Normal Values of Forced Vital Capacity (FVC), Forced Expiratory Volume (FEV_{1.0}), and Peak Flow Rate (PFR) in Children

A. E. DUGDALE and MARGARET MOERI

From the Department of Child Health, University of Queensland, Australia

In children, the respiratory tract is probably more often affected by disease than any other system of the body. In spite of this, quantitative methods of evaluation are seldom used outside special respiratory units. No clinician would manage a patient with potential renal failure without laboratory aids, even if it were only an estimation of the blood urea, but he would seldom give children with potential respiratory failure the benefit of the simplest functional studies.

Various instruments, including dry spirometers and the peak flow meter are relatively inexpensive, can be taken to the bedside, and can be used efficiently without specialized training. Although the results obtained do not give a complete assessment of the functional capacity of the respiratory system, they do give valuable information about the gaseous phase of respiration. Normal values for children, using dry spirometers, are lacking and there are few studies using the Wright peak flow meter in children (Nairn *et al.*, 1961). This study is designed to present normal data as nomograms which can be used routinely by clinicians.

Material and Methods

Through the kindness of Dr. G. May, Director of School Health Services in Queensland, Australia, we were able to test 261 normal children at a primary school in Brisbane. The school was in a middle and upper class suburb, and the children ranged in age from 6½ to 12½ years. A form containing questions about the child's past medical history was sent to his home to be completed by the parents. Any child who had a history of asthma or other allergic conditions, bronchitis, or recurrent chest infections was excluded. Children with acute infections at the time of testing were also excluded.

The date of birth and sex of each child were noted and the height, weight, and head circumference measured.

The child was then shown the apparatus used for testing respiratory function and instructed in its use. The Wright peak flow meter (Wright and McKerrrow, 1959) was used first. The child was seated and assisted in holding the machine at face level. Up to five attempts were made depending on the age and co-operation of the child. The two highest readings, which were technically satisfactory and in which the child appeared to use maximal effort, were averaged and the average recorded. The two highest readings usually varied by less than 5 to 10 litres per second. After a rest for approximately five minutes, the child used the McKesson 'Vitalor' in the same manner.

The data were recorded in a workbook and later transferred to punch cards. The data used were: sex of child; age (in years to 2 decimal places); height; weight; head circumference; FEV_{0.5}; FEV_{1.0}; FVC; and peak flow rate.

Results

The age and sex distribution of the child is shown in Table I.

As we had access to a computer, it was possible to calculate all the correlations between the anthropometric and respiratory function data as well as the correlations within these classes. This gave 36 correlation coefficients for boys, with a similar number for girls. The data were then converted to logarithms and a similar set of correlation coefficients

TABLE I

Age and Sex Distribution of Children in the Study

Age (yr.)	Male	Female
6-6 11/12	6	7
7-7 11/12	17	13
8-8 11/12	35	22
9-9 11/12	22	24
10-10 11/12	21	23
11-11 11/12	22	25
12-12 11/12	13	12
Total	133	128

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TABLE II
Correlation Coefficients in Males after Logarithmic Conversion of Data

	Age	Height	Weight	Head Circumference	FEV _{0.5}	FEV _{1.0}	FVC	PFR
Age	1.000	0.814	0.722	0.400	0.687	0.711	0.712	0.718
Height		1.000	0.888	0.583	0.777	0.816	0.835	0.766
Weight			1.000	0.686	0.757	0.773	0.779	0.737
Head circumference				1.000	0.552	0.564	0.556	0.537
FEV _{0.5}					1.000	0.939	0.873	0.860
FEV _{1.0}						1.000	0.954	0.810
FVC							1.000	0.748
PFR								1.000

TABLE III
Correlation Coefficients in Females after Logarithmic Conversion of Data

	Age	Height	Weight	Head Circumference	FEV _{0.5}	FEV _{1.0}	FVC	PFR
Age	1.000	0.800	0.736	0.517	0.625	0.719	0.749	0.762
Height		1.000	0.811	0.616	0.687	0.778	0.807	0.712
Weight			1.000	0.625	0.654	0.752	0.799	0.666
Head circumference				1.000	0.458	0.559	0.567	0.494
FEV _{0.5}					1.000	0.869	0.769	0.765
FEV _{1.0}						1.000	0.959	0.767
FVC							1.000	0.730
PFR								1.000

TABLE IV
Regression Equations, Correlation Coefficients, and Standard Deviations Calculated from Data after Logarithmic Conversion

	Function	Regression Equation	Correlation Coefficient	Standard Deviation
Boys	FVC (ml.)	$\log_e \text{FVC} = 1.052 + 1.715 \log_e \text{Ht.}^* + 0.253 \log_e \text{Wt.}^*$	0.844	0.124 (13%)
	FEV _{1.0} (ml.)	$\log_e \text{FEV}_1 = 0.491 + 0.919 \log_e \text{FVC}$	0.954	0.067 (7%)
	PFR (l./sec.)	$\log_e \text{PFR} = -0.869 + 2.142 \log_e \text{Ht.}$	0.766	0.145 (15%)
Girls	FVC	$\log_e \text{FVC} = 1.735 + 1.362 \log_e \text{Ht.} + 0.318 \log_e \text{Wt.}$	0.835	0.112 (12%)
	FEV _{1.0}	$\log_e \text{FEV}_1 = 0.643 + 0.901 \log_e \text{FVC}$	0.959	0.055 (6%)
	PFR	$\log_e \text{PFR} = -0.540 + 2.024 \log_e \text{Ht.}$	0.712	0.154 (17%)

* Height, in centimetres; weight, in kilogrammes.

obtained. The coefficients obtained after logarithmic conversion were better than those derived from the original data, so all the diagrams and tables which follow have been based on logarithmic data. The correlation coefficients for males and females are shown in Tables II and III.

Examination of these tables shows that the respiratory data correlate best with height, then less well with weight, age, and head circumference in that order.

The regression equations for forced vital capacity (FVC) for boys and girls taken separately were calculated from the height data, and multiple regression equations using both weight and height were also determined (Table IV). The correlation coefficients were higher in the multiple than in the simple regressions. However, the gain was not

significant for boys, and fell just short ($p = 0.07$) of the usually accepted level ($p = 0.05$) in girls. Nevertheless, the slight improvement in the estimate of the FVC in girls was thought to justify the use of height and weight in the construction of nomograms. These are shown in Fig. 1 and 2. Clinically the upper limit of the normal range is seldom used as most disease states tend to lower the FVC. For this reason the mean and the lower limit of normal, which was taken as the mean minus two standard deviations or approximately the second centile, have been shown.

The correlation coefficient between the FVC and FEV_{1.0} is high, showing that the two are closely related. The principal clinical use of the FEV_{1.0} is in determining the FEV_{1.0}/FVC ratio, as a measure of airways resistance. The relation-

FIG. 1.—Nomogram for determining the expected forced vital capacity (FVC) in boys. Place a ruler so that it cuts the columns for height and weight at the observed values. The average and lower normal ($-2SD$) values are shown.

ship of the FEV_{1.0} to the height and weight have not been further developed, but the equations relating the FEV_{1.0} and the FVC have been calculated, and are shown in Table IV. The equations linking FEV_{1.0} and FVC were very similar in the two sexes, but it was shown that there was a significant difference in the standard deviations. This made separate charts for boys and girls necessary. Fig. 3 is designed so that the expected FEV_{1.0} can be derived from a known value of the FVC. The clinically important part of the range of the FEV_{1.0} is the lower end of the normal range, so the 50th, 10th, and 3rd centiles have been shown. To find the normal range of the FEV_{1.0}, a ruler should be laid across the chart so that the edge corresponds with the known FVC (shown on both sides). The edge of the ruler will cut the FEV_{1.0} columns and show the expected values.

The correlation between the FEV_{0.5} and the FVC was not as good as that for the FEV_{1.0} and the FVC. It is possible that the FEV_{0.5} gives information of value, but the normal range derived from our figures is wide, and further work is required before its value is established. No further calculations have been done on the FEV_{0.5}.

The regression equations between peak flow and height were calculated for each sex and are shown in Table IV. It was found that the lines represented by the equations were significantly different so that again the data for the two sexes could not be combined. Use of both height and weight to estimate the peak flow rate (PFR) gave no significant improvement. The estimates of PFR have therefore been made on height alone. Fig. 4 (p. 234) shows the estimate of PFR based on height, and should be used in a manner similar to Fig. 3.

FIG. 2.—Nomogram for determining the expected forced vital capacity (FVC) in girls. This should be used in the same manner as Fig. 1.

Discussion

The objective assessment of respiratory function in children is a relatively recent technique, and one which is still practised mainly in specialized respiratory units. Its widespread application has been delayed by the lack of suitable apparatus and a set of normal values. The Wright peak flow meter and the newer dry spirometers, of which the McKesson 'Vitalor' is an example, are now readily available. They are reliable and robust, and are suitable for use by staff who are not experts in respiratory physiological measurement. Satisfactory tests can be obtained regularly from children over the age of 5 years and sometimes from younger children. However, the lack of normal values for children may have delayed their acceptance, and it is hoped that this study will fill that need.

Air flows and vital capacity have been found to correlate best with height (Ferris and Smith, 1953;

Helliesen *et al.*, 1958; Nairn *et al.*, 1961; Lunn, 1965). Nairn *et al.* (1961) also correlated peak flow with surface area but found that the result was much less satisfactory than when height was used. Our study tends to confirm this finding, though weight probably played a part in determining the FVC in girls. Various mathematic devices have been used to make the height fit the pulmonary function tests (Helliesen *et al.*, 1958; Bjure, 1963), but it appears that the logarithmic conversion used here is as satisfactory as any (Bjure, 1963). In all published studies the range of normal values is very similar.

The respiratory function tests which have been used here do not give a complete picture of lung function, but they do give a reasonable guide to the state of air movement. Most pulmonary diseases in childhood alter this aspect of respiration, so in practice these relatively simple bedside tests have been found to be valuable. This is particularly

FIG. 3.—Chart for determining the expected $FEV_{1.0}$ for boys and girls when the FVC is known. Place a ruler across the chart so that it cuts the left- and right-hand columns at the measured value of the FVC.

true in long-term conditions such as asthma, where they may give the only objective guide to the progress of the disease and the efficacy of treatment. These respiratory function tests should be incorporated in the diagnosis and treatment of many of the respiratory illnesses of children.

Summary

The normal values in children for the forced vital capacity (FVC), the forced expiratory volume in one second ($FEV_{1.0}$), and the peak flow rate (PFR) have been determined in a group of 261 healthy schoolchildren.

Charts which allow the ready determination of these values have been presented.

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[Fig. 4 overleaf, p. 234

FIG. 4.—Chart for determining the peak flow rate (PFR). Place a ruler so that the edge cuts the left- and right-hand columns at the measured height.