Pulmonary Function in Normal Children Aged 11-15 Years

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SUMMARY

Prediction equations for forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), maximum mid-expiratory flow rate (MMFR) and peak expiratory flow rate (PFR) have been derived from a study of 367 asymptomatic Caucasian and Coloured (mixed race) children, aged 11-15 years, who did not smoke. Significant ethnic differences were found in FEV₁, FVC, FEV₁/FVC, and MMFR/FVC, but not in MMFR or PFR. The practical and epidemiological value of these observations is discussed.


Pulmonary function tests are important in the evaluation and management of patients with respiratory disease, because they add objectivity to the subjective impression gained by clinical examination. While measurements of gas exchange require laboratory facilities, ventilatory function can be measured so easily with relatively inexpensive apparatus that its measurement should be a routine part of the physician's and general practitioner's evaluation of patients with chronic respiratory symptoms. Serial measurements of simple ventilatory indices such as forced expiratory volume in 1 second (FEV₁) and peak expiratory flow rate (PFR) have greatly enhanced our understanding of the natural history of chronic obstructive lung disease¹ and have drawn attention to interesting and important different patterns of recovery from severe asthma.² Interpretation of ventilatory tests requires, inter alia, reference to normal predicted values, and since there are differences in ventilatory function between communities, particularly between Caucasians and non-Caucasians,³ it is ideal to have normal values for the population being served. Ethnic differences are also of great importance in epidemiological studies.⁴ There are no standards for ventilatory function in South African children and the object of this report is to present normal values for simple indices of ventilatory function based on a study of asymptomatic children aged 11-15 years who were non-smokers, and to point out differences between Caucasian children and those of mixed race (Coloureds).

SUBJECTS AND METHODS

Children aged 11-15 years who did not smoke, and who had no chronic respiratory symptoms, were studied. The 206 Caucasian children attended 4 schools serving predominantly social classes 1 and 2, and the 161 Coloured children attended a single school serving predominantly social classes 3 and 4. There was no selection within each group, but almost all the children in the age group who were non-smokers and had no respiratory symptoms were studied, PFR was measured with the Wright peak flow meter,⁵ and FEV₁, forced vital capacity (FVC) and maximum mid-expiratory flow rate (MMFR) were measured from the FVC manoeuvre recorded on a dry spirometer (Vitalograph⁶). Each child performed at least 3 maximal forced expirations on each instrument, and the best value was used for analysis after correction to BTPS. Data were processed with a Univac computer and statistical analysis was performed using BDS package programmes.

RESULTS

The age distribution and physical characteristics within each age group are shown for the 2 groups of children in Table I. The mean heights and weights were higher in the Caucasians than in the Coloureds in each age group and the means in each group as a whole were significantly different (P<0.01). Prediction formulae derived by multiple regression analysis of indices of ventilatory function against height, weight, age and sex, are shown in Table II. Covariance analysis of each index in Caucasians and Coloureds showed significant differences in FEV₁ and FVC between the 2 groups (P<0.001), but not in MMFR or PFR. The mean and standard deviations for FEV₁/FVC and MMFR/FVC were 0.88 ± 0.05 and 1.02 ± 0.22 in Caucasians and 0.90 ± 0.05 and 1.15 ± 0.29 in Coloureds. Comparison of these derived indices by the two-tailed t test showed significant differences between the 2 groups (P<0.001). In Table II, R² represents the fraction of the variance of each index which is accounted for by the regression equations, and it can be seen from Table II that in Caucasians 74% of the variance in FEV₁, 76% of FVC, 43% of MMFR, and 44% of PFR are accounted for by factors considered in the equations (height, weight, age and sex). In the Coloureds a lesser percentage of the variance of each index is accounted for by the regression equations. Analysis by t test of the regression coefficients showed that the most significant variable in relation to each index in both Caucasians and Coloureds was height. In the Caucasians, weight was also significant for FEV₁, FVC and MMFR (P<0.01), but not for PFR. In the Coloureds weight was significant for FEV₁ and FVC only (P<0.01). Age was significant for FEV₁ and MMFR in Caucasians and for MMFR in Coloureds (P<0.01). Sex was a significant factor (P<0.05) for FVC, MMFR and PFR in Caucasians and for FVC only in Coloureds. The correlations between individual indices and of each index with physical characteristics are shown in Table III.
TABLE I. PHYSICAL CHARACTERISTICS CLASSIFIED BY AGE AND ETHNIC GROUP

<table>
<thead>
<tr>
<th>Age</th>
<th>Ethnic group</th>
<th>Number</th>
<th>Mean and range</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Caucasian</td>
<td>47</td>
<td>150 (136 - 166)</td>
<td>40 (30 - 59)</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>54</td>
<td>140 (125 - 157)</td>
<td>31 (21 - 47)</td>
</tr>
<tr>
<td>12</td>
<td>Caucasian</td>
<td>60</td>
<td>156 (143 - 169)</td>
<td>46 (33 - 66)</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>53</td>
<td>147 (131 - 162)</td>
<td>38 (24 - 54)</td>
</tr>
<tr>
<td>13</td>
<td>Caucasian</td>
<td>55</td>
<td>163 (143 - 181)</td>
<td>53 (39 - 80)</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>29</td>
<td>153 (129 - 167)</td>
<td>41 (25 - 62)</td>
</tr>
<tr>
<td>14</td>
<td>Caucasian</td>
<td>36</td>
<td>166 (156 - 190)</td>
<td>56 (39 - 92)</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>18</td>
<td>156 (143 - 166)</td>
<td>45 (34 - 56)</td>
</tr>
<tr>
<td>15</td>
<td>Caucasian</td>
<td>8</td>
<td>171 (158 - 184)</td>
<td>55 (43 - 75)</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>7</td>
<td>159 (153 - 171)</td>
<td>50 (39 - 65)</td>
</tr>
</tbody>
</table>

* Caucasians — mean 159; SD 9.8.
Coloured — mean 147; SD 9.4.
† Caucasians — mean 48.3; SD 11.3.
Coloured — mean 35.9; SD 8.5.

TABLE II. LUNG FUNCTION PREDICTION EQUATIONS FOR ASYMPTOMATIC 11 - 15-YEAR-OLD CHILDREN WHO DID NOT SMOKE (MULTIPLE REGRESSION ANALYSIS)

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Number</th>
<th>Index</th>
<th>Mean</th>
<th>Intercept</th>
<th>( a )</th>
<th>( b )</th>
<th>( c )</th>
<th>( dt )</th>
<th>SEE</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coloureds</td>
<td>161</td>
<td>FEV(_1)</td>
<td>2.34</td>
<td>-3.26</td>
<td>+0.035</td>
<td>+0.013</td>
<td>-0.009</td>
<td>+0.087</td>
<td>0.284</td>
<td>0.692</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FVC</td>
<td>2.60</td>
<td>-3.52</td>
<td>+0.038</td>
<td>+0.019</td>
<td>-0.019</td>
<td>+0.153</td>
<td>0.296</td>
<td>0.735</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMFR</td>
<td>3.96</td>
<td>-3.07</td>
<td>+0.025</td>
<td>+0.013</td>
<td>+0.168</td>
<td>-0.188</td>
<td>0.734</td>
<td>0.311</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFR</td>
<td>359</td>
<td>-309</td>
<td>+3.700</td>
<td>+0.550</td>
<td>+8.500</td>
<td>-11.4</td>
<td>54</td>
<td>0.428</td>
</tr>
<tr>
<td>Caucasians</td>
<td>206</td>
<td>FEV(_1)</td>
<td>3.13</td>
<td>-5.39</td>
<td>+0.044</td>
<td>+0.011</td>
<td>-0.076</td>
<td>+0.017</td>
<td>0.356</td>
<td>0.738</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FVC</td>
<td>3.57</td>
<td>-6.53</td>
<td>+0.054</td>
<td>+0.013</td>
<td>+0.082</td>
<td>+0.188</td>
<td>0.390</td>
<td>0.764</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMFR</td>
<td>3.5</td>
<td>-4.34</td>
<td>+0.034</td>
<td>+0.017</td>
<td>+0.148</td>
<td>-0.407</td>
<td>0.764</td>
<td>0.431</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFR</td>
<td>412</td>
<td>164</td>
<td>2.87</td>
<td>+0.95</td>
<td>+5.55</td>
<td>+11.1</td>
<td>47</td>
<td>0.444</td>
</tr>
</tbody>
</table>

* Index = intercept + (height \( \times a \)) + (weight \( \times b \)) ± (age \( \times c \)) ± (sex \( \times d \)).
† Sex = 1 for males; 0 for females.
SEE = Standard error of estimate for the population studied.
\( R^2 \) = Proportion of the variance in FEV\(_1\), FVC, MMFR and PFR that is explained by the regression line.

TABLE III. CORRELATION COEFFICIENTS BETWEEN PHYSICAL CHARACTERISTICS AND MEASURED INDICES

<table>
<thead>
<tr>
<th>Correlation matrix — Caucasians</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>FEV(_1)</td>
</tr>
<tr>
<td>FVC</td>
</tr>
<tr>
<td>MMFR</td>
</tr>
<tr>
<td>PFR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlation matrix — Coloureds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>FEV(_1)</td>
</tr>
<tr>
<td>FVC</td>
</tr>
<tr>
<td>MMFR</td>
</tr>
<tr>
<td>PFR</td>
</tr>
</tbody>
</table>

Prediction formulae derived by linear regression of the measured indices against height are shown in Table IV. Comparison of \( R^2 \) for each index in this table with those in Table II shows that most of the variance of each index of ventilatory function is related to height.

Regression lines for FVC, FEV\(_1\), PFR and MMFR against height are shown in Fig. 1. The differences in FEV\(_1\) and FVC between Caucasians and Coloureds become progressively greater with increasing height above 140 cm.
TABLE IV. LUNG FUNCTION PREDICTION EQUATIONS FOR NON-SMOKING ASYMPTOMATIC CHILDREN 11-15 YEARS OF AGE (SINGLE REGRESSION ANALYSIS)

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Number</th>
<th>Index</th>
<th>Mean</th>
<th>Intercept</th>
<th>a</th>
<th>SEE</th>
<th>Correlation coefficient</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coloureds</td>
<td>161</td>
<td>FEV₁</td>
<td>2.34</td>
<td>-4,138</td>
<td>+0.044</td>
<td>0.29</td>
<td>0.82</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FVC</td>
<td>2.60</td>
<td>-4,808</td>
<td>+0.05</td>
<td>0.31</td>
<td>0.84</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMFR</td>
<td>2.96</td>
<td>-3,958</td>
<td>+0.05</td>
<td>0.76</td>
<td>0.51</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFR</td>
<td>3.59</td>
<td>-349</td>
<td>+4.8</td>
<td>55</td>
<td>0.64</td>
<td>0.41</td>
</tr>
<tr>
<td>Caucasians</td>
<td>206</td>
<td>FEV₁</td>
<td>3.13</td>
<td>6,249</td>
<td>+0.06</td>
<td>0.37</td>
<td>0.85</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FVC</td>
<td>3.57</td>
<td>7,468</td>
<td>+0.09</td>
<td>0.41</td>
<td>0.86</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMFR</td>
<td>3.6</td>
<td>-6,126</td>
<td>+0.061</td>
<td>0.81</td>
<td>0.6</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFR</td>
<td>4.12</td>
<td>-244</td>
<td>+4.1</td>
<td>48</td>
<td>0.65</td>
<td>0.42</td>
</tr>
</tbody>
</table>

* Index = intercept + (height × a); SEE = standard error of estimate for population studied; R² = proportion of the variance in FEV₁, FVC, MMFR and PFR that is explained by the regression line.

TABLE V. COMPARISON OF LUNG FUNCTION INDICES USING DIFFERENT PREDICTION EQUATIONS*

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Lung function index</th>
<th>Weng and Levison²⁺</th>
<th>Binder et al.²⁺</th>
<th>Dickman et al.²⁺</th>
<th>Zapletal et al.²⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian</td>
<td>FVC</td>
<td>3.60</td>
<td>3.50</td>
<td>3.24</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>3.09</td>
<td>2.90</td>
<td>2.78</td>
<td>2.59</td>
</tr>
<tr>
<td></td>
<td>MMFR</td>
<td>3.29</td>
<td>3.57</td>
<td>3.56</td>
<td>3.51</td>
</tr>
<tr>
<td></td>
<td>PFR</td>
<td>416</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>FVC</td>
<td>3.43</td>
<td>3.50</td>
<td>2.96</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>3.07</td>
<td>2.90</td>
<td>2.63</td>
<td>2.37</td>
</tr>
<tr>
<td></td>
<td>MMFR</td>
<td>3.70</td>
<td>3.57</td>
<td>3.70</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>PFR</td>
<td>405</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>FVC</td>
<td>2.67</td>
<td></td>
<td>2.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>2.33</td>
<td></td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MMFR</td>
<td>2.90</td>
<td></td>
<td>3.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FVC</td>
<td>2.52</td>
<td></td>
<td>1.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>2.25</td>
<td></td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MMFR</td>
<td>3.09</td>
<td></td>
<td>2.77</td>
<td></td>
</tr>
</tbody>
</table>

* Average height + weight + age of children in the present study were used in all the prediction equations (see Table I).
† These authors did not state whether their subjects were Caucasians, non-Caucasians, or both.

Fig. 1. Relationship of indices of ventilatory function to standing height (--- Caucasians; — Coloureds).

A comparison of predicted values (based on the mean height (age and weight within each of the 2 groups of children in this study) using the various prediction formulae available is shown in Table V.

DISCUSSION

The Wright peak flow meter and Vitalograph spirometer were selected for use in this study because they are robust, reliable, easy to use, relatively inexpensive and have little inter-instrumental variability, and are therefore the best instruments for widespread use in a country such as South Africa where respiratory disease services with more sophisticated equipment are limited to major teaching hospitals.

Children aged 11-15 years were studied because they could co-operate fully, and also because there are many reports of differences in pulmonary function between Caucasian and non-Caucasian adults, but only one report comparing children of different ethnic groups.
While it would have been ideal to study Caucasians, Coloureds and Blacks, access to Black schools was not possible. The differences in height and weight could be contributed to by ethnic factors, but in view of the socio-economic differences between the 2 groups, and evidence from previous studies, they are much more likely to be nutritional in origin.

The reasons for ethnic differences in ventilatory function are not clear, but could relate to differences in lung elastic recoil, or to the smaller sitting-to-standing height ratio in Blacks compared with Caucasians. The differences in FEV₁ and FVC between Coloureds and Caucasians in this study are considered to be ethnic, despite the difference in physical characteristics in the 2 groups, since covariance analysis takes such physical differences into account. FEV₁/FVC and MMFR/FVC are independent of lung size by virtue of having FVC as the denominator, and differences between the 2 groups are again considered to be ethnic. While it is possible that malnutrition in early life could have influenced lung growth and resulted in the lower FEV₁ and FVC in the children of lower socio-economic status, ethnic differences have been shown between White and Black American children of the same height and weight for age, and there is no evidence to suggest that malnutrition disproportionately reduces lung growth.

The practical importance of differences in ventilatory function between adults of different ethnic groups has been stressed in relation to pre-employment evaluation for jobs in which occupational lung disease may occur. The practice of excluding people with spirometric values more than 2 standard deviations below that predicted from such jobs would result in unnecessary rejection of more non-Caucasians than Caucasians. In children, the major practical importance would be in comparing measured values with predicted values in the evaluation of children with chronic respiratory symptoms. The importance of having accurate predicted values for epidemiological studies of the effect of inhaled pollutants on the lung is also clear.

The differences found by covariance analysis between Caucasians and Coloureds for FEV₁ and FVC in this study, although significant (P<0.001), were not of the same order of magnitude as the differences reported between White and Black American children. In both cases, however, the magnitude of the differences between White and non-White increased progressively at heights over 140 cm. The importance of having prediction equations for the population being served is evident from the discrepant predicted values obtained by using formulae based on other populations (Table V) in particular, since the ethnic group has not always been stated in some of the earlier reports. The use of the prediction equations of Binder et al. for Whites would result in an underestimate of FVC and FEV₁ by 10% and an over-estimate of MMFR by 9% in our Caucasian boys, and an underestimate of FVC and FEV₁ by 14% in our Caucasians girls. Applying the equations of Binder et al. for Blacks to our Coloureds would result in under-estimating FVC and FEV₁ by 23% and 16% respectively in our Coloured boys, and underestimating FVC, FEV₁ and MMFR by 21%, 24% and 10% respectively in our Coloured girls.

The 95% confidence limits (± 2 SEE around the regression) for each of the indices in this study are of about the same order of magnitude as in previous studies, and are widest for MMFR and PFR. The width of the 95% confidence limits and the observation that only 70% of the variance in FVC and FEV₁ and 30-40% of the variance in MMFR and PFR can be accounted for by considering age, height, weight and sex, means that other important factors must be contributing to the variance seen within a group of apparently normal subjects. Possibilities to consider include true differences in the relationship between parenchymal and tracheobronchial anatomy (dysynaptic growth), and in the effects of childhood respiratory illness which have not resulted in chronic respiratory symptoms. This latter suggestion is perhaps supported by the observation that less of the variance of each index of ventilatory function, and particularly of MMFR, is accounted for by age, height, weight and sex in the children of the lower socio-economic group in whom malnutrition and early childhood respiratory disease are likely to be more common. This raises the question of how one should define 'normal' for the purposes of such studies as these, and this is as yet an unresolved problem. Ideally, asymptomatic patients who do not smoke, who have no previous history of chest disease, and who have normal lung elastic recoil and airways resistance, and no evidence of frequency dependence of compliance should be studied, but this would be difficult to do on a large scale. Future studies will hopefully elucidate the reasons for the wide 95% confidence limits of all these, measurements, particularly those thought to reflect small airways obstruction.

I wish to thank Janis Burger for enthusiastic and excellent technical assistance, Peter Ritchkin and Debbie Bradshaw of the Department of Mathematical Statistics at the University of Cape Town for help with statistical analysis, and the University of Cape Town Foundation for financial support.

REFERENCES