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REVIEW

A review of the racial differences in the lung function of normal Caucasian, Chinese and Indian subjects

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It is almost 150 years since HUTCHINSON [1] measured the vital capacity (VC) of more than 2,000 men and described it in relation to body height, weight and age. Since then, the increase of VC with age in children and the decrease of VC with age in adults has been well described. There have been many reports of normal values of lung function for different races and for people living in different geographical conditions. Comparisons of reported normal values show that Caucasians living in Europe and America [2–10] have similar values but that Chinese [11–19], Indian [20–27] and African Negro [28–35] populations all have lower values.

Spirometric and lung volume measurements are widely used for routine clinical assessment of patients with lung disease and in epidemiological studies. However, their interpretation requires appropriate values for predicting normality. This review summarizes lung function values presented in the literature for Caucasians, Chinese and Indians from studies that have employed methods that are commonly used in lung function laboratories. From the data, we have constructed nomograms for easy reference and have compared differences between the three racial groups.

Comparison of normal values

Reports of regression equations for lung function in normal nonsmoking population samples were selected [2–31]. Results are included in this review only if the study sample size exceeded 180 subjects and excluded smokers, if volumes were expressed at body temperature, standard pressure, saturated (BTPS), and if the population lived no more than 1,500 m above sea level.

For each of the three racial groups of Caucasians, Chinese and Indians, we have summarized the data for forced vital capacity (FVC), or vital capacity (VC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC), total lung capacity (TLC), residual volume (RV) and peak expiratory flow rate (PEFR).

The regression coefficients for FVC (or VC) and for FEV_1, expressed as a function of height, age and weight, from three studies for each race, are shown for adults in table 1 and for children in table 2. The regression coefficient for age was negative in adults of both sexes in all three racial groups indicating a decrease in these ventilatory function measurements with age.

Predicted values for FVC (or VC) at ages 10, 30 and 60 yrs were calculated from each of the regression equations given in table 1 and 2 and used to calculate mean values for each race. The mean regression lines for FVC on height for males and females are shown in figure 1. At all ages and heights, the values for Caucasians are higher than those for Chinese and Indian populations, which appear similar to one another.

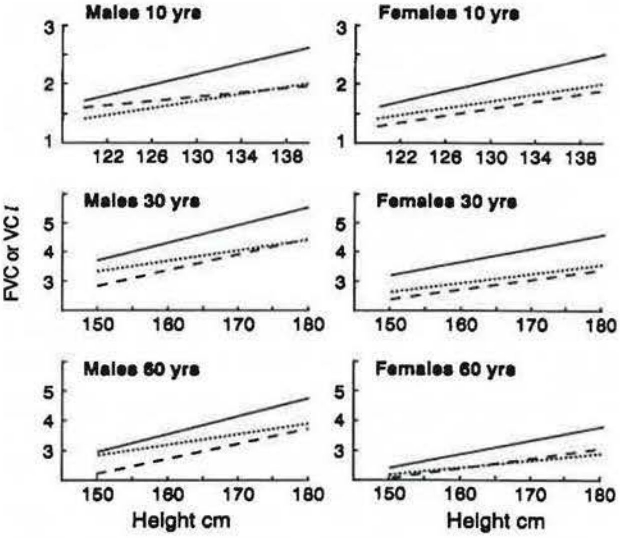

Fig. 1. – Regression lines for forced vital capacity (FVC) or vital capacity (VC) on height calculated from equations given in tables 1 and 2 for males and females aged 10, 30 and 60 yrs. —— :Caucasian; - - - : Indian; ·······: Chinese.

The regression lines for FEV_1 on height, calculated using the same method, are shown in figure 2. Again, in both adults and children, the values for Caucasians are higher. The values for FEV_1 in Indian populations appear consistently lower at all ages than those for the other two racial groups.

Tables 3 and 4 shows the regression coefficients for TLC, FRC and RV in male and female adults. The values for RV from all studies showed an increase with age, and the values from most studies showed a decrease of TLC with age.

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Table 1. – Regression coefficients for forced vital capacity (or vital capacity), and forced expiratory volume in one second as a function of height (cm), age (yrs) and weight (kg) in adults

Race	Author(s)	Ref.	FVC Height	FVC Age	FVC Weight	FVC Constant	FVC SEE or SD*	FEV_1 Height	FEV_1 Age	FEV_1 Constant	FEV_1 SEE or SD*
MALES											
Caucasian	CRAPO *et al.*	[6]	0.060	-0.021		-4.65	0.644	0.041	-0.024	-2.19	0.486
	QUANJER	[8]	0.061	-0.032		-4.74	0.560*	0.041	-0.031	-2.10	0.430*
	SALORINE	[9]	0.068	-0.026		-5.64	0.690	0.054	-0.027	-3.98	0.520*
Chinese	DACOSTA	[11]	0.041	-0.011		-2.76	0.449	0.027	-0.019	-0.77	0.329
	HOU *et al.*	[12]	0.032	-0.024	0.010	-1.19	0.444	0.033	-0.029	-1.09	0.391
Indian	UDWADIA *et al.*	[20]	0.054	-0.018		-4.83	0.601*	0.037	-0.022	-2.65	0.452*
	POROHIT *et al.*	[26]	0.049	-0.027		-3.60	0.622*	0.046	-0.024	-3.64	0.591*
FEMALES											
Caucasian	CRAPO *et al.*	[6]	0.049	-0.022		-3.59	0.393	0.034	-0.026	-1.58	0.326
	QUANJER	[8]	0.046	-0.027		-3.05	0.420*	0.032	-0.031	-1.13	0.350*
	SALORINE	[9]	0.050	-0.024		-3.47	0.400	0.035	-0.026	-1.39	0.340
Chinese	DACOSTA	[11]	0.018	-0.015	0.013	-0.29	0.368	0.017	-0.018	0.23	0.278
	HOU *et al.*	[12]	0.029	-0.017	0.006	-1.34	0.332	0.026	-0.022	-0.75	0.228
Indian	UDWADIA *et al.*	[20]	0.043	-0.010		-3.76	0.444*	0.032	-0.012	-2.58	0.389*
	POROHIT *et al.*	[26]	0.031	-0.019		-1.59	0.362*	0.044	-0.015	-3.95	0.437*

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; SD: standard deviation; SEE: standard error of the estimate.

Table 2. – Regression co-ordinates for forced vital capacity (or vital capacity) and forced expiratory volume in one second as a function of height (cm) and age (yrs) in children

Race	Author(s)	Ref.	Sex	FVC Regression	FVC SEE or SD*	FEV_1 Regression	FEV_1 SEE or SD*
Caucasian	MORTON *et al.*	[36]	M	0.041 Ht - 3.299		0.034 Ht - 2.647	
		[36]	F	0.042 Ht - 3.643		0.038 Ht - 3.261	
	BJURE	[37]	M	$1.04\ Ht^3 \times 10^{-6}$ - 0.136	0.40*	$0.85\ Ht^3 \times 10^{-6}$ - 0.012	0.32*
			F	$0.80\ Ht^3 \times 10^{-6}$ + 0.416	0.38*	$0.74\ Ht^3 \times 10^{-6}$ + 0.241	0.33*
	MORSE *et al.*	[38]	M	$0.83\ Ht^3 \times 10^{-6}$ + 0.266	0.30*		
	STRANG	[41]	F	Predictive nomogram		$0.71\ Ht^3 \times 10^{-6}$ + 0.11	0.32*
Chinese	LAM *et al.*	[19]	M	Predictive nomogram		Predictive nomogram	
	WU and YANG	[14]	F	$0.8\ Ht^3 \times 10^{-6}$			
Indian	MALIK and JINDAL	[39]	M	0.012 Ht + 0.020 Age - 0.4	0.80*	0.012 Ht + 0.017 Age - 0.3	0.70*
			F	0.011 Ht + 0.005 Age - 2.5		0.011 Ht + 0.004 Age - 2.3	0.60*
	PADMANABHA *et al.*	[40]	M	0.033 Ht - 2.849	0.21	0.025 Ht - 2.228	0.18

For abbreviations see legend to table 1.

Table 3. – Regression coefficients for total lung capacity and functional residual capacity in adults as a function of height (cm), age (yrs) and weight (kg) or body surface area (BSA) (m²)

			TLC				FRC				
Race	Author(s)	Ref.	Height	Age	Constant	SEE/SD*	Height	Age	Weight /BSA	Constant	SEE/SD*
MALES											
Caucasian	Crapo *et al.*	[7]	0.080	0.003	-7.333	0.792*	0.047	0.009		-5.290	0.719
	Quanjer	[8]	0.080		-7.081	0.700*	0.023	0.009		-1.090	0.600*
Chinese	DaCosta	[11]	0.079		-7.934	0.544	0.061		-0.026	-5.586	0.370
	Chuan and Chia	[15]	0.073		-6.984	0.589*	0.069		-0.032	-6.644	0.401
Indian	Udwadia *et al.*	[20]	0.074	-0.001	-7.495	0.780*	0.042	0.005		-4.648	0.639*
	Vijayan	[27]	0.064	0.021	-6.241		0.042			-4.139	
FEMALES											
Caucasian	Crapo *et al.*	[7]	0.059		-4.537	0.536	0.036	0.003		-3.182	0.523
	Quanjer	[8]	0.066		-5.791	0.600*	0.022	0.001		-1.000	0.500*
Chinese	DaCosta	[11]	0.037	-0.016	-1.203	0.533	0.017	-0.017		0.326	0.392
	Chuan and Chia	[15]	0.038		-2.008	0.469*	0.040		-0.026	-2.722	0.359*
Indian	Udwadia *et al.*	[20]	0.056	0.003	-5.251	0.630*	0.034	0.007		-3.600	0.571*
	Vijayan	[27]	0.037		-2.235		0.048		-0.018	-4.418	

TLC: total lung capacity; FRC: functional residual capacity. For other abbreviations see legend to table 1.

Table 4. – Regression coefficients for residual volume in adults as a function of height (cm), age (yrs) and weight (kg)

			RV				
Race	Author	Ref.	Height	Age	Weight	Constant	SEE/SD*
MALES							
Caucasian	Crapo *et al.*	[7]	0.022	0.021		-2.840	0.374
	Quanjer	[8]	0.013	0.022		-1.232	0.410*
Chinese	DaCosta	[11]	0.045	0.012	-0.017	-5.392	0.306
	Chuan and Chia	[15]	0.035	0.020	-0.019	-3.910	0.305*
Indian	Udwadia *et al.*	[20]	0.019	0.007		-1.945	0.497*
	Vijayan	[27]		0.021		0.840	
FEMALES							
Caucasian	Crapo *et al.*	[7]	0.020	0.020		-2.421	0.381
	Quanjer	[8]	0.018	0.016		-2.003	0.350*
Chinese	DaCosta	[11]	0.012			-0.740	0.306
	Chuan and Chia	[15]	0.020	0.009	-0.016	-1.336	0.259*
Indian	Udwadia *et al.*	[20]	0.014	0.007		-1.167	0.478*
	Vijayan	[27]	0.013	0.006	-0.009	-0.617	

RV: residual volume. For other abbreviations see legend to table 1.

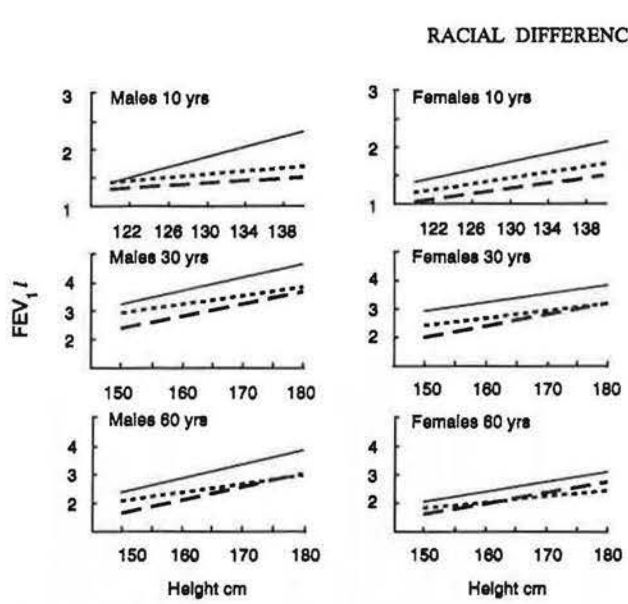

Fig. 2. – Regression lines for forced expiratory volume in one second (FEV_1) on height calculated from equations given in tables 1 and 2 for males and females aged 10, 30 and 60 yrs. —— :Caucasian; - - -: Indian; ······: Chinese.

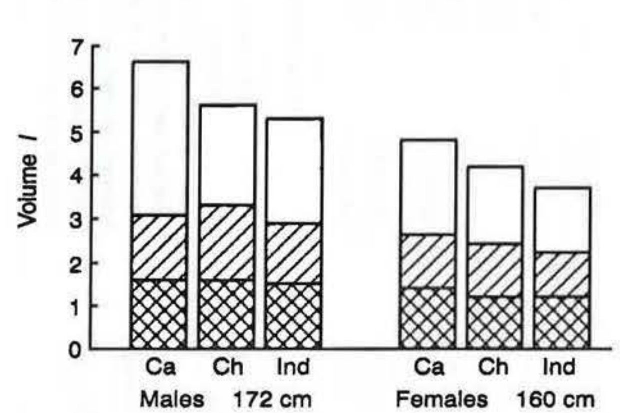

Fig 3. – Total lung capacity (▭), functional residual capacity (▨) and residual volume (▩) calculated from males of 172 cm and females of 160 cm, both of age 30 yrs, as a mean of values presented as regressions in tables 3 and 4. Ca: Caucasian; Ch: Chinese; Ind: Indian.

The mean volume from each study, calculated for males of 172 cm height and 30 yrs and females of 160 cm height and 30 yrs, are shown in figure 3. In Caucasian males, the TLC is larger than for the other two racial groups which have similar values. In Chinese and Indians, the TLC was 15–20% lower than in Caucasians. The FRC was 6% higher in Chinese and 6% lower in Indians than in Caucasians. There was comparatively little difference in RV between racial groups. In males, the RV was 6% lower in Indians and in Chinese than in Caucasians. In females, the RV was 14% lower in Indians and in Chinese than in Caucasians.

Table 5 shows the regression equations for PEFR, which are plotted in figure 4. There were no consistent differences in PEFR between the racial groups. As with the other lung function measurements reported, PEFR in adults was higher at age 30 yrs than at age 60 yrs, and higher in males than in females.

Nomograms

Nomograms for rapid predictions of normal lung function values, based on the predictors of height and age, are presented in figures 5 to 10. These have been constructed from the regressions referenced in the legends and which are given in tables 1, 3 and 4. In order to present a nomogram for RV in Chinese males and females, and for FRC in Chinese males, a standard weight of 60 kg was assumed for males and 50 kg for females [11]. No age coefficient was given for TLC in Caucasian and Chinese and so the predicted values should be read parallel to the height scale.

Accuracy of reported values

Care has been taken to include studies likely to have obtained the most accurate predictive equations for lung function. Studies with small sample sizes or those using samples that could not be regarded as 'normal' have been excluded. However, even with careful scrutiny of methods, variations existed between reports especially with regard to the coefficients given for age and weight in Indian and Chinese populations. Therefore, in order to obtain the best estimate of predicted values, we have used mean values for a standard height to quantify racial differences.

Differences in lung volume values may result from use of different types of spirometers or differences in recording techniques between studies. Even with rigorous calibration, it is known that results from different spirometers may not always be interchangeable [44]. Although there was wide variation in the type of equipment used in each study (table 6), there seemed no reason to exclude any study on recording method criteria.

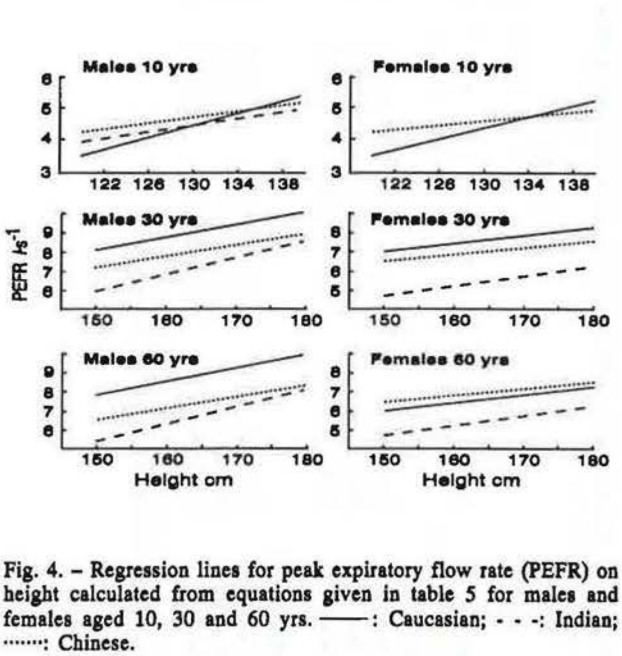

Fig. 4. – Regression lines for peak expiratory flow rate (PEFR) on height calculated from equations given in table 5 for males and females aged 10, 30 and 60 yrs. ——: Caucasian; - - -: Indian; ·······: Chinese.

Table 5. – Regression coefficients for peak expiratory flow rate (l·min⁻¹) in adults and children as a function of height (cm) and age (yrs)

	Adults						Children				
Race	Author	Ref.	Height	Age	Constant	SEE/SD*	Author	Ref.	Height	Constant	SEE/SD*
MALES											
Caucasian	QUANJER	[8]	0.067	-0.011	-1.610	1.200*	GODFREY *et al.*	[42]	0.088	-7.046	1.247*
Chinese	HOU *et al.*	[12]	0.058	-0.023	-0.789	1.186	LAM *et al.*	[18]	Predictive nomogram		
Indian	UDWADIA *et al.*	[20]	0.085	-0.019	-6.208	1.457*	KASHYAP and MALIK	[43]	0.049	-1.534	0.492
FEMALES											
Caucasian	QUANJER	[8]	0.040	-0.034	2.060	1.020*	GODFREY *et al.*	[42]	0.088	-7.039	0.676*
Chinese	HOU *et al.*	[12]	0.033	-0.022	1.592	0.995	LAM *et al.*	[18]	Predictive nomogram		
Indian	UDWADIA *et al.*	[20]	0.050	-0.002	-2.715	1.031*					

For abbreviations see legend to table 1.

Table 6. – Methods used in reviewed studies

Author	Ref.	n	Age yrs	Altitude	Method
CRAPO *et al.*	[7]	251	15–91	<1400 m	Water-sealed metal bell spirometer
QUANJER	[8]	703	21–64		Pneumotachograph
SALORINE	[9]	170	20–69		Wet spirometer
DACOSTA	[11]	207	20–66	Sea-level	Godart closed circuit spirometer
HOU *et al.*	[12]	517	17–76	Sea-level	SRL Sentry-82 (USA) Chestgraph (Japan)
UDWADIA *et al.*	[20]	760	15–65	Sea-level	Hewlett-Packard 47804S
PUROHIT *et al.*	[26]	1027	15–55	200–500	Autospirometer (model ST-460) Sanyo
CHUAN and CHIA	[15]	101	21–55	Sea-level	Collins 9 *l* helium residual volume

Author	Ref.	Ethnic Region	Population/selection criteria
CRAPO *et al.*	[7]	Salt Lake City, Utah USA	More than 90% church volunteers
QUANJER	[8]	Rural and urban areas	Normal population
SALORINE	[9]		Hospital staff and healthy clinic attenders
DACOSTA	[11]	Singapore	Hospital staff volunteers; 30% of men light smokers
HOU *et al.*	[12]	Guangnong, Guangzhou	Hospital staff and student volunteers
UDWADIA *et al.*	[20]	Bombay	Volunteers-hospital and educational institute staff
PUROHIT *et al.*	[26]	Rajasthan, NW India	Healthy nonsmoking hospital staff and students
CHUAN and CHIA	[15]	Singapore	Professional and clerical members of the hospital staff

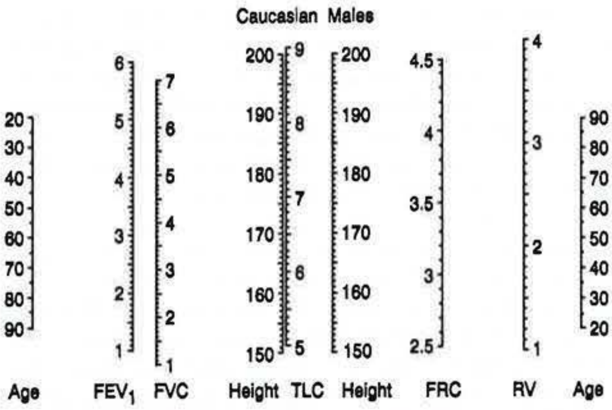

Fig. 5. – Nomogram for calculating predicted values for total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC) and residual volume (RV) in Caucasian males [8]. Values for TLC are not related to age and are read parallel to the two height scales.

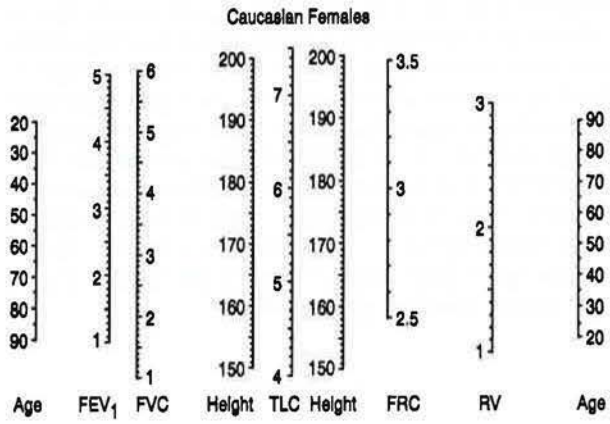

Fig. 6. – Nomogram for calculating predicted values for total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC) and residual volume (RV) in Caucasian females [8]. Values for TLC are not related to age and are read parallel to the two height scales

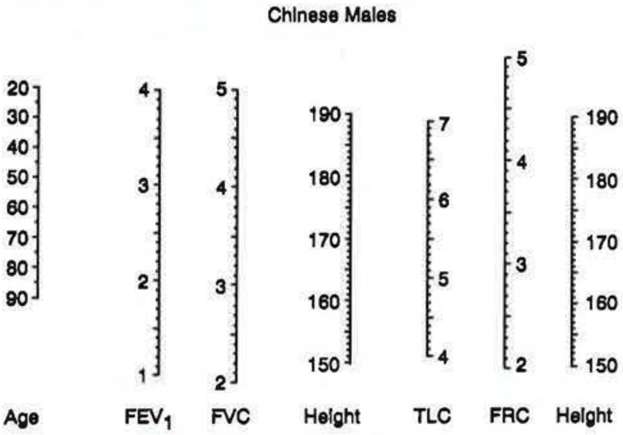

Fig. 7. – Nomogram for calculating predicted values for total lung capacity (TLC) [15], forced vital capacity (FVC) [11], forced expiratory volume in one second (FEV_1) [11] and functional residual capacity (FRC) [11] in Chinese males. Values for TLC and FRC are not related to age and are read parallel to the two height scales. In nomograms derived from regressions which include weight, a standard weight of 60 kg has been used to calculate the scales.

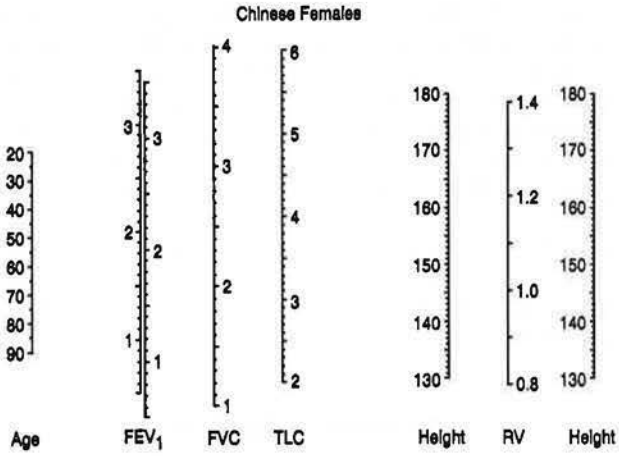

Fig. 8. – Nomogram for calculating predicted values for total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC) and residual volume (RV) in Chinese females [11]. In nomograms derived from regressions which include weight, a standard weight of 50 kg has been used to calculate the scales.

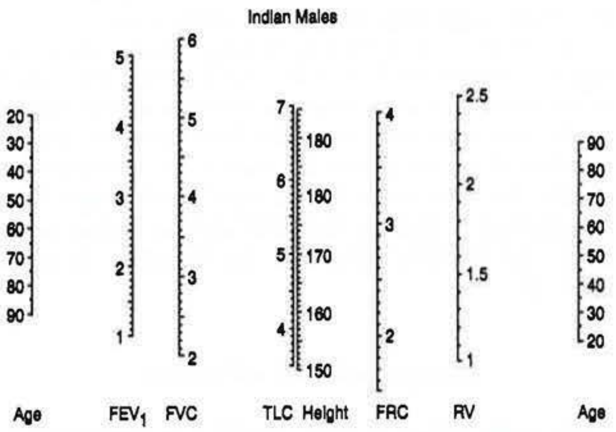

Fig. 9. – Nomogram for calculating predicted values for total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC) and residual volume (RV) in Indian males [20].

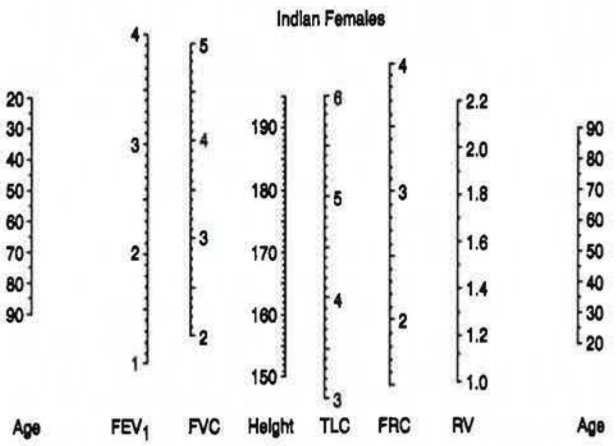

Fig. 10. – Nomogram for calculating predicted values for total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), functional residual capacity (FRC), total lung capacity (TLC) and residual volume (RV) in Indian females [20].

Reported differences between the racial groups may reflect variations in the accuracy of height and age as predictors of lung volumes. However, where r values are reported they are almost always greater than 0.8, indicating that age and height are responsible for over 60% of the variation in lung function. Unless the variance of a fitted slope is small, the confidence interval for a regression line is smallest around the centre and progressively greater away from the centre [45]. Thus, in the figures, differences in lung function values between the heights 155–175 cm are most likely to reflect real differences.

Statistical comparisons

Because insufficient summary statistics were reported, normal statistical procedures to assess the significance of the differences between races could not be employed. We have therefore used Student's t-test to compare estimated values for means and standard deviations. We recognize that this procedure can only give an approximate judgement of apparent differences.

To compare the divisions of lung volume shown in figure 3, values for TLC, FRC and RV were calculated as the mean of values from the selected studies shown in the tables for each race. We have used the largest standard deviation given for each race. Comparisons suggest that Caucasians have a significantly larger TLC than Indians or Chinese ($p<0.001$) and that Indian males have a significantly lower FRC than the other two races ($p<0.001$).

Interpretation of differences

The larger values for FEV_1 and FVC in Caucasians at age 10 yrs (Figs 1 and 2) provide evidence that racial differences in lung volume begin in childhood. In adulthood, there are obvious large differences in TLC (fig. 3). Because there is very little difference in RV between the three races, a larger TLC in Caucasians is apparently responsible for the larger FEV_1 and FVC values found in this race. Moreover, because Caucasians have larger FRC values than Indians they must also have larger inspiratory capacities.

In Caucasians, the larger TLC may be a function of increased lung mass, of differences in thoracic muscle strength or of differences in chest shape. The reported differences in FEV_1 %FVC and PEFR between racial groups suggest that airway calibre is not different. However, PEFR is a product of absolute lung volume elastic recoil, airway calibre and expiratory muscle strength and, thus, Caucasians would be expected to have the highest values for PEFR standardized for age and height since their increased weight would confer an increased expiratory force.

The lack of a consistent difference in FEV_1 %FVC and PEFR between racial groups suggests that airway calibre is not different and, therefore, it is unlikely that the larger TLC is a result of larger airway or alveolar size. It is possible that Caucasians may be able to stretch their lung mass to a greater volume because of greater inspiratory muscle strength, which in turn may be determined by the shape of the chest wall. Conversely, the high RV/TLC ratio in Indians may reflect a lower expiratory muscle strength in this race or it may reflect earlier airway closure during expiration.

Because of our careful selection of methods, differences reported are likely to be related to racial origin, although other influences such as environment or socioeconomic status cannot be discounted. Differences in lung volumes attributable to race have been confirmed by other workers. A recent study has shown that Caucasian teenagers have higher lung function values than Chinese teenagers living in the same country [46], and thus the environment is unlikely to be a major factor in this difference. HUANG *et al.* [47] suggest that observed differences between races are related to genetic factors that may lead to the formation of airways of different size or with different elastic recoil. Racial differences in spirometric function found in young people have been attributed to smaller ratios of trunk length to standing height in some races [48]. A highly significant relationship between the ratio of trunk length to standing, height and VC in 13 different ethic groups has been found [49]. It is thought that an adaptive mechanism to preserve body heat may have reduced limb length in some ethnic groups - for example, eskimos have a relative short limb length but have the largest VC for each cm of standing height [49].

Summary

In the clinic, predicted normal values are widely used for routine assessments and, therefore, it is important that the noted differences in lung volumes between the races are recognized. Further epidemiological studies, using comparative methods and standard statistical techniques, are essential in order to quantify apparent differences between the races and to standardize normal values for race, especially with regard to age, with greater accuracy.

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Revue des différences raciales de fonction pulmonaire chez les sujets normaux, caucasiens, chinois et indiens.
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RÉSUMÉ: En clinique, les valeurs prédites normales sont largement utilisées pour les appréciations de routine; il est dès lors important que les différences raciales observées dans les volumes pulmonaires soient bien connues. Des études épidémiologiques, utilisant des méthodes comparatives et des techniques statistiques standardisées, sont essentielles pour quantifier les différences apparentes entre races et pour standardiser de façon plus précise les valeurs normales par race en tenant compte, en particulier, de l'âge.
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