Lung function reference values in Singaporean children aged 6–18 years

G J Connett, S H Quak, M L Wong, J Teo, B W Lee

Abstract

Background **– A study was undertaken to produce reference values of lung function in Chinese children and a means of calculating adjusted standard deviation scores of lung function for Malay and Indian ethnic groups.**

Methods **– A cross sectional study of lung function (forced expiratory volume in one second and forced vital capacity) measured with a Jaeger spirometer was performed in a representative sample of Singaporean children made up of 1403 Chinese, 335 Malays, and 206 Indians.**

Results **– The relation between natural logarithms of lung function and height was approximately linear until 150 cm in boys and 140 cm in girls. At these heights there were abrupt changes in the gradients of both lines. Separate regression lines were derived for heights above and below these inflection points. Significant differences in lung function were seen in Chinese compared with Malay and Indian children. In particular, values were considerably lower among Indian boys.**

Conclusions **– The relation between lung function and height in Chinese children is best described by two regression equations over separate height ranges. Information is provided for the calculation of reference values and standard deviation scores, together with the correction factors that need to be applied to derive these values in Malay and Indian children.**

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Although several papers have published reference values for lung function throughout childhood in white[1] and Asian races,[2,3] there have been considerable differences between studies in the type of analysis used to derive summary equations. The need for uniformity in data presentation to simplify comparisons of study results has recently been emphasised by Chinn and Rona.[4] They described a simple statistical analysis using logarithmic data transformations to stabilise the increasing variance of lung function with increases in height. The skewed distributions of residuals on the logarithmic scale were normalised around the median by back transformation. The means and standard deviations of antilogged residuals were then used to construct standard deviation scores or centiles for predicted values.

This method has been used to analyse lung function data obtained in a cross sectional study on a representative sample of healthy Singaporean school children aged 6–18 years. Summary equations were derived for our predominantly Chinese community and these were used to make ethnic group comparisons with Malay and Indian children.

Methods

Children were recruited over a two month period (June and July) from six schools chosen to represent a cross section of the Singaporean child community. Children aged 6–18 years were randomly selected from classes in each school year and spirometric measurements were attempted on all children attending the class on the morning of each day of study after a brief physical examination.

A Jaeger pneumotach spirometer was used to obtain maximum flow-volume loops. After small group instruction, each child made 3–6 efforts while standing and wearing a nose clip. Data from those providing two technically satisfactory results were included using results from the flow-volume loop with the greatest sum of forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC). The spirometer was calibrated daily and results were corrected to BTPS units.

A total of 2196 measurements was made. Parents of children aged less that 12 years completed a detailed questionnaire about respiratory symptoms (American Thoracic Society ATS-DLD-78) and a similar questionnaire was self completed by older children. Data were excluded from 102 children with histories or physical signs suggesting chronic respiratory or cardiac disease, as were data from 48 children with an acute respiratory illness within three weeks of the day of testing. Height was measured in bare feet with a stadiometer to within the last complete 0·1 cm. National ethical committee approval was obtained for the study.

DATA ANALYSIS

Data from boys and girls were analysed separately. The results from Chinese children were divided into 5 cm height groups. The data from boys were divided into 14 groups across a height range of 107·6–177·5 cm, and for girls the data were divided into 13 groups using a height range of 107·6–172·5 cm. Six children

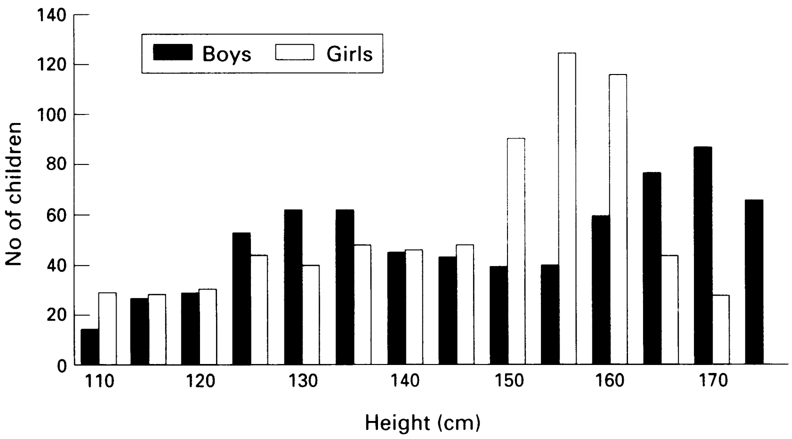

Figure 1 Distribution of children's height by sex. Data shown for Chinese children only.

falling outside these height ranges were excluded from the analysis. Within-group means for each 5 cm height range were plotted against their respective standard deviations using the original data and natural logarithms of the data to check that the transformation stabilised the increasing variance of lung function with increasing height – that is, achieved homoscedasticity. Mean values of lung function variables were also plotted against height and this was repeated after natural logarithm (ln) transformation. After visual inspection of the plotted data, regression equations for ln (lung function) were fitted. Multiple regression was used to test the significance of using two regression equations for different height ranges compared with a single equation for the entire data set in each sex. The mean and standard deviation of the antilogged residuals were used to calculate centile positions and standard deviation scores for measured values.

The regression equations derived from Chinese children were used to calculate predicted lung function measurements in Malay and Indian children. The means and standard deviations of the ratio of actual to predicted values were used to derive standard deviation scores for these two ethnic groups.

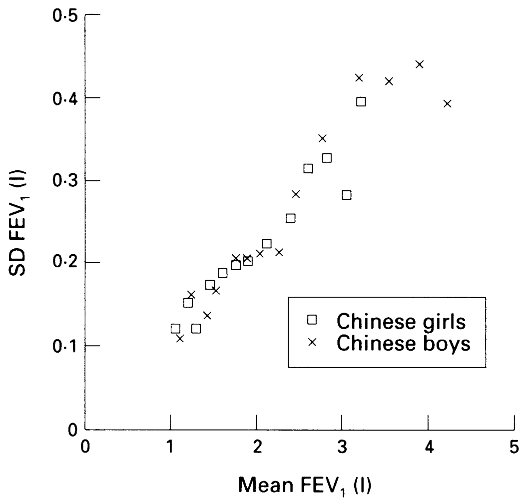

Figure 2 Standard deviation of FEV_1 plotted against mean FEV_1.

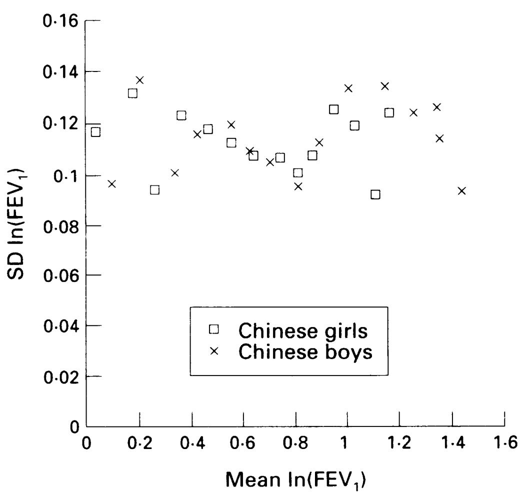

Figure 3 Standard deviation of $ln(FEV_1)$ plotted against mean $ln(FEV_1)$.

Results

Technically unsatisfactory results were obtained in 52 boys and 44 girls. This left 1944 children with analysable data representing 88·8% of the original tests. The group was made up of 1403 Chinese (male:female 694:709), 335 Malay (male:female 168:167) and 206 Indians (male:female 108:98). The numbers of Chinese children in each of the 5 cm height ranges are shown in fig 1. Standard deviations of FEV_1 within 5 cm height groups are plotted against mean values in fig 2. The increase in standard deviation in proportion to mean values was stabilised when the data were replotted after logarithmic transformation (fig 3). Similar results were obtained from the analysis of FVC (data not shown).

Figures 4–7 are plots of mean lung function against height for each sex after back transformation of the log data. These show smooth, approximately linear relationships in both sexes, but there is an abrupt change in the gradient of these relationships occurring at 140 cm in girls and 150 cm in boys for FEV_1 and FVC. The changes in gradient were still apparent when the data were plotted after logarithmic transformation. Multiple regression analysis was used to compare a single regression equation for all heights with two separate regression equations for heights above and below the point at which the gradient changed. The analysis showed a highly significant improvement in the description of the data for boys ($p<0·001$) but not for girls when two equations were used. Nevertheless, two regression equations were used to describe data in girls and in boys so that the analysis was consistent for both sexes and because inspection of the graphical data suggested that it would be appropriate (figs 6 and 7). The data from girls in the 137·6–142·5 cm height range and boys in the 147·6–152·5 cm height range were used to derive regression equations above and below the inflection points. Solutions for lung function reference values at the mid points of these height ranges were within 0·1 litres of each other using either equation. Regression models using ln(height), ln(age) and ln(weight) were also tested. Ln(height) was the most im-

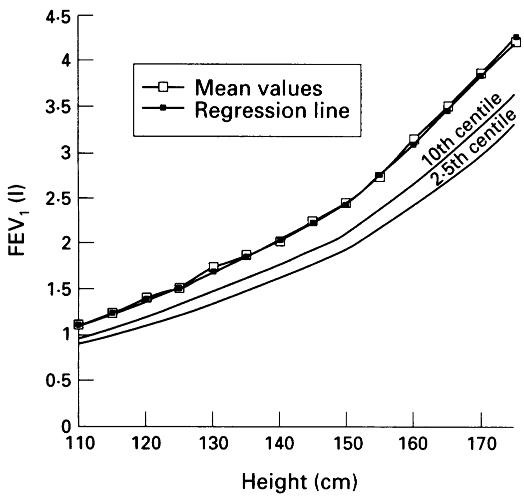

Figure 4 FEV_1 plotted against height in Chinese boys.

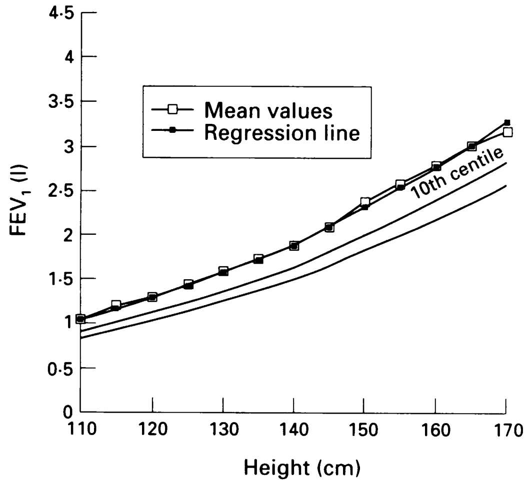

Figure 6 FEV_1 plotted against height in Chinese girls.

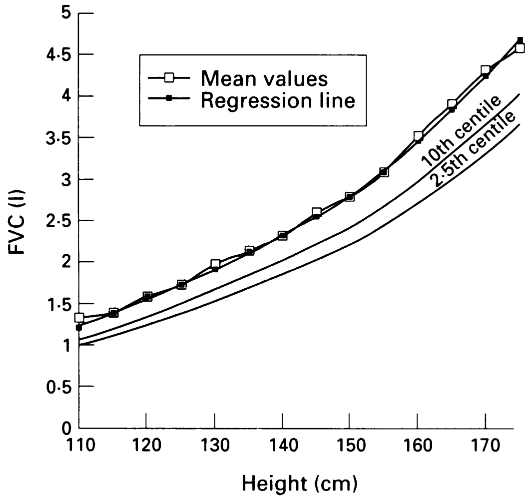

Figure 5 FVC plotted against height in Chinese boys.

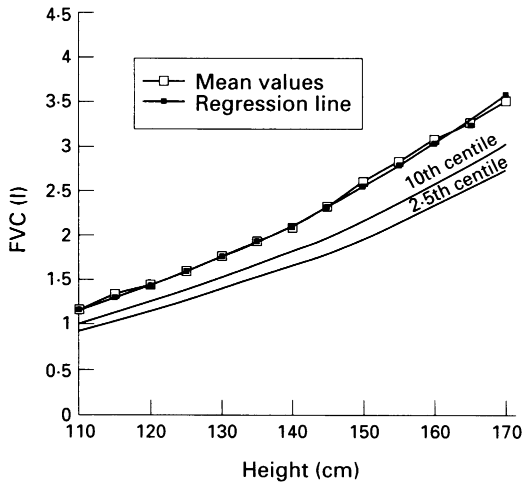

Figure 7 FVC plotted against height in Chinese girls.

portant predictor. Inclusion of ln(age) and/or ln(weight), or the use of polynomial functions, explained less than an additional 1% of the variation of the data within all the height ranges. Solutions to simple regression equations for ln(lung function) using ln(height) are shown in table 1 and antilogged regression lines together with 10th and 2·5th centile lines are shown in figs 4–7. Regression equations for FEV_1/FVC showed that this ratio was independent of height in both sexes. Median and centile values for this ratio are shown in table 2. Figure 8 compares the mean values of FEV_1 in the Chinese boys and girls.

The equations in table 1 were used to calculate predicted ln(lung function) values in the samples of Malay and Indian children and the means and standard deviations of the ratio of actual to predicted lung functions calculated. The results are shown in table 3. These results showed a tendency for Malays and Indians to have lower lung functions than the Chinese. These differences were significant for all groups ($p<0·01$) except for the high height range of Malay girls. Differences were greatest among Indian boys.

Discussion

The aim of this study was to derive reference values of lung function for Singaporean Chinese children and to describe differences in lung function variables between Chinese, Malay, and Indian ethnic groupings. Data have

Table 1 Multiple regression equations of ln(FEV_1) on ln(height) in Singaporean Chinese children

Function	*Height range for function (cm)*	*Regression coefficients*		*Sex (no. of children)*	*Multiple correlation coefficient (R^2)*	*Distribution of exponentiated (residuals)*	
		Intercept	*ln(height) (SE)*			*Mean*	*SD*
ln(FEV_1)	107·5–150	−12·002	2·573 (0·067)	Boys (369)	0·80	1·0057	0·1061
	150·1–177·5	−16·991	3·571 (0·122)	Boys (364)	0·70	1·0065	0·1141
	107·5–140	−11·684	2·494 (0·090)	Girls (262)	0·79	1·0058	0·1079
	140·1–172·5	−13·203	2·804 (0·100)	Girls (493)	0·61	1·0064	0·1129
ln(FVC)	107·5–150	−12·277	2·656 (0·066)	Boys (369)	0·81	1·0277	0·2370
	150·1–177·5	−16·097	3·417 (0·122)	Boys (364)	0·69	1·0065	0·1142
	107·5–140	−11·397	2·457 (0·088)	Girls (262)	0·75	1·0055	0·1055
	140·1–172·5	−12·789	2·739 (0·103)	Girls (493)	0·59	1·0069	0·1176

Table 2 Median and centile values of FEV_1/FVC ratios in Chinese boys and girls

	Boys	Girls
Median	0·89	0·91
10th centile	0·82	0·85
2·5th centile	0·78	0·82

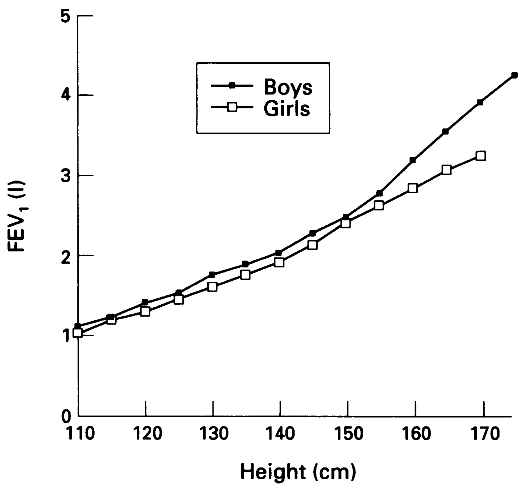

Figure 8 Comparison of mean values of FEV_1 in Chinese schoolchildren.

been presented in a way that allows the calculation of standard deviation scores or centiles to facilitate a meaningful interpretation of how far individual measurements depart from normality. Our regression equations have used a single function – ln(height). Although others have included the function ln(age),[3–5] which assumes increased importance over wider age ranges, we have used two separate equations to describe the changes in lung function that occur during childhood. Ln(age) explained a very small proportion of the data within these two equations.

The tendency for lung function to increase with height at an increased rate in the latter part of puberty has been addressed in several longitudinal studies and attributed to pubertal effects on lung volume and muscle strength.[6–8] In one cross sectional study in which normative standards for white school children in the UK were produced and in which pubertal staging was performed,[9] a sudden increase in lung function was shown around the age of puberty and a significant divergence of male and female lung function occurred after puberty. Our data also show a significantly greater increase in lung function with height during late childhood but differ in that, rather than an abrupt discontinuity in the relationship around puberty, we have shown inflection points. This change in gradient is more obvious in the data from boys than girls and has been noted in some studies of white children.[5 10] Our failure to demonstrate discontinuous changes in lung function around the adolescent growth spurt is probably because of the nature of a cross sectional study. Absolute height is a poor predictor of the peak height velocity that occurs in the latter stages of puberty,[11] so a tendency for individuals to have sudden changes in lung function might not be seen because of large differences in the heights and ages at which this occurs.

It is interesting to note that the change in gradient of the regression lines in our Chinese children occurs at lower heights than the discontinuity points described in white children[9] (fig 9). This is probably because Chinese Singaporeans tend to be shorter than Western children of the same age, and demonstrate the early signs of puberty at a younger age than their Western counterparts.[12] Such differences need to be taken into consideration when data from different races are compared among pubertal children.

Our data suggest that there are important differences in lung function between races. In particular, it appears that lung function is lower in Indian children than Chinese children. This is in agreement with reported comparisons between Indians and white children in the UK.[4] Similar results have also been reported in adult studies comparing white, Indian, and Chinese men.[13] Large differences in lung function between Indians and white people were attributed to a shorter chest length in Indians which is a racial characteristic. It was hypothesised that smaller reductions in lung function in Chinese than in white subjects of the same height were caused by differences in nutritional status.

Racial differences in the heights at which pubertal changes in lung function occur make it difficult to compare our data with those from other studies. However, we have derived predicted values for FEV_1 and FVC using the regression equations given by Chinn and Rona obtained from an English representative sample using ln(height) and ln(age) functions in pre-

Table 3 Distribution of exponentiated (residuals) for Malay and Indian children taken from the model using Chinese school children

Ethnic group		Height range (cm)	FEV_1	FVC
Boys:				
Malay	(n=71)	107·5–150	0·9655 (0·1082)	0·9539 (0·0978)
	(n=97)	150·1–177·5	0·9588 (0·1194)	0·9542 (0·1159)
Indian	(n=51)	107·5–150	0·9291 (0·1157)	0·9082 (0·1181)
	(n=57)	150·1–177·5	0·8966 (0·1065)	0·8975 (0·1091)
Girls:				
Malay	(n=64)	107·5–140	0·9588 (0·1013)	0·9460 (0·1016)
	(n=103)	140·1–172·5	0·9972 (0·1084)	0·9867 (0·1136)
Indian	(n=40)	107·5–140	0·9257 (0·1390)	0·9494 (0·1124)
	(n=58)	140·1–172·5	0·9577 (0·1037)	0·9565 (0·1104)

Values are mean (SD).

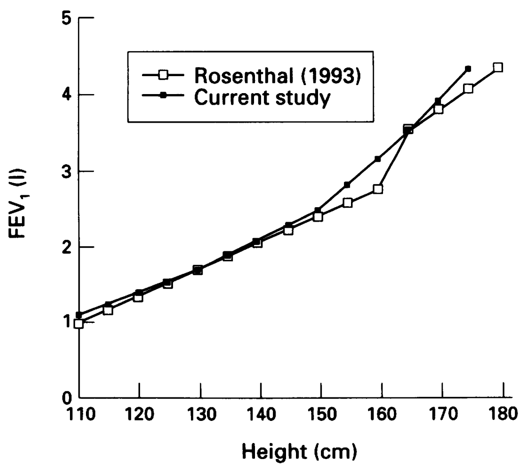

Figure 9 Fitted regression line for Chinese children compared with reference data by Rosenthal et al for British white children.[9]

pubertal children aged 6–11 years.[4] The mean (SE) ratio of the difference between predicted ln(lung function) and actual ln(lung function) was 1·0012 (0·006) for FEV_1 and 0·9925 (0·006) for FVC among boys. In girls the values were 0·9995 (0·006) and 0·9806 (0·007) for FEV_1 and FVC, respectively. The results are very similar except for a significantly lower value of FVC among the Chinese girls ($p<0·01$) . The reduced FVC causes an increased FEV_1/FVC ratio which has been found in other studies in which comparisons between similar ethnic groups have been made.[12,14] This does not indicate that the Chinese have larger airways. The increased ratio is probably caused by a smaller volume of air emptying into airways of comparable calibre and has been attributed to racial differences in alveolar number.[13] It is unlikely that nutritional factors are a cause for the FVC reduction in our study.

In conclusion, we have presented reference data for healthy Singaporean Chinese school children. The study has shown that lung function in prepubertal Singaporean Chinese children is similar to that in white children of the same height. Lung function increases at an increased rate with respect to height at around the time of puberty and this starts at a lower height than in white children. The increased rate continues throughout the latter part of childhood. Indian, and to a lesser extent Malay, children appear to have lower lung function than the Chinese. Regression equations and the means and standard deviations of the distribution of exponentiated residuals are provided for the calculation of standard deviation scores or the centile position of individual measurements.

Appendix

A Chinese boy with a height of 125 cm performs an FEV_1 of 1·25 l. His predicted FEV_1 using the regression equation for ln(FEV_1) can be calculated from table 1 as follows:

$$\ln(FEV_1) = -12{\cdot}002 + (2{\cdot}573 \times \ln[125])$$
$$FEV_1 = 1{\cdot}52$$

The standard deviation score for this value is a measure of how many standard deviations the actual value departs from this predicted value. The ratio of this boy's actual to predicted value is $1{\cdot}25/1{\cdot}52 = 0{\cdot}82$.

The mean (SD) value of the ratio between actual and predicted values from the regression equation in the sample population was 1·0057 (0·1061) (table 1). A standard deviation score can therefore be calculated for the ratio between actual and predicted values compared with the normal distribution of that ratio

$$= (0{\cdot}82 - 1{\cdot}0057)/0{\cdot}1061$$
$$= -1{\cdot}75$$

The centile position for a standard deviation score can be obtained from a table of areas in the tail of normal distributions which is available in most statistical textbooks. If the child was an Indian the appropriate corrected mean and standard deviations of the distribution of exponentiated residuals, given in table 3, would be used to determine the standard deviation score:

$$= (0{\cdot}82 - 0{\cdot}9291)/0{\cdot}1157$$
$$= -0{\cdot}94$$

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