Eur Respir J
1991, 4, 829–838

What factors explain racial differences in lung volumes?

P.M. Donnelly* T-S. Yang, J.K. Peat, A.J. Woolcock

What factors explain racial differences in lung volumes? P.M. Donnelly, T-S. Yang, J.K. Peat, A.J. Woolcock.
ABSTRACT: In order to examine the physical characteristics that may determine racial differences in lung volumes, we studied healthy, nonsmoking Caucasian, Chinese and Indian males of similar ages (range 18–51 yrs). We measured spirometric function, flow volume curves, lung volumes, inspiratory and expiratory muscle pressures, alveolar distensibility and diffusing capacity, together with height, weight and fat free mass. Chest shape was measured using radiographs. The mean total lung capacity and vital capacity in the Caucasian group, expressed as percentage predicted, were 5 and 10% higher than in the Chinese group and 17 and 20% higher than in the Indian group. Chinese values for these measurements were 12 and 10% greater than Indian. We found that Caucasians had higher fat free masses, higher inspiratory and expiratory muscle pressures and wider chests than the other races. The Caucasians and Chinese had longer chests than the Indians. There was no difference in alveolar distensibility or in the diffusion coefficient between the groups. These findings suggest that Caucasians have larger lung volumes than Chinese and Indians because they have increased numbers of alveoli and physically larger chest cavities, and not because of greater alveolar distensibility. Chest dimensions, together with height and race explained 90% of the variation in forced vital capacity and 86% of the variation in total lung capacity. Height multiplied by fat free mass, a "physique factor", previously suggested as the best predictive factor for forced vital capacity in Caucasians, did not account for much of the variation in forced vital capacity between Caucasians and Indians, presumably because it takes no account of differences in chest dimensions.
Eur Respir J., 1991, 4, 829–838.

* Institute of Respiratory Medicine, Royal Prince Alfred Hospital and University of Sydney, NSW, Australia.

Correspondence: Prof. A.J. Woolcock, Institute of Respiratory Medicine, Royal Prince Alfred Hospital, Camperdown, NSW, 2050 Australia.

Keywords: Adults; alveolar distensibility; anthropometric; chest shape.

Received: March 1990; accepted after revision March 21, 1991.

Although differences in lung function are well-documented between races the factors responsible are not established. In Caucasians, total lung capacity (TLC) is approximately 15–22% larger than in Chinese and Indians [1]. As a result, forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) are also larger. However, functional residual capacity (FRC), residual volume (RV), peak expiratory flow rate (PEFR) and FEV_1, expressed as a percentage of FVC, are very similar for the three races [1].

To explain these differences, the characteristics of body size have been explored. Height and age are the most commonly used predictive factors for these lung volumes but it has been suggested that other factors, including fat free mass [2], thoracic diameter and trunk length, may predict lung volume [3–5]. Thus, it is likely that both anatomical and mechanical factors may account for differences in lung volume. In a national health survey of young nonsmoking Americans, Schwartz *et al.* [6] found that blacks had consistently lower lung volume and flow measurements than whites. Inclusion of sitting height in predictive equations only partly explained these differences. However, when FVC was used as a surrogate to control for lung size, the lung function of blacks was similar to that of whites.

We studied groups of Caucasian, Chinese and Indian males in order to examine the possible contributions of physical characteristics of the lungs and chest wall to racial differences in lung volumes. Alveolar distensibility, spirometric function, diffusing capacity, respiratory muscle pressures, fat-free mass (FFM) and chest shape (together with lung volumes and flow rates) of the three groups were compared to determine the extent to which these factors contributed to the variability in lung volumes. Our aim was not to study a large sample of men to make predictive equations for lung volumes of all Caucasians, Chinese and Indians, but rather to study healthy individuals from these three races to try to define the important factors which determine the observed differences in lung volumes.

Methods

Subjects

The subjects studied were 13 Caucasian, 14 Chinese and 11 Indian men aged 18–51 yrs. Two of the Caucasians were aged 18 and 19 yrs and the remainder were over 21 yrs of age. All of the Chinese subjects were over 22 yrs of age. Two of the Indian subjects were aged 20 yrs and the remainder were over 23 yrs. All subjects were nonsmokers and none had a history of recurrent respiratory illness, such as asthma or chronic cough. Some undertook only occasional exercise, such as jogging, playing tennis or golf, and none were trained athletes. Most Caucasian and Indian subjects were members of the medical or general staff of Royal Prince Alfred Hospital. The Indian subjects were either Australian or Fijian born - seven originated from northern India, three from southern Indian (Tamil) and one was of Singhalese origin. The Chinese subjects were from mainland China, Hong Kong or Singapore. Three were airline pilots based in China, and the remainder were visiting students.

Informed consent was obtained from each subject. Height and weight were measured prior to the tests, each of which was conducted by the same investigator, using the same equipment, throughout the study.

Spirometric function

Forced vital capacity and FEV_1 were measured using a Model S Vitalograph wedge bellows spirometer. Repeat manoeuvres were performed until two FVC recordings reproducible to 50 ml were obtained. The test with the highest value for FEV_1 and FVC was recorded and converted to body temperature and pressure, saturated (BTPS).

Flow volume curves

Peak expiratory flow rate was measured using a Medscience wedge spirometer with internal correction of volumes to BTPS. Signals of volume and flow rate were recorded on a memory oscilloscope and photographed for a permanent record. The test was repeated until two reproducible curves were obtained (shape and volume) from which the best PEFR was recorded.

Lung volumes

Functional residual capacity, inspiratory capacity (IC) and relaxed vital capacity (VC) were measured in a Gould 2800 pressure body plethysmograph after the internal temperature had stabilized. Immediately after measurement of thoracic gas volume, subjects inspired maximally in order that IC could be measured and added to FRC to obtain TLC. Measurements were computed from the mean FRC with the largest VC and mean IC taken from 3–4 measurements of each parameter. Residual volume was obtained by subtraction of VC from TLC.

Respiratory muscle pressure

Inspiratory muscle pressure at RV (PI/RV) and expiratory muscle pressure at TLC (PE/TLC) were recorded using a hand held pressure gauge calibrated to 0–350 cmH_2O. The gauge mouth piece had a 1 mm air leak to prevent glottic closure during testing. Subjects were instructed to inhale and exhale with the glottis open and not to use their buccal cavity. Measurements of muscle pressure were repeated until values reproducible to 5 cmH_2O, held for at least one second, were obtained.

Alveolar distensibility

Static pressure-volume (P-V) data were generated during 8–12 interrupted deflations from TLC to FRC with the subject seated in an Emerson volume plethysmograph. Transpulmonary pressure was measured with a one metre oesophageal balloon catheter (balloon length 10 cm, gas volume 0.5 ml) and a Hewlett Packard differential pressure transducer 267B. Several tidal volumes were recorded to establish baseline volume prior to asking subjects to inspire fully to TLC. Transpulmonary pressure was measured during a maximum inspiratory effort maintained for approximately one second at full inflation. The mean of the four highest values was recorded. After measurement of TLC and maximal elastic recoil, subjects were asked to relax against the occluded mouthpiece which allowed pressure and volume just below TLC to be recorded with sufficient data points to provide an entire fitted curve. Static deflation of the TLC to 50% below TLC was obtained over 1–2 s duration for each interruption with lung deflation occurring as a result of passive elastic recoil. Up to five P-V curves, each with 7–10 data points, were pooled to produce a final curve. Curves that deviated significantly from the mean because of oesophageal spasm were excluded.

An exponential function of the form $V = A\text{-}Be^{-KP}$, where V is lung volume, P is static elastic recoil pressure and A, B and K are constants, was fitted to the P-V data from TLC to a lower volume limit not less than 50% of TLC (*e.g.* 53±2.0% TLC) [7] and was analysed by computer. The exponential constant K describes the shape of the P-V curve independently of TLC. The constant A is the volume asymptote and B is the difference between A and the volume at a zero recoil pressure. The distribution of the original P-V data about the derived curve was quantified by the ratio of residual variance to the total variance for volume (mean residual variance = 1.8±0.8%). The ratio A/TLC% was 102.1±2.3% near TLC, indicating a good fit.

Single breath diffusing capacity

The diffusing capacity of the lungs (DLCO) at rest was measured by the single breath method of OGILVIE *et al.* [8], performed in duplicate after a five minute interval, using a Hewlett-Packard single breath diffusion system (HP4704A). The diffusion coefficient (KCO) was calculated as mean DLCO (standard temperature and pressure, dry (STPD)) divided by mean alveolar volume (BTPS) according to CRAPO and MORRIS [9]. Diffusion capacities were not corrected for haemoglobin levels.

Fat free mass

Total body fat was calculated from skinfold thickness measured using Harpenden skinfold calipers, as described by DURNIN and WOMERSLEY [10]. Skinfold thickness was measured on the left side of the body, over the biceps and triceps muscles, below the angle of the scapula and above the superior iliac spine. Three readings were taken at each site, two seconds after the calipers had been applied, and the mean value at each site was used. Body fat, expressed as a percentage of body weight, was calculated by the equation of BROZEK *et al.* [11] and FFM was then calculated as percentage lean mass:

$$FFM = \text{body weight (kg)} \times (100 - \text{\% body fat}) / 100$$

Chest dimensions

Chest dimensions were assessed from posterior-anterior and lateral chest radiographs taken at TLC in the standing position. To control for variation in subject distance from the X-ray plate, a 20 cent coin was taped to the left pectoral muscle but later analysis showed that no adjustment was necessary. Radiographs were measured by superimposing translucent graph paper onto the X-ray above a lighted viewing box and chest shape was traced using lung margins as the boundary. Parallel horizontal lines were drawn 2 cm apart from apices to lung base and measured in millimetres. Lateral radiographs were measured similarly except that lines were drawn parallel to a horizontal line drawn from the costophrenic angle to meet an extension of the anterior lung margin. Chest width was measured at the apex, centre and base of the lungs. Chest length was measured at the midline.

The mean value for each of these measurements in each group was used to draw the representative chest shapes. The surface area of the chest was estimated by tracing each mean shape on to high quality paper of even weight. Each shape was cut out and weighed to assess relative surface areas and the thoracic index was calculated.

Statistical methods

Ore-Nay analysis of variance was used to assess the significance of difference in lung function and body measurements between the racial groups. Stepwise multiple regression was used to determine the best model to account for variability in VC and TLC. In all models, interactions were tested and found to be nonsignificant.

Predicted values

The spirometric data of CRAPO *et al.* [12], the lung volume data of CRAPO *et al.* [13], the data of COTES [14] for PEFR and the data of CRAPO and MORRIS [9] for DLCO and KCO were used to calculate expected Caucasian values. The normal values for K reported by COLEBATCH *et al.* [15] were used. Results for all subjects were expressed in absolute units and as percentages of the Caucasian values predicted on the basis of age and height.

Results

Table 1 shows the age, physical characteristics, FFM and PE/TLC and PI/RV of the three groups. The mean age and height of each group was not statistically different but the Caucasian group was significantly heavier and had a significantly higher FFM than either of the other two groups. The Caucasians had a significantly greater PE/TLC than the Chinese group and a significantly greater PI/RV than either the Chinese or Indian group.

Table 1. – Physical characteristics of the three study groups

	Caucasian	Chinese	Indian
Total number	13	14	11
Age yrs	29.3	30.3	29.8
	(9.8)	(6.8)	(10.4)
Height cms	176.0	171.5	171.6
	(7.7)	6.5	(8.4)
Weight kg	78.8	62.1*	69.4*
	(10.2)	(8.5)	(8.9)
Fat %	20.9	15.4*	20.3
	(5.0)	5.9	(7.3)
FFM kg	63.3	52.4*	54.7*
	(6.0)	(6.9)	(7.0)
PE/TLC cmH_2O	158	124*	124
	(47)	(26)	(37)
PI/RV cmH_2O	132	95*	110*
	(28)	(25)	(13)

Data are mean and SD in parenthesis. *: $p<0.05$ for the difference from the Causcasian group. PE/TLC: expiratory muscle pressure at total lung capacity; PI/RV: inspiratory muscle pressure at residual volume; FFM: fat free mass.

The differences in mean lung volumes and flow rates between the three study groups are shown in table 2. Mean absolute values for TLC, FVC and PEFR were significantly higher in the Caucasians than in the Chinese or Indians and mean FEV_1 was significantly higher in the Caucasians than in the Indians, but there was no

Table 2. – Lung function of the three study groups

		Caucasian	Chinese	Indian
Total number		13	14	11
Mean height cms		176.0	171.5	171.6
TLC	*l*	7.09	6.42*	5.71*
		(0.89)	(0.83)	(0.66)
	% pred	105	100	88***#
		(13)	(13)	(10)
FVC	*l*	5.64	4.83*	4.41*
		(0.70)	(0.58)	(0.70)
	% pred	107	97*	87***
		(12)	(12)	(14)
RV	*l*	1.45	1.59	1.30
		(0.36)	(0.38)	(0.31)
	% pred	92	107	86#
		(23)	(26)	(19)
FRC	*l*	3.17	3.21	2.66
		(0.87)	(0.47)	(0.55)
	% pred	96	104	85#
		(26)	(15)	(18)
RV/TLC	%	20.5	24.8	22.9
		(3.5)	(3.9)	(6.4)
	% pred	87	108***	103
		(15)	(17)	(28)
FEV_1	*l*	4.45	4.25	3.67*
		(0.49)	(0.47)	(0.67)
	% pred	106	102	88***#
		(12)	(12)	(16)
FEV_1/FVC	%	78.9	88.1*	83.2*
		(4.2)	(6.2)	(5.0)
	% pred	97	107**	102#
		(5)	(7)	(6)
PEFR $l \cdot s^{-1}$		11.90	10.45*	9.91*
		(1.14)	(1.21)	(1.75)
	% pred	111	104*	99**
		(11)	(12)	(17)

Data are mean values and SD in parentheses. *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$ for the difference from the Caucasian group. #: $p<0.05$ for the difference between the Chinese and Indian groups. TLC: total lung capacity; FVC: forced vital capacity; RV: residual volume; FRC: functional residual capacity; RV/TLC: RV as a percentage of TLC; FEV_1: forced expiratory volume in one second; FEV_1/FVC: FEV_1 as a percentage of FVC; PEFR: peak expiratory flow rate.

significant differences for RV or FRC found between the Caucasians and the other two racial groups. The Chinese group had a significantly higher mean FEV_1 and FRC than the Indian group ($p<0.05$), and thus also had a higher FEV_1/FVC ratio ($p<0.05$), but other mean lung function measurements in the Chinese and Indian groups were similar. When the mean FVC% of Caucasians was used as a surrogate to control Chinese and Indian PEFR for lung volume (FVC%), there was no significant difference in PEFR between the three groups (fig. 1).

When mean TLC values, as a percentage of the predicted value for Caucasians were compared, the Chinese and Caucasian values were similar but the Indian values were significantly lower ($p<0.001$). The percentage of the predicted values for TLC, RV, FRC, FEV_1 and FEV_1/FVC ratio were significantly greater in the Chinese than in the Indian group ($p<0.05$).

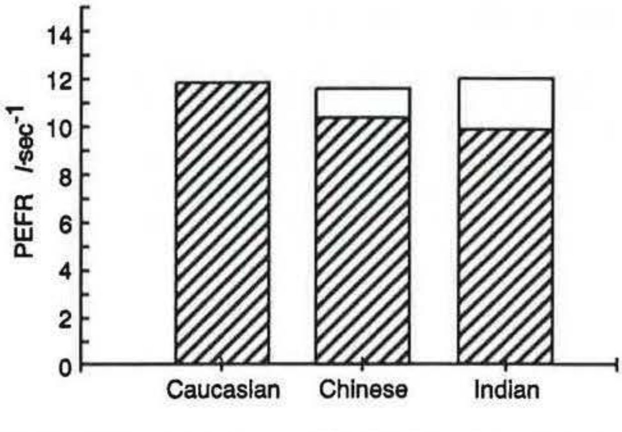


Fig. 1. – Peak expiratory flow rates (PEFR) in Caucasians, Chinese and Indian subjects presented as mean observed values and after standardizing to Caucasian forced vital capacity (FVC). ▨ : observed PEFR; ▭ : PEFR standardized to Caucasian FVC. p=NS.

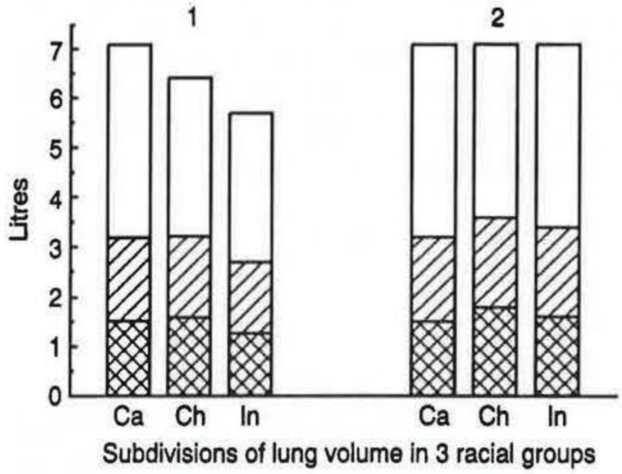


Fig. 2. – Total lung capacity (TLC), functional residual capacity (FRC), and residual volume (RV) in Caucasians (Ca), Chinese (Ch) and Indian (In) subjects presented as mean observed values (1) and after standardizing to Caucasian TLC (2). ▭ : TLC; ▨ : FRC; ▩ : RV.

Mean TLC, FRC and RV values in each racial group are shown in figure 2, both as observed values and standardized to Caucasian TLC. Because observed mean TLC was lower in the Chinese and Indians and the three groups had similar mean RV values, the proportion of RV to TLC was higher in the Chinese and Indian groups.

The DLCO, KCO and K expressed as mean and percentages of Caucasian predicted values, are shown in table 3. The observed significant differences in DLCO were reflected in the differences in the TLC within the groups (table 2). The mean values for KCO and K were very similar for the three groups.

Because X-rays were not always possible to arrange on the study day and because of the difficulty in getting subjects to return for further study, chest radiographs were measured in only 8 Caucasian, 11 Chinese and 8 Indian subjects. Representative chest shapes, using mean chest measurements (table 4), are shown in figure 3.

Table 3. – Diffusing capacity, diffusion coefficient and alveolar distensibility of the three study groups

	Caucasian	Chinese	Indian
Total number	13	14	11
Mean height cms	176.0	171.5	171.6
DLCO $ml\cdot min^{-1}\cdot mmHg^{-1}$	41.8	34.75*	30.77*
	(5.82)	(5.71)	(4.77)
% pred	103	90	80
KCO DLCO/VABTPS	5.70	5.66	5.73
	(0.93)	(0.71)	(0.84)
% pred	94	94	94
K kPa	1.187	1.238	1.167
	(0.281)	(0.322)	(0.221)
% pred	94	98	93
K cmH_2O^{-1}	0.118	0.123	0.116
	(0.028)	(0.032)	(0.022)

Data are mean and SD in parentheses. *: $p<0.05$ for the difference from the Caucasian group. DLCO: diffusing capacity of lung for carbon monoxide; KCO: carbon monoxide transfer coefficient calculated as mean DLCO (STPD) divided by mean alveolar volume (VA) (BTPS); K: alveolar distensibility.

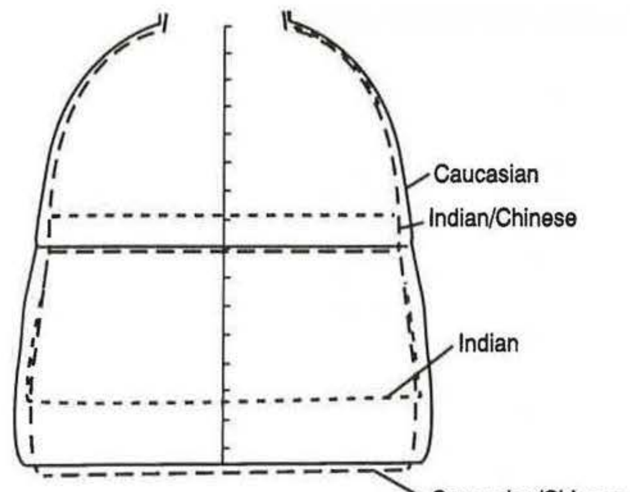
Table 4. – Anterior and lateral chest measurements (cms) and thoracic index of the three study groups

	Caucasian	Chinese	Indian	f value
Total number	8	11	8	
Anterior chest measurements				
Length	31.1	31.8	26.7	6.81**
	(2.2)	(1.2)	(3.3)	
Width Centre	29.2	27.4	26.9	5.12**
	(1.1)	(1.9)	(1.2)	
Apices	10.3	10.1	9.4	NS
	(0.9)	(2.1)	(0.5)	
Base	31.6	28.5	29.1	7.84**
	(1.3)	(2.1)	(2.0)	
Lateral chest measurements				
Length	31.9	32.1	29.7	NS
	(2.7)	(1.5)	(3.1)	
Width Centre	21.8	20.5	20.5	NS
	(2.4)	(1.1)	(1.8)	
Apices	7.1	6.7	7.3	NS
	(1.1)	(1.3)	(0.9)	
Base	20.6	18.6	19.6	NS
	(2.7)	(1.5)	(1.5)	
Thoracic index#				
	134.8	133.8	131.8	NS
	(12.2)	(11.5)	(13.0)	

Data are mean values and SD in parentheses. **: $p<0.01$ (significance levels between groups calculated by analysis of variance; #: Mean alveolar anterior width (centre)/mean lateral width (centre) × 100.

Analysis of variance showed a significant difference between racial groups in anterior chest length ($f=6.81$, $p<0.01$), anterior centre width ($f=5.12$, $p<0.01$) and anterior base width ($f=7.84$, $p<0.01$) but not in apex chest width or in lateral chest measurements. Thus, the Caucasians had wider chests than the other races and the Caucasians and Chinese had longer chests than the Indians.

Comparison of the estimated areas of chest shapes obtained by cutting out and weighing the representative shapes in figure 3, showed that the Chinese chest surface area was 93% and the Indian was 82% of the Caucasian. These percentages were almost identical with those for TLC expressed as a percentage of the Caucasian (91% for Chinese and 81% for the Indian mean value).



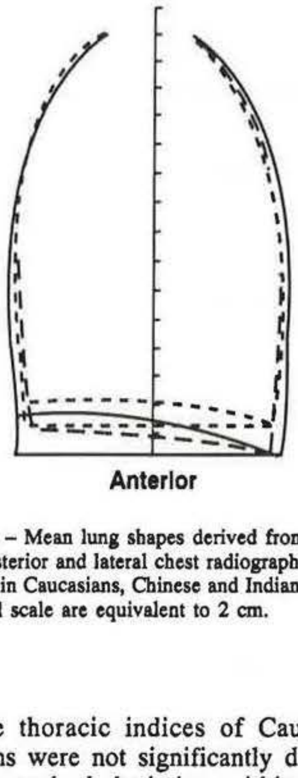


Fig. 3. – Mean lung shapes derived from measurements made of anteroposterior and lateral chest radiographs taken at total lung capacity (TLC) in Caucasians, Chinese and Indian subjects. Graduations on the vertical scale are equivalent to 2 cm.

The thoracic indices of Caucasians, Chinese and Indians were not significantly different because of the high standard deviation within the groups (table 4). Regression analyses showed that VC and TLC were more closely correlated with anterior chest width (r^2=0.77), anterior chest length (r^2=0.64), body height (r^2=0.67), FFM × height (r^2=0.72) and FFM (r^2=0.67) than with lateral chest length (r^2<0.47) or lateral chest width (r^2=0.34). A regression model, with racial group as a dummy variable and body height included, found that the anterior chest width (centre) explained more of the variation in both FVC (90%) and TLC (86%) than did anterior chest length, anterior chest width (base) or FFM. The effect of race was highly significant (F=18.34, df=2,21, p<0.001).

The predictive equations of best fit were as follows:

FVC = (0.157 × anterior chest width) + (0.040 × height) - (0.490 for Chinese) - (1.008) for Indians - 6.067

r^2 = 0.901, SE (chest width) = 0.042, SE (height) = 0.008

TLC = (0.243 × anterior chest width) + (0.047 × height) - (0.002 for Chinese) - (0.804 for Indian) - 8.350

r^2 = 0.843, SE (chest width)=0.058, SE (height) = 0.011

Discussion

The aim of this study was to examine some of the factors that account for the observed differences in lung volumes between Caucasians, Chinese and Indians. In the small group of men that we studied, differences were found between Caucasians and Chinese in TLC and FVC similar in magnitude to those found in another recent study [16] and, in addition, differences in TLC, RV and FRC were found between Chinese and Indians.

The shape of the chest appeared to be the most important determining factor, at least for measurements at TLC. At TLC the Caucasians had wider chests than the other two groups, while those of the Indians were shorter. These differences were in proportion to the differences in measured volumes. Anterior chest width (centre of chest) and body height taken together explained 86% and 90% of the variation in TLC and FVC, respectively, in each race. By comparison, weight, FFM and lateral chest measurements were less precise predictors of TLC and FVC.

It is possible, but unlikely, that our measurements of FFM were not precise enough to give values which correlated with TLC. Measurements of FFM, based on skinfold thickness, could be unreliable if different races have different skinfold thickness. However, it has been shown that adult Asians living in an American environment have body weight and fat measurements similar to white Americans [17]. We used four measurements of skinfold thickness in each subject, reducing the likelihood of large errors caused by occasional individuals with unusual fat distribution.

It is also possible that the lateral chest measurements were not different between the races because of the wide standard deviation of the lateral chest measurements. This was due to overlapping of the ribs in the lateral radiographs, making precise measurements difficult. However, over all, there seems to have been little systematic difference in these measurements between the racial groups.

If these data are shown to be reproducible, it seems likely that for the prediction of TLC, an index of chest shape may be needed. Chest radiographs are not always available but measurements of the external rib cage, such as those made by Tanner *et al.* [18] are easily made. The relationship of external rib cage measurements to chest radiograph measurements has still to be defined.

There is further evidence for the importance of chest shape as a determinant of lung volume. It has been shown that thoracic diameter is lower in blacks, who also have lower TLC and FVC values, than whites [3, 19]. Sitting height has been shown to be a better predictor of FRC than height in Caucasians and Afro-Caribbean children [20]. Trunk length, as a proportion of standing height (relative sitting height) is also closely associated with lung volume differences in different racial groups [5]. Of 13 racial groups whose lung function data were analysed, the highest VC and the highest value for relative sitting height were found in Eskimos followed by Scandinavians, Caucasians, Koreans and American Indians. Chinese were ahead of Asian Indians. GHIO *et al.* [5] postulated that racial variation in lung volumes and relative sitting height is the result of adaption of the human extremities in their function to exchange or conserve heat in response to environmental stress. It may be that the longer and wider chests of Caucasians evolved as a strategy for preserving core body temperature at a time when Europe had a colder climate than today [21].

In Caucasians the factors which best predict lung volume have been constantly under review [2, 3, 19, 20]. Height and age are the simplest and explain a large amount of the variation. A "physique factor" created by multiplying height by FFM has been reported to explain differences in VC between athletic and non-athletic Caucasians [2]. However, in this study, FFM multiplied by height did not explain the differences in FVC between races as well as anterior chest width, presumably because these measurements take no account of chest size differences. We found [unpublished observations] that FFM × height was a good predictor of FVC in healthy Caucasian males and elite Caucasian runners, who had normal lung volumes and similar, chest surface areas. However, this measurement did not predict FVC well in elite Caucasian swimmers who had significantly larger chest surface areas. In the current study FFM and height were closely correlated (r^2=0.62) so that body height explains much of the variation that might be attributed to FFM.

The larger lungs and larger chests of Caucasians at TLC could be due to an increased number of alveoli or more distended alveoli. Our data suggest that the differences in TLC are not due to greater distension of the alveoli but rather to increased number. In support of more distended alveoli it could be argued that the greater inspiratory muscle strength in the Caucasians allowed more distension of the alveoli resulting in the larger TLC. This seems unlikely because increased inspiratory muscle strength with training achieves only slight increases in FVC and TLC [22]. Also ZINMAN and GAULTIER [23] failed to show a relationship between the large lung volumes in swimmers and their inspiratory pressures measured at the mouth.

Evidence for an increased number of alveoli comes from finding similar values for the diffusion coefficient (Kco) and the distensibility (K). These similar values indicate that the alveoli have equal surface area to volume ratios and were, therefore, of similar size.

Total lung capacity is determined by the number and size of airspaces in the lungs. Alveolar distensibility (K) is not related to alveolar number [24] or to height [15, 25] and is independent of lung size and sex [15]. In intact human subjects K is an independent determinant of TLC [25], a finding that is difficult to explain unless K reflects airspace size. Because we found similar K and Kco values in all races, the larger TLC in Caucasians is probably a result of increased numbers of alveoli in the lungs.

To test this conclusion further, we calculated the surface area to volume ratios of two hypothetical alveolar units, one with a radius of 1.0 cm and a normal distensibility coefficient (K) of 0.125 cmH_2O^{-1} and the other with a 30% increase in distensibility, proportional to the average difference in PI/RV between Caucasians and the other two groups (table 1). Since K has been shown to relate directly to a morphometric estimate (mean linear intercept) of the average size of airspaces in excised human lungs and in the lungs of other mammals [24, 26], for the enlarged alveolus the resultant radius would be 1.3 cm and the K value would be 0.162 cmH_2O^{-1}. Calculation revealed that increasing the alveolar size reduced the surface area to volume ratio by 23%. If this was the case in the men studied, the Kco values would not have been proportional to the TLC in each racial group. This strongly suggests that the differences in ethnic lung volumes can be explained by a difference in alveolar number, rather than in alveolar size.

The dimensions of the chest, and thus chest volume, in Chinese and Indian subjects may affect the development of alveoli. The shape of the thoracic cage changes considerably during normal development from infancy. The chest undergoes anterior-posterior compression, which tends to be less in females than males and results in wider chests in males [27]. The thoracic index in adults ranges from 130% in women to 135% in men and parallels the observed differences in lung volumes between men and women.

The factors responsible for the number of alveoli have yet to be determined but growth hormone may play a large part. Reduced lung volumes associated with low growth hormone levels, and increased lung volumes associated with elevated growth hormone levels, have been found in adults with acromegaly and hypopituitarism [28, 29]. In both conditions, the ventilated airspaces retain normal elastic properties. A study by BRODY *et al.* [29] found larger chest dimensions and TLC values (139%) in acromegalic males with elevated levels of circulating growth hormone. Despite their large lung size the finding of a normal specific lung compliance and normal DLCO in these subjects suggested to BRODY *et al.* [29] that the increased TLC was a result of an increase in alveolar size rather than an increase in alveolar number. However, the smokers were not identified in their study. Because smoking can reduce DLCO without altering other lung function measurements [30], this may have influenced their findings.

The level and type of physical activity, the dwelling altitude and the amount of FFM, may all provide feedback to control growth hormone release which may in turn affect chest shape, thereby regulating alveolar development and influencing lung size. COTES and DAVIES [31] found a relationship between thigh muscle width and VC in British male and female factory workers and

Table 5. – A comparison of FVC and TLC in Chinese and Indian subjects reported in other papers with the present data (Reported volumes are mean±1SD for a male 172 cm and 30 yrs)

Chinese

Year	1969	1971	1977	1982	1984	1986	1990
Authors	Chuan/Chia	Da Costa *et al.*	Ching/ Horsfall	Lam *et al.*	Huang *et al.*	Hou *et al.*	Donnelly *et al.*
Country	Singapore	Singapore	Hong Kong	Hong Kong	Chinese students in USA	Guangzho China	Chinese students in Australia
Group	H	H	H/L	H	H	H	H
Reference	[35]	[36]	[37]	[38]	[16]	[39]	[present data]
FVC *l*	3.95±0.38	4.02±0.38	3.96±0.44	4.36±0.72	*4.83±0.16	4.27±0.44	4.83±0.58
TLC *l*	5.62±0.59	5.56±0.54	5.44±0.56	N.E.	*6.40±0.26	N.E.	6.42±0.83

Indians

Year	1964	1969	1970	1977	1984	1986	1988	1988	1988	1990
Authors	Cotes/Malhotra army officers	Jain/Ramiah	Miller *et al.*	Kamat *et al.*	Singh	Udwadia *et al.*	Vijayan	Purohit *et al.*	Chatterjee *et al.*	Donnelly *et al.*
Country	Wales	Delhi	Guyana#	Madras	Madras	Bombay	Madras	Rajasthan	Calcutta	Australian/Fijian
Group	H	H, N	H/L	H/L, S	H, S	H, S	S	H, N-W	H, N-E	H
Reference	[40]	[41]	[42]	[43]	[44]	[45]	[46]	[47]	[48]	[present data]
FVC *l*	4.18‡	4.19±0.10	4.40±0.46	3.78±0.55	3.96±0.51	3.95±0.51	3.92‡	4.01±0.62	4.15±0.45	4.41±0.70
TLC *l*	5.49‡	5.51±0.18	N.E.	N.E.	N.E.	5.20±0.78	5.39‡	N.E.	N.E.	5.71±0.66

*: volume adjusted for age difference; ‡: SD not given; #: originally from Utar Paradash, N. India; H/L: subjects of mixed socioeconomic background; H: high socioeconomic group; L: "low" socioeconomic group; N.E.: not estimated; N: North; S: South; N-W: North-West; N-E: North-West; FVC: forced vital capacity; TLC: total lung capacity.

athletes. In male subjects Sutton [32] has shown an eightfold increase in serum growth hormone levels following hypoxic exercise compared to normoxic conditions. Malik and Singh [33] showed the VC to be 15–18% higher in adolescent males residing at 3,500 m compared with an ethnically similar population residing at a lower altitude (1,500–2,200 m). Thus, there is increasing evidence that factors that affect growth hormone influence the size of the VC. The precise way in which growth hormone controls alveolar number is unknown.

Studies of FEV_1/FVC and PEFR in Caucasian, Indian and Chinese populations have usually found similar values [1]. In this study we found higher PEFR values in Caucasians. These men had higher values for TLC and increased expiratory muscle pressures and both of these factors are known to influence PEFR [1, 34]. When our Chinese and Indian PEFR data were corrected for differences in FVC, using the mean Caucasian value, the resultant PEFR values were not different (fig. 3), indicating similar airway calibres in the three racial groups.

We found higher FEV_1/FEV_1 ratios in Chinese and Indians compared with Caucasians. This may be caused by the proportionately lower FVC values in these races, so that during expiration a smaller volume empties into airways of similar calibre. Schwartz *et al.* [6] observed that the FEV_1 /FVC ratio increased with decreasing FVC in both black and white young adults. It seems likely that the airway calibre is similar in all racial groups while the differences observed in TLC and FVC indicate differences in the number of alveoli.

Having demonstrated that there are differences between the races in lung volumes and in chest shape, the question arises, were the men we studied typical of the three racial groups? To try to answer this question, we compared the data from previous studies carried out within and outside China and India to the present data [16, 35–48] in table 5. The data are arranged in chronological order and include information on geographical and socioeconomic factors. We calculated the FVC and TLC from regression equations in the literature for a Chinese and an Indian male 172 cm in height and 30 yrs old.

In the present study values for FVC and TLC were 15% and 14% greater than the mean values obtained for Chinese subjects in Singapore, Hong Kong and Guangzhou [35–39] but similar to those of Huang *et al.* [16] measured in the USA. There is anecdotal suggestion that as nutrition improves, so do body height and lung volumes. Since we found Chinese and Caucasians to have similar chest shapes we predict that the next generation of Caucasians and Chinese will have similar lung volumes.

Indian subjects, born outside of India [42], had 11% and 6% greater values for FVC and TLC, respectively, than the mean value for those born on the subcontinent [41, 43–48]. Our group of mixed Indian origin (seven out of eleven originated from Northern India) had both FVC and TLC values that were 6% higher than the mean FVC and TLC of all the other Indians studied. Since our Caucasians also had FVC and TLC values that were 7% and 5% greater than predicted, the relative differences between our Indian and Caucasian groups was maintained. Therefore, our Caucasian and Indian values are probably representative of these races. The differences in TLC and FVC are probably due to the shorter chest length in the Indians, a racial characteristic which is independent of nutritional status.

This difference may also explain the difference in FRC and RV between Indians and the other two races but we did not make measurements of chest dimensions at FRC and RV.

This study shows that differences in lung volume appear to be caused by differences in alveolar number rather than in alveolar distension, or inspiratory muscle pressure. In turn, the number of alveoli appears to be related to chest shape. Chest width appears to be a good predictor of TLC and FVC in these three races. However, it remains to be determined whether external rib cage measurements are as precise as chest radiographs appear to be and if the findings can be applied to other racial groups.

Acknowledgements: The authors would like to thank V. Keena for preparing the manuscript, P. Caldon for typing the manuscript, and J. Reynolds for preparing the figures.

References

1. Yang TS, Peat JK, Keena VK, Donnelly PM, Unger W, Woolcock AJ. – A review of the racial differences in the lung function of normal Caucasian, Chinese and Indian subjects. (In preparation, to be re-submitted to *Eur Respir J*, 1991).
2. Biersteker MWA, Biersteker PA. – Vital capacity in trained and untrained healthy young adults in the Netherlands. *Eur J Appl Physiol*, 1985, 54, 46–53.
3. Rossiter CE, Weill H. – Ethnic differences in lung function: evidence for proportional differences. *Int J Epidemiol*, 1974, 3, 55–61.
4. Damon A. – Negro-white differences in pulmonary functional vital capacity, timed vital capacity and expiratory flow rate. *Hum Biol*, 1966, 38, 381–393.
5. Ghio AJ, Crapo RO, Elliott CG, Jensen RL, Berlin SL. – Ethnic differences in lung volume are associated with variation in trunk size. *Am Rev Respir Dis*, 1989, 139(Abstract), A30.
6. Schwartz J, Katz SA, Fegley RW, Tockman MS. – Sex and race differences in the development of lung function. *Am Rev Respir Dis*, 1988, 138, 1415–1421.
7. Colebatch HJH, Ng CKY, Nikov N. – Use of an exponential function for elastic recoil. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1979, 46, 387–393.
8. Ogilvie CM, Forster RE, Blakemore WS, Morton JW. – A standardised breath holding technique for the clinical measurement of the diffusing capacity of the lungs for carbon monoxide. *J Clin Invest*, 1957, 36, 1–17.
9. Crapo RO, Morris AH. – Standardized single breath normal values for carbon monoxide diffusing capacity. *Am Rev Respir Dis*, 1981, 123, 185–189.
10. Durnin JVGA, Womersley J. – Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr*, 1974, 32, 77–97.
11. Brozek J, Grande F, Anderson JT, Keys A. – Densitometric analysis of body composition: revision of some quantitative assumptions. *Ann NY Acad Sci*, 1963, 110, 113–140.
12. Crapo RO, Morris AH, Gardner RM. – Reference spirometric values using techniques and equipment that meet ATS recommendations. *Am Rev Respir Dis*, 1981, 123, 659–664.
13. Crapo RO, Morris AH, Clayton PD, Nixon CR. – Lung volumes in healthy nonsmoking adults. *Bull Eur Physiopathol Respir*, 1982, 18, 419–425.
14. Cotes JE. – *In*: Lung function: assessment and application in medicine. 3rd Ed. Blackwell Scientific Publications Oxford, 1975, p.386.
15. Colebatch HJH, Greaves IA, Ng CYK. – Exponential analysis of elastic recoil and aging in healthy males and females. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1979, 47, 683–691.
16. Huang SY, White DP, Douglas NJ, Moore LG, McCullough RE, Weil JV, Reeves JT. – Respiratory function in normal Chinese: comparison with Caucasians. *Respiration*, 1984, 46, 265–271.
17. Netland PA, Brownstein H. – Anthropometric measurements for Asian and Caucasian elderly. *J Am Diet Assoc*, 1985, 85, 221–223.
18. Tanner JM, Hiernaux J, Jarman S. – Growth and physique studies. *In:* Human Biology: A Guide to Field Methods. J.S. Weiner, J.A. Lourie eds, Blackwell, Oxford, 1969.
19. Boutros-Toni F. – Comparison anthrometrique du tronc et des membres chez les leucodermes et les melanodermes. *Biometrie Humaine*, 1980, 15, 57–71.
20. Pool JB, Greenough A. – Ethnic variation in respiratory function in young children. *Respir Med*, 1989, 83, 123–125.
21. Scheinfeld A. – *In*: Your Heredity and Environment. Chatto and Windus, London, 1965, p. 583.
22. Leith DE, Bradley M. – Ventilatory muscle strength and endurance training. *J Appl Physiol*, 1976, 41, 508–516.
23. Zinman R, Gaultier C. – Maximal static pressures and lung volumes in young female swimmers: one year follow-up. *Pediatr Pulmonol*, 1987, 3, 145–148.
24. Haber PS, Colebatch HJH, Ng CKY, Greaves IA. – Alveolar size as a determinant of pulmonary distensibility in mammalian lungs. *J Appl Physiol*, 1983, 54, 837–845.
25. Colebatch HJH, Greaves IA, Ng CKY. – Pulmonary distensibility and ventilatory function in smokers. *Bull Eur Physiopathol Respir*, 1985, 21, 439–447.
26. Greaves IA, Colebatch HJH. – Elastic behaviour and structure of normal and emphysematous lungs post mortem. *Am Rev Respir Dis*, 1980, 121, 127–136.
27. Osmond DG. – Functional anatomy of the chest wall. *In:* The Thorax. Part A. C. Roussos, P.T. Macklem eds, Marcel Dekker, New York, 1985, pp. 199–233.
28. De Troyer A, Desir D, Copinschi G. – Regression of lung size in adults with growth hormone deficiency. *Q J Med*, 1980, 195, 329–340.
29. Brody JS, Fisher AB, Gocmen A, DuBois AB. – Acromegalic pneumonomegaly: Lung growth in the adult. *J Clin Invest*, 1970, 49, 1051–1060.
30. Frans A, Stanescu DC, Veriter C, Clerbaux T, Brasseur L. – Smoking and pulmonary diffusing capacity. *Scand J Respir Dis*, 1975, 56, 165–183.
31. Cotes JE, Davies CTM. – Factors underlying the capacity for exercise: a study of physiological anthropometry. *Proc Roy Soc Med*, 1969, 62, 620–624.
32. Sutton JR. – Effect of acute hypoxia on the hormonal response to exercise. *J Appl Physiol*, 1977, 42, 587–592.
33. Malik SL, Singh IP. – Ventilatory capacity among

highland Bods: a possible adaptive mechanism at high altitude. *Ann Hum Biol*, 1979, 6, 471–476.
34. Schrader PC, Quanjer PhH, Olievier ICW. – Respiratory muscle force and ventilatory function in adolescents. *Eur Respir J*, 1988, 1, 368–375.
35. Chuan PS, Chia M. – Respiratory function tests in normal adult Chinese in Singapore. *Singapore Med J*, 1969, 10, 265–271.
36. Da Costa JL. – Pulmonary function studies in healthy Chinese adults in Singapore. *Am Rev Respir Dis*, 1971, 104, 128–131
37. Ching B, Horsfall PAL. – Lung volumes in normal Cantonese subjects: preliminary studies. *Thorax*, 1977, 32, 352–355.
38. Lam K-K, Pang S-C, Allan WGL, Hill LE, Snell NJC, Nunn AJ, Prime FJ. – A survey of ventilatory capacity in Chinese subjects in Hong Kong. *Ann Hum Biol*, 1982, 9, 459–472.
39. Hou S, Zhang YG, Guo XC, He J. – The reference values of lung function of Cantonese. Second Guangdong Guangzhou Hong Kong Macau Congress on Diseases of the Chest: Abstract. 1986.
40. Cotes JE, Malhotra MS. – Differences in lung function between Indians and Europeans: Abstract. Proceedings of the Physiological Society, 1964, 6–7 Nov, 17–18.
41. Jain SK, Ramiah JJ. – Normal standards of pulmonary function tests for healthy Indian men 15–40 years old: comparison of different digression equations (prediction formulae). *Indian J Med Res*, 1968, 57, 1, 1453–1466.
42. Miller GJ, Ashcroft MT, Swan AV, Beadnell HMSG. – Ethnic variation in forced expiration volume and forced vital capacity of African and Indian adults in Guyana. *Am Rev Respir Dis*, 1970, 102, 979–981.
43. Kamat SR, Tyagi NK, Rashid SSA. – Lung function in Indian adult subjects. *Lung India*, 1982, 11–21.
44. Singh HD. – Mean expiratory flow volume curves in South Indian men. *Lung India*, 1984, II, 293–296.
45. Udwadia FE, Sunavala JD, Sheyte VM, Jain PK. – The maximal expiratory flow-volume curve in normal subjects in India. *Chest*, 1986, 89, 852–856.
46. Vijayan VK. – Tropical eosinophilia: bronchoalveolar lavage and pulmonary pathophysiology in relation to treatment. PhD Thesis 1988, University of Madras.
47. Purohit SD, Srivastava AB, Gupta PR, Gupta SD, Mathur BB, Gupta ML. – Spirometric norms in heathy adults of Rajasthan. *Lung India*, 1989, VII, 9–14.
48. Chatterjee S, Saha D, Chatterjee BP. – Pulmonary function studies in healthy nonsmoking men of Calcutta. *Ann Hum Biol*, 1988, 15, 365–374.

Quels sont les facteurs expliquant les différences raciales de volumes pulmonaires? P.M. Donnelly, T-S. Yang, J.K. Peat, A.J. Woolcock.

RÉSUMÉ: Pour examiner les caractéristiques physiques qui peuvent être responsables des différences raciales de volumes pulmonaires, nous avons étudié des hommes bien portants, non fumeurs, caucasiens, chinois et indiens, d'âges similaires (extrêmes: 18 et 51 ans). Nous avons mesuré les valeurs spirométriques, les courbes débit-volume, les volumes pulmonaires, les pressions musculaires inspiratoire et expiratoire, la distensibilité alvéolaire et la capacité de diffusion, de même que la taille, le poids et la masse non graisseuse. La forme du thorax a été mesurée sur des clichés thoraciques. La capacité pulmonaire totale moyenne et la capacité vitale du groupe caucasien, exprimées en pouvcentes des valeurs prédites, s'avèrent de 5 et de 10% supérieures à celles du groupe chinois, et de 17 et 20% supérieures à celles du groupe indien. Les valeurs des chinois pour ces diverses mesures étaient de 12 et 20% supérieures à celles des indiens. Nous avons observé que les caucasiens avaient des masses non graisseuses plus élevées, des pressions des muscles inspiratoires et expiratoires plus élevées, et des thorax plus larges que les autres races. Les caucasiens et les chinois ont des thorax plus longs que les indiens. Il n'y a pas de différence dans la distensibilité alvéolaire ou dans les coefficients de diffusion entre les groupes. Ces observations suggèrent que les caucasiens ont des volumes pulmonaires plus grands que les chinois et les indiens, en raison d'un nombre plus grand d'alvéoles et de cages thoraciques physiquement plus grandes, et non en raison d'une distensibilité alvéolaire plus importante. Les dimensions du thorax, associées à la taille et à la face, expliquent 90% des variations de la capacité vitale forcée et 86% des variations de la capacité pulmonaire totale. La taille, multipliée par la masse non graisseuse, un "facteur physique", suggérée antérieurement comme le meilleur facteur prédictif de la capacité vitale forcée chez les caucasiens, n'intervient pas beaucoup dans les variations de capacité vitale forcée entre caucasiens et indiens, probablement parce qu'elle ne prend pas en compte les différences de dimensions du thorax.
Eur Respir J., 1991, 4, 829–838.