	6·07	25·88	0·24	0·86	8·05	29·06
6·87	8·84	4·77	20·35	7·53	27·19	3·14	11·33
−1·51	−1·94	−2·52	−10·75	−5·13	−18·53	−1·22	−4·40
26·56	34·17	5·79	24·70	0·41	1·48	1·04	3·76
28·64	36·85	9·33	39·83	24·65	89·00	16·71	60·28
77·73		23·44		27·69		27·72	
8·28	20·90	9·21	30·81	−0·11	−0·21	4·88	13·65
7·00	17·67	−0·70	−2·34	26·41	49·55	19·74	55·22
1·53	3·86	0·13	0·44	−6·78	−13·10	−2·21	−6·18
14·01	35·37	11·09	37·10	0·46	0·86	2·64	7·38
8·79	22·19	10·16	33·99	33·52	62·89	10·70	29·93
39·61		29·89		53·30		35·75	
11·19	16·23	0·00	0·00	1·27	2·89	1·85	5·18
23·69	34·36	1·26	9·35	4·86	11·05	3·85	10·79
−2·00	−2·90	−3·64	−27·00	−9·07	−20·62	−5·19	−14·55
26·49	38·42	−0·37	−2·74	−1·27	−2·89	−0·76	−2·13
9·57	13·88	16·23	120·40	48·19	109·57	35·93	100·70
68·94		13·48		43·98		35·68	
21·60	25·87	11·25	61·95	0·95	2·17	0·51	1·49
−4·12	−4·93	2·37	13·05	10·53	24·04	16·94	49·40
48·81	58·45	0·50	2·75	−2·94	−6·71	−4·19	−12·22
10·38	12·43	−0·22	−1·21	4·28	9·77	2·72	7·93
6·83	8·18	4·27	23·51	30·98	70·73	18·31	53·40
83·50		18·16		43·80		34·29	

%R^2 =Percentage contribution to " explained " variance.

and Brooks, 1934; and Kaltreider, Fray, and Hyde, 1938) pointed out that in normal subjects when the various divisions of lung volume were expressed as percentages of the total they showed a much smaller range of variability than when their absolute values were used. This was fully confirmed by the results of investigations which we have previously published (Whitfield, Waterhouse, and Arnott, 1950a). The value of the Residual Air/Total Lung Volume ratio as an index of ventilatory efficiency is well known, and its importance has been emphasized by many workers in respiratory physiology (Meakins and Christie, 1930; Hurtado and Boller, 1933; Hurtado, Kaltreider, Fray, Brooks, and McCann, 1934; Kaltreider, Fray, and Hyde, 1938; Aslett, d'Arcy Hart, and McMichael, 1939). It was therefore thought desirable to explore the correlations of the various divisions of lung volume when expressed as percentages of the total, and simple correlation coefficients have been calculated between each of the divisions of lung volume expressed as percentages of the total lung volume on the one hand, and age, height, weight, chest expansion, and radiological chest volume on the other. These are shown in Table VI (pp. 130 and 131) which shows that in general very much lower degrees of correlation have been found than when the absolute values were used. It will be noted that, as when the absolute values were used, the vital capacity,

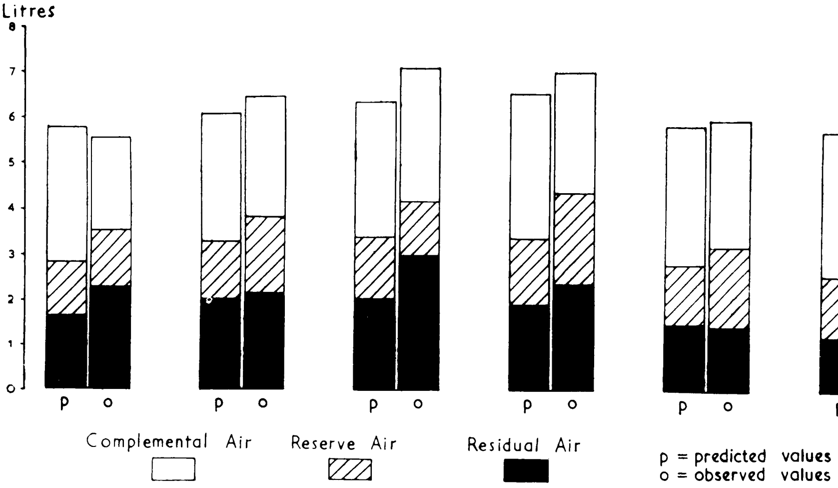

FIG. 7.—Males (sitting).

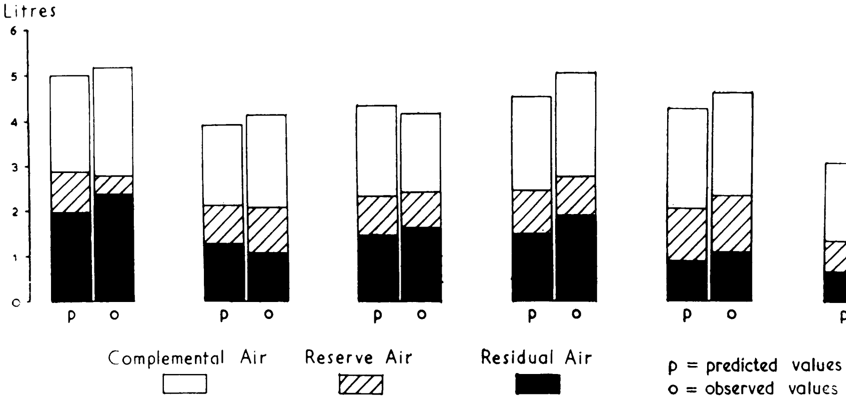

FIG. 8.—Females (sitting).

complemental air, and reserve air show a negative, and the functional residual air and residual air a positive, correlation with age. This is as would be expected, knowing as we do that with age the vital capacity and its two components, complemental air and reserve air, tend to diminish and the functional residual air and residual air to increase. The correlation coefficients are of much the same order as those obtained when the absolute values were used, but in no instance do they exceed 0·50, and in the small group of females examined in recumbency no appreciable correlation with age was found.

The correlations with height and weight are very small and irregular and cannot be regarded as having any significance. Chest expansion, however, shows appreciable correlation coefficients, which are positive with vital capacity and complemental air, and negative with functional residual air and residual air, which is again what one would expect to find. The small positive correlation coefficients

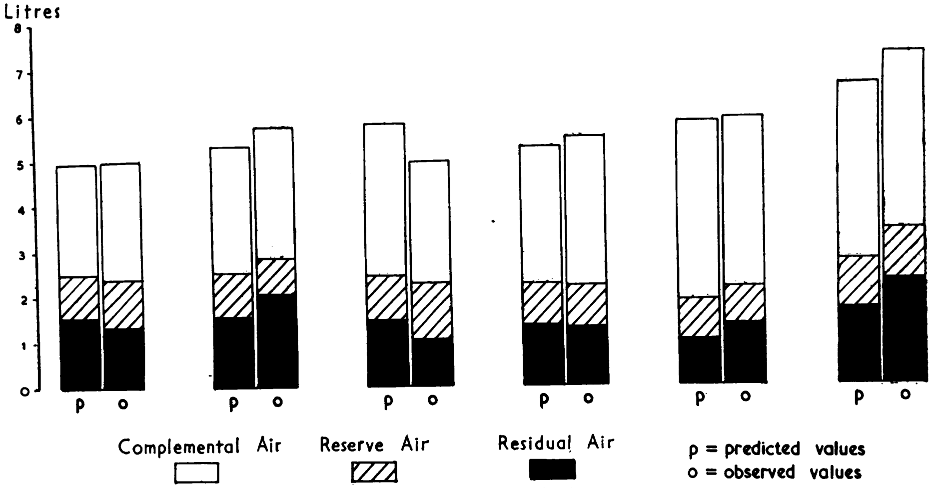

FIG. 9.—Males (lying).

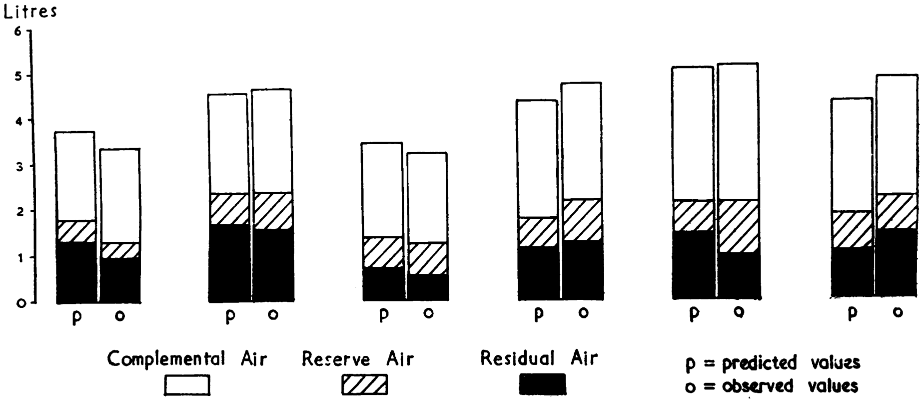

FIG. 10.—Females (lying).

of chest expansion with the reserve air when sitting become slightly negative in recumbency, which postural change is probably due to the diminution in the reserve air which follows the assumption of the recumbent posture. The correlation coefficients obtained between chest expansion and functional residual air and residual air are larger than those obtained when absolute values were used and are uniformly negative. The positive correlation coefficients between vital capacity and chest expansion and between complemental air and chest expansion are, however, much smaller than those obtained with the absolute values. The correlations between the radiological chest volume and the various divisions of lung volume expressed as percentages of the total are small and irregular and no deductions can be drawn from them.

Table VI also includes multiple correlation coefficients between each of the divisions of lung volume expressed as a percentage of the total lung volume on the

TAB

Posture	Sex and No. of Subjects	Independent Variable	Vital Capacity/Total Lung Volume %			Complemental Air/Total Lung Volume %		
			r	β	*b*	*r*	β	*b*
SITTING	Males (58)	Age	−·464	−·364	−·188	−·304	−·228	−·113
		Height	·140	−·086	−·246	·096	−·100	−·274
		Weight	·115	·287	·120	·136	·327	·130
		Chest expansion	·460	·315	3·532	·318	·237	2·538
		Radiological chest volume	−·037	−·085	−·326	−·020	−·131	−·481
		R²	·3378			·1820		
		R	·581			·427		
		Constant			70·497			51·670
	Females (31)	Age	−·441	−·389	−·184	−·170	−·149	−·093
		Height	−·157	−·441	−1·102	−·115	−·250	−·822
		Weight	·119	·469	·196	·056	·306	·169
		Chest expansion	·461	·311	5·164	·112	·051	1·111
		Radiological chest volume	−·231	−·151	−·757	−·197	−·189	−1·244
		R²	·4745			·1142		
		R	·689			·338		
		Constant			113·829			92·245
LYING	Males (38)	Age	−·422	−·309	−·144	−·441	−·293	−·171
		Height	·159	−·023	−·049	·145	·023	·062
		Weight	·097	·474	·152	·070	·548	·220
		Chest expansion	·288	·236	2·182	·253	·244	2·838
		Radiological chest volume	−·150	−·540	−1·632	·246	·724	−2·747
		R²	·3210			·4109		
		R	·567			·641		
		Constant			76·213			55·205
	Females (16)	Age	−·099	−·237	−·140	−·106	−·177	−·071
		Height	−·287	−·527	−2·030	−·115	−·315	−·828
		Weight	·106	·561	·222	·240	·581	·157
		Chest expansion	·281	·165	2·852	·462	·382	4·504
		Radiological chest volume	−·200	−·319	−1·919	·225	·460	−1·888
		R²	·3444			·4743		
		R	·587			·689		
		Constant			193·423			100·775

r = Correlation Coefficient. R = Multiple Correlation Coefficient.

one hand, and age, height, weight, chest expansion, and radiological chest volume together on the other. It will be seen that though the correlation coefficients obtained in the case of the functional residual air and residual air are approximately the same as when the absolute values were used, those obtained for the vital capacity, complemental air, and reserve air are uniformly lower. In no instance has a correlation coefficient exceeding 0·7 been obtained. In order to ascertain to what extent age, height, weight, chest expansion, and radiological chest volume respectively contribute to the multiple correlation, their percentage contribution (i.e. explanation) to the total variance and their percentage contribution to the

LE VI

$\frac{\text{Reserve Air}}{\text{Total Lung Volume}}\%$			$\frac{\text{Functional Residual Air}}{\text{Total Lung Volume}}\%$			$\frac{\text{Residual Air}}{\text{Total Lung Volume}}\%$		
r	*β*	*b*	*r*	*β*	*b*	*r*	*β*	*b*
—·218	—·183	—·075	·304	·228	·113	·464	·364	·188
·060	·012	·029	—·096	·100	·274	—·140	·086	·246
—·019	—·032	—·011	—·136	—·327	—·130	—·115	—·287	—·119
·196	·112	·994	—·318	—·237	—2·538	—·460	—·315	—3·532
—·023	·051	·155	·020	·131	·481	·037	·085	·326
·0617			·1820			·3378		
·248			·427			·581		
		18·830			48·330			29·503
—·252	—·224	—·091	·170	·149	·093	·441	·389	·184
—·006	—·131	—·280	·155	·250	·822	·157	·441	1·102
·052	·076	·027	—·056	—·306	—·169	—·119	—·469	—·196
·364	·284	4·053	—·112	—·051	—1·111	—·461	—·311	—5·164
·033	·113	·487	·197	·189	1·244	·231	·151	·757
·1684			·1142			·4745		
·410			·338			·689		
		21·568			7·755			—13·829
·131	·058	·027	·441	·293	·171	·422	·309	·144
—·023	—·051	—·111	—·145	—·023	—·062	—·159	·023	·049
·008	—·212	—·068	—·070	—·548	—·220	—·097	—·474	—·152
—·030	—·070	—·656	—·253	—·244	—2·838	—·288	—·236	—2·182
·158	·366	1·115	·246	·724	2·747	·150	·540	1·632
·0668			·4109			·3210		
·259			·641			·567		
		20·978			44·795			23·787
—·042	—·188	—·068	·106	·177	·071	·099	·237	·140
—·338	—·505	—1·203	·115	·315	·828	·287	·527	2·030
—·094	·267	·065	—·240	—·581	—·157	—·106	—·561	—·222
—·057	—·155	—1·653	—·462	—·382	—4·504	—·281	—·165	—2·852
—·075	—·008	—·031	·225	·460	1·888	·200	·319	1·919
·1631			·4743			·3444		
·404			·689			·587		
		92·634			—·775			—93·423

β = Standardized Regression Coefficient. *b* = Final Unstandardized Regression Coefficient.

" explained " variance have been calculated; the results obtained are set out in Table VII from which it will be seen that they are very irregular and that it is difficult to draw any very precise conclusions from the analysis. However, age and chest expansion appear to be the most important factors, though radiological chest volume, height, and weight offer large contributions in occasional instances.

The standardized regression coefficients, the final unstandardized regression coefficients, and the constants for the multiple correlations are also given in Table VI.

Details of the statistical method employed are given in Appendix A.

TABLE VII

Posture	Sex and No. of Subjects	Independent Variable	Subdivisions of Lung Volume as Percentages of Total					
			Reserve Air		Functional Residual Air and Complemental Air		Residual Air and Vital Capacity	
			100 βr	%R^2	100 βr	%R^2	100 βr	%R^2
SITTING	Males (58)	Age	3·98	64·50	6·95	38·21	16·89	50·00
		Height	0·07	1·13	−0·97	−5·33	−1·20	−3·55
		Weight	0·06	0·97	4·43	24·35	3·30	9·77
		Chest expansion	2·18	35·33	7·52	41·34	14·48	42·87
		Radiological chest volume	−0·12	−1·94	0·26	1·43	0·31	0·92
		R^2	6·17		18·19		33·78	
	Females (31)	Age	5·65	33·55	2·53	22·13	17·12	36·08
		Height	0·08	0·48	2·88	25·20	6·94	14·63
		Weight	0·39	2·32	1·73	15·14	5·57	11·74
		Chest expansion	10·34	61·40	0·57	4·99	14·32	30·18
		Radiological chest volume	0·38	2·26	3·72	32·55	3·50	7·38
		R^2	16·84		11·43		47·45	
LYING	Males (38)	Age	0·76	11·4	12·94	31·49	13·04	40·62
		Height	0·11	1·65	0·33	0·80	−0·36	1·12
		Weight	−0·18	−2·70	3·85	9·37	4·57	14·24
		Chest expansion	0·21	3·15	6·18	15·04	6·78	21·12
		Radiological chest volume	5·77	86·51	17·79	43·30	8·07	25·14
		R^2	6·67		41·09		32·10	
	Females (16)	Age	0·79	4·84	1·88	3·96	2·34	6·79
		Height	17·08	104·7	3·60	7·59	15·13	43·93
		Weight	−2·50	−15·33	13·95	29·41	5·96	17·31
		Chest expansion	0·88	5·40	17·64	37·19	4·63	13·44
		Radiological chest volume	0·06	0·37	10·36	21·84	6·38	18·52
		R^2	16·31		47·43		34·44	

100 βr = Percentage contribution (i.e. " explanation ") to total variance.
%R^2 = Percentage contribution to " explained " variance.

SUMMARY AND CONCLUSIONS

(1) The total lung volume and its subdivisions have been determined in 58 normal males and 31 normal females in the sitting posture, and in 38 normal males and sixteen normal females in recumbency.

(2) The correlation between the results obtained and the age, height, weight, chest expansion, and radiological chest volume of the subjects has been calculated.

(3) The total lung volume, vital capacity, complemental air, and reserve air show negative, and the functional residual air and residual air positive, correlations with age, but in no instances do the correlation coefficients exceed 0·50.

(4) All divisions of lung volume show positive correlations with both height and weight. The correlation coefficients with height are higher than those with

weight, and for total lung volume, vital capacity, and complemental air are of the order of 0·60 to 0·70 in most instances.

(5) The total lung volume, vital capacity, and complemental air all show high positive correlations with chest expansion and radiological chest volume, correlation coefficients up to 0·78 being obtained.

The reserve air shows similar positive correlations but these are less in degree especially in recumbency.

(6) The functional residual air and residual air show no significant correlation with chest expansion, but correlation coefficients of the order of 0·40 to 0·60 were obtained with radiological chest volume.

(7) The results obtained are compared with those published by other workers.

(8) Multiple correlations between each division of lung volume and age, height, weight, chest expansion, and radiological chest volume considered together gave correlation coefficients approaching unity in the case of total lung volume, vital capacity, and complemental air. The multiple correlation coefficients obtained with reserve air, functional residual air, and residual air were generally of the order of 0·50 to 0·70, but they were uniformly higher than any of the simple correlation coefficients.

(9) The total lung volume, vital capacity, and complemental air can be very accurately predicted if age, height, weight, chest expansion, and radiological chest volume are known. The degree of precision with which the reserve air, functional residual air, and residual air can be predicted from similar data is not so high.

(10) When the various divisions of lung volume are expressed as percentages of the total lung volume they show less variability than when their absolute values are used, but their degrees of correlation with height, weight, and radiological chest volume is less when so expressed.

(11) The correlation between age and the various divisions of lung volume is approximately the same whether absolute or percentage values of lung volume are used.

(12) The chest expansion shows a higher (negative) correlation with functional residual air and residual air, and a lower (positive) correlation with vital capacity, complemental air, and reserve air when percentage values are used for the lung volume divisions than when absolute values are employed.

(13) When percentage values are used the functional residual air and residual air show multiple correlation coefficients with age, height, weight, chest expansion, and radiological chest volume together, similar to those obtained when absolute values are used. The multiple correlation coefficients given by vital capacity, complemental air, and reserve air are, however, uniformly lower when percentage values are employed.

We wish to express our gratitude to Professor Lancelot Hogben, F.R.S., for placing the facilities of his department at our disposal, to Mr. A. C. Pincock for valuable technical advice and help, to Mr. Dee for help in the production of diagrams, and to Imperial Chemical Industries for a grant towards expenses.

REFERENCES

Aslett, E. A., d'Arcy Hart, P., and McMichael, J. (1939). *Proc. Roy. Soc. B*, **126**, 502.
Baldwin, E. de F., Cournand, A., and Richards, D. W. (1948). *Medicine, Baltimore*, **27**, 243.
Binger, C. A. L. (1923). *J. exp. Med.*, **38**, 445.
———, and Brow, G. R. (1924). *Ibid.*, **39**, 677.
Christie, R. V. (1932). *J. clin. Invest.*, **11**, 1099.
Cripps, L. D. (1924). *Spec. Rep. med. Res. Coun.*, **84.**
———, Greenwood, M., and Newbold, E. M. (1923). *Biometrika*, **14**, 316.
Dreyer, G. (1919). *Lancet*, **2**, 227.
Hurtado, A., and Boller, C. (1933). *J. clin. Invest.*, **12**, 793.
———, and Fray, W. W. (1933). *Ibid.*, **12**, 807.
——— ———, Kaltreider, N. L., and Brooks, W. D. W. (1934). *Ibid.*, **13**, 169.
———, Kaltreider, N. L., Fray, W. W., Brooks, W. D. W., and McCann, W. S. (1934). *Ibid.*, **13**, 1027.
Hutchinson, J. (1846). *Med. Chir. Trans.*, **29**, 137.
Kaltreider, N. L., Fray, W. W., and Hyde, H. van Z. (1938). *Amer. Rev. Tuberc.*, **27**, 662.
Lundsgaard, C., and Van Slyke, D. D. (1918). *J. exp. Med.*, **27**, 65.
———, and Schierbeck, K. (1922-23). *Proc. Soc. exp. Biol., N.Y.*, **20**, 160.
Meakins, J. C., and Christie, R. V. (1929-30). *Ann. intern. Med.*, **3**, 423.
Peabody, F. W., and Wentworth, J. A. (1917). *Arch. intern. Med.*, **20**, 443.
Robinson, S. (1938). *Arbeitsphysiologie*, **10**, 251.
West, H. F. (1920). *Arch. intern. Med.*, **25**, 306.
Whitfield, A. G. W., Waterhouse, J. A. H., and Arnott, W. M. (1950a). *British Journal of Social Medicine*, **4**, 1.
——— ——— and ——— (1950b). *Ibid.*, **4**, 86.

APPENDIX

STATISTICAL METHODS

To obtain the multiple regression equations used in this paper we calculated from the matrix of intercorrelations between the five anthropometric indices an inverse matrix; this was done for each of the four groups (males, females; sitting, lying). For each fraction of lung volume (absolute or relative) we then first obtained a set of "β's", or standardized regression coefficients: these are the regression coefficients when each variable (anthropometric indices as the independent variables, and lung fraction as the dependent) is expressed in units of its standard deviation ("standardized"). The β's are more easily comparable one with another than the final coefficients, to show their relative importance in determining the lung fraction under consideration, because of their freedom from arbitrary units of measurement. Thence to the final regression coefficients ("b's") in terms of the original units is an elementary step.

R^2, the square of the multiple correlation coefficient, and also the proportion of the original variance in the dependent variable (lung fraction) "explained" by the regression equation, is calculated in the usual way as the sum of the products of each β and its corresponding correlation coefficient (r). The partial "explanations" by the five anthropometric indices are also shown, both absolutely and as percentages of R^2, the total proportion of variance accounted for by the equations. The fact that *Weight* frequently shows a meaningless negative contribution is due to its high intercorrelation with *Height*: the two are effectively measuring the same property of gross size, so that a better estimate of the contribution of overall size is obtained by adding together the contributions of *Height* and *Weight* (that is utilizing the conventional conception of surface area). It will be noticed that occasionally negative contributions arise in some other indices, notably in the last three fractions for Males Lying, where the multiple correlation coefficient is small. It seems that in the lying position, the Radiological Chest Volume exerts the greatest effect upon the volume fraction, frequently usurping the contributions of some of the other indices. The proportionate contribution figures exhibited in Tables V and VII should in any case be regarded as general indications of the effects rather than as precise numerical estimates.

In Table A are shown the diagonal elements of the four inverse matrices, from which may be calculated the significance of the β-coefficients (and of course of the final coefficients). For this purpose, the standard deviation of any β-coefficient is given by the formula:

$$\sigma_\beta = \sqrt{\frac{1-R^2}{n-6} M_A}$$

where R^2 is the square of the multiple correlation coefficient for the regression equation containing the required β-coefficient, n is the number of individuals on which the result is based, and M_A is the diagonal element for that anthropometric index to which the β-coefficient refers.

APPENDIX TABLE A

Posture	Sitting		Lying	
Sex	Males	Females	Males	Females
Age	1·6477	1·4686	2·0186	1·2900
Height	2·3205	1·9009	2·5389	1·6973
Weight	2·4046	1·8391	3·0376	2·0956
Chest expansion	1·4335	1·1855	1·9799	1·2240
Radiological chest volume ..	3·0950	1·5648	2·8566	1·2896
n=number of subjects ..	58	31	38	16

We append two examples of the significance of our regression equations, one which is highly significant, and one which is not significant. The regression equation for Total Lung Volume, for Males Lying, has a multiple correlation coefficient (R) whose square is 0·7223. If we wish to test the significance in this equation of the β-coefficient referring to the Radiological Chest Volume, which has the value 0·7637, we proceed as follows:

$$R^2 = 0{\cdot}7223$$

$$1 - R^2 = 0{\cdot}2777$$

$$\therefore \quad \frac{1-R^2}{n-6} = \frac{0{\cdot}2777}{38-6} = 0{\cdot}008678.$$

From Table A we have

$$M_{RCV}=2\cdot 8566$$

$$\text{so that S.D.}(\beta_{RCV})=\sqrt{2\cdot 8566\times 0\cdot 008678}$$

$$=0\cdot 1574.$$

Applying " Student's " *t*-test,

$$t=\frac{\beta_{RCV}}{\text{S.D.}(\beta_{RCV})}=\frac{0\cdot 7637}{0\cdot 1574}=4\cdot 85 \text{ for 32 degrees of freedom.}$$

The probability of obtaining so high a value as this by chance alone is less than 1 in 1,000.

If we now consider the regression equation for the Functional Residual Air as a proportion of the Total Lung Volume in Females Sitting, and wish to test the significance of the β-coefficient relating to age, which has the value 0·1486, we perform a similar set of operations to the preceding.

$$R^2=0\cdot 1142$$

$$n=31$$

$$\therefore \quad \frac{1-R^2}{n-6}=0\cdot 03543.$$

From Table A we have

$$M_{Age}=1\cdot 4686$$

$$\text{so that S.D.}(\beta_{Age})=\sqrt{1\cdot 4686\times 0\cdot 03543}=0\cdot 2281$$

$$\text{whence } t=\frac{0\cdot 1486}{0\cdot 2281}=0\cdot 65 \text{ for 25 degrees of freedom.}$$

The probability corresponding to this value of t is $P=0\cdot 52$, so that the chances are about even, and the value of the β-coefficient cannot be considered significantly different from zero.