THE SHAPE AND MEASUREMENTS OF THE FORCED EXPIRATORY SPIROGRAMS IN HEALTHY CHILDREN

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Measurement of the forced vital capacity (FVC) and the volume of air expired by a forcible effort against time (FEV) by means of a recording spirometer remains one of the most practical and helpful tests available for the assessment of ventilatory function. It is simple, easily performed, and on repetition does not show any learning effect in children.[1, 2] In the test the spirographic tracing of a forcible expiration on a fast-moving kymograph is termed the forced expiratory spirogram (FES). Details of its form and the volume of expired air over any desired time period can be measured from this spirogram.

The low resistance spirometer of Bernstein, D'Silva and Mendel,[3] has become the instrument of choice for the spirometric measurement of ventilatory capacity both in adults and in children. Using this type of spirometer normal values in children have been established for the $FEV_{.75}$ [1, 4, 5], the FEV_1[4, 5], the FVC[1, 4, 5] and the forced expiratory time.[1] Not only must published normal values be confirmed, but normal values for volumes expired in other time intervals must also be established.

The purpose of this paper is to report on:

1. The establishment of prediction formulae in children aged 7–16 years for the $FEV_{.25-.75}$, FEV_1 and FEV_A from data obtained from the same spirograms measured for the determination of prediction formulae for the $FEV_{.75}$ and FVC in normal girls and boys;[1]
2. A comparison of the values obtained in the present study and a previous publication[1] for the $FEV_{.25-.75}$, FEV_A, $FEV_{.75}$, FEV_1 and FVC with other published series in which a similar type of spirometer was used; and
3. The shape of the FES in the normal child and the reconstruction of the predicted 'normal' FES for any given child.

The terminology and abbreviations used are those recommended by Gandevia and Hugh-Jones,[6] except for the FEV_A which is defined as the point on the FES where, from being initially almost straight, the tracing changes to a curve as the speed of expiration begins decreasing. The FEV_A is recorded as follows: A straight line is drawn along the initial almost straight portion of the FES and the FEV_A is then recorded as the point where the curve of the FES commences to deviate from the initial straightness (Fig. 1).

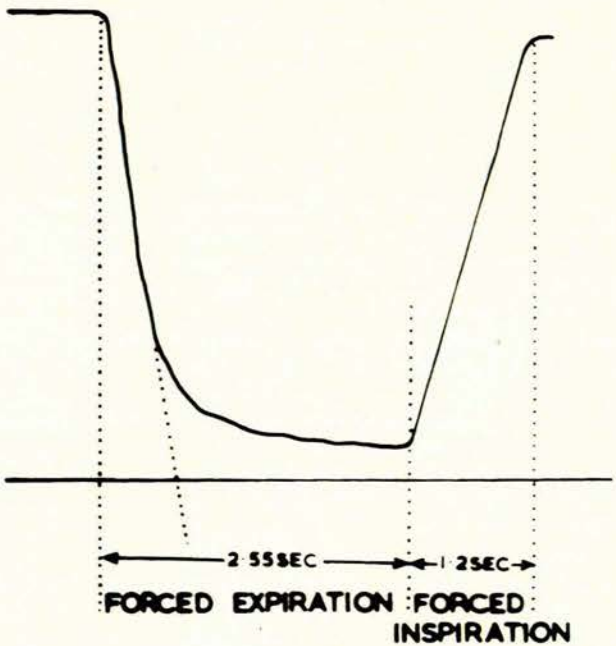

Fig. 1. The normal forced expiratory spirogram. Female, aged 13 years 3 months, 'normal'. Weight 94 lb.; height 61 inches; sitting height 31¼ inches. $FEV_{.25\ sec.}=1\cdot50$ litres. $FEV_{.75\ sec.}=2\cdot65$ $FEV_{.25-.75\ sec.}=1\cdot15$. $FEV_{1\ sec.}=2\cdot05$. $FEV_A=2\cdot1$. $FVC=2\cdot9$.

MATERIAL AND METHOD

One hundred and twenty-two normal boys and 55 normal girls were studied. The criteria for 'normality' and the method of conducting the test have been discussed in a previous paper.[1] For each child 4–6 recordings were made in a standing position with the low resistance spirometer.[3] The forced

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expiratory spirograms were measured and the $FEV_{.25-.75}$, FEV_A, $FEV_{.75}$, the FEV_1 and FVC of the spirogram with the largest $FEV_{.75}$ were recorded in each instance. This spirogram was taken as representing the best effort of the child.

The $FEV_{.25-.75}$, $FEV_{.75}$ and FVC were recorded in the 122 boys and 55 girls. In 10 of the younger children (6 boys and 4 girls) the FVC was expired under 1 second and the FEV_1 was therefore recorded in 116 boys and 51 girls.

RESULTS

Anthropometric and Spirometric Measurements

The spirometric data ($FEV_{.25-.75}$, FEV_A and FEV_1) and the standing and sitting heights of the children studied were statistically analysed by regression and correlation analyses. Correlation coefficients (r) were calculated and the standard deviation (SD) determined by calculating the standard error of the estimate (σ_z). The results are given in Table I and the relationship between the standing height and the $FEV_{.25-.75}$, FEV_A and FEV_1 for girls and boys respectively is shown in Figs. 2–4.

The spirometric value which might be expected in a normal child and the limits within which 95% of all normal cases should fall for standing height or sitting height can be predicted from the formula:

$$\text{Spirometric Volume in Litres} = a + b \text{ Anthropometric measurement} \pm 2\sigma_z$$

Although the subject of a previous communication,[1] the results of the statistical analyses for the $FEV_{.75}$ and FVC and standing height and sitting height are given with those for the $FEV_{.25-.75}$, FEV_A and FEV, to facilitate the reconstruction of the predicted 'normal' FES for any given child in Table I.

Differences in the Sexes

Values for the $FEV_{.25-.75}$, FEV_A, FEV_1 and FVC calculated for a girl and boy of standing height of 57 inches from the prediction formula are given in Table II.

These results show values for boys to be slightly higher than those for girls of the same height. These differences are probably not of practical clinical significance except for the FVC values. In the latter case, the employment of separate prediction formulae for the two sexes is probably jus,tified. These findings are in agreement with those of Strang,[4] who also found little or no difference in the FEV_1 for girls and boys, but found the FVC in boys to be consistently larger than in girls.

Comparison with Other Series

It is difficult to compare the values obtained for the different spirometric measurements in the group of children in this series with results obtained by other investigators. This is mainly because of the different criteria for the selection of cases and differences in the spirometric systems used. This latter difficulty can be partly overcome by only comparing the present results with those series[4, 5] in which a spirometer similar to the one employed in the present investigations was used.

A further difficulty, however, is the difference in the selection of the particular spirogram to be measured from the 4 - 6 normally recorded. The spirogram chosen should represent the best effort on the part of the child. In the present series this was taken to be the spirogram with the largest $FEV_{.75}$. This was done for the following reasons: (i) because the measurement of the FEV is a test for dynamic lung function and measurement of the FEV gives a better indication of the degree of airway obstruction, e.g. in asthma, than measurement of the FVC, and (ii) the $FEV_{.75}$ is measured because the forcible expiration recorded as the FES may be completed in less than one second in smaller children. Strang[4] measured the mean value for the FEV_1 and FVC out of four readings. In Table III the results of Strang[4] and Bjure[5] for the FEV_1 and FVC are compared with those obtained in the present series. No literature on the $FEV_{.25-.75}$, FEV_A and $FEV_{.75}$ measured with a Bernstein spirometer in children, is available for purposes of comparison.

The spirometric values in the present series were not corrected to BTPS. According to Ferris and Smith[7] such a correction on the average increases volumes by 7–9%. If this correction is carried out, the values of the FEV_1 and FVC approximate the results of Strang.[4] If the values of Bjure[5] are corrected to BTPS, higher values are obtained for both

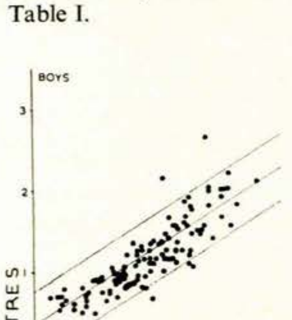

Fig. 2

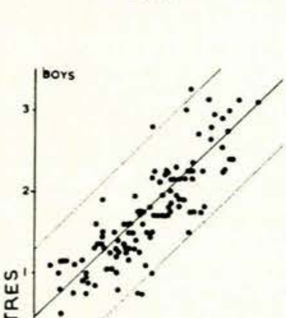

Fig. 3

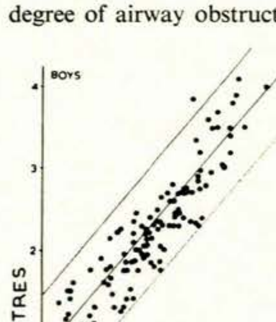

Fig. 4

Fig. 2. The relationship between the standing height and $FEV_{.25-.75}$ in boys and girls. *Fig. 3.* The relationship between the standing height and FEV_A in boys and girls. *Fig. 4.* The relationship between the standing height and the FEV_1.

the FEV_1 and FVC than for those of the present series and of Strang.[4]

Forced Expiratory Spirograms

The spirograms recorded were found in general to be remarkably uniform in shape and almost specific for any particular occasion for a given individual. The curves of the spirograms were characterized by two different phases. The first phase of expiration was invariably recorded as an almost straight line, but as the speed of expiration lessened, the tracing curved from this initial straightness and became horizontal on the completion of the forced expiration (Fig. 1). The curve was always smooth, concave upwards, and any undulations could be traced to varying efforts during expiration such as coughing or attempts to obtain additional air by a quick short inspiration. The angle at which the second phase began (Fig. 1, FEV_A) was, in the majority of cases, sharply defined, but sometimes the change from the straight lines was so gradual that an accurate measurement of this point was difficult. For practical purposes, however, this point could always be determined within reasonable limits ($\pm$ 50 ml.).

TABLE III. COMPARISON OF THE FEV_1 AND FVC

Series	Predicted value in litres	SD	Values corrected to BTPS
Heese (1961)			
51 girls	FEV_1 = 2·113	0·326	No
116 boys	FEV_1 = 2·216	0·321	No
Present Series			
55 girls	FVC = 2·310	0·345	No
122 boys	FVC = 2·526	0·439	No
Strang (1959)			
209 girls	FEV_1 = 2·36	0·17	Yes
209 boys	FVC = 2·73	0·32	Yes
Bjure (1963)			
82 girls	FEV_1 = 2·303	0·30	No
	FVC = 2·626	0·35	No
79 boys	FEV_1 = 2·373	0·29	No
	FVC = 2·774	0·37	No

The times taken for the completion of the FES[1] and ranges, were:

Children under 9 years = 1·5 sec. (0·6–2·6 sec.).
,, 9–12 years = 1·7 sec. (1·1–2·7 sec.).
,, over 12 years = 1·9 sec. (1·1–2·6 sec.).

TABLE I. STATISTICAL TABLE

Girls		Standing height	Sitting height
$FEV_{.25-.75}$	a	—1·677	—1·787
	b	0·048	0·094
(55 subjects)	σ_z	0·214	0·203
	r	0·754	0·783
FEV_A	a	—2·188	—2·139
	b	0·065	0·121
(55 subjects)	σ_z	0·312	0·316
	r	0·731	0·724
$FEV_{.75}$	a	—2·470	—2·702
	b	0·077	0·152
(55 subjects)	σ_z	0·308	0·316
	r	0·809	0·797
FEV_1	a	—2·943	—2·830
	b	0·089	0·164
(51 subjects)	σ_z	0·326	0·340
	r	0·812	0·795
FVC	a	—3·219	—3·438
	b	0·097	0·189
(55 subjects)	σ_z	0·345	0·341
	r	0·839	0·843
Boys			
$FEV_{.25-.75}$	a	—2·384	—3·070
	b	0·062	0·139
(122 subjects)	σ_z	0·211	0·205
	r	0·862	0·858
FEV_A	a	—3·457	—4·554
	b	0·090	0·205
(122 subjects)	σ_z	0·344	0·362
	r	0·833	0·813
$FEV_{.75}$	a	—3·140	—3·706
	b	0·089	0·188
(122 subjects)	σ_z	0·325	0·365
	r	0·860	0·819
FEV_1	a	—4·276	—5·425
	b	0·114	0·255
(116 subjects)	σ_z	0·321	0·426
	r	0·902	0·827
FVC	a	—4·770	—4·937
	b	0·128	0·249
(122 subjects)	σ_z	0·439	0·577
	r	0·873	0·767

TABLE II. DIFFERENCE IN SEXES

Spirometric value in litres	Girl	Boy
$FEV_{.25-.75}$	1·042	1·151
FEV_A	1·528	1·662
$FEV_{.75}$	1·919	1·933
FEV_1	2·113	2·216
FVC	2·310	2·526

DISCUSSION

The spirometer of Bernstein, D'Silva and Mendel[3] employed in the present investigation, has become the instrument of choice for the spirometric measurement of ventilatory function, because of its low flow resistance and the small distortion of the recorded curves on the fast-moving kymograph. Where this type of spirometer is employed, the establishment of prediction formulae for the expected 'normal' spirometric measurements for any given child has therefore become important.

The agreement of the present findings for the FEV_1 and FVC with those of Strang,[4] indicates that the values presented in this communication for the $FEV_{.25-.75}$, FEV_A, $FEV_{.75}$, FEV_1 and FVC can be taken to represent the expected 'normal' for children belonging to all sections of the community. The predicted 'normal' FES for any child can therefore be reconstructed and be compared with the FES obtained for the particular child.

The severity of the airway obstruction and the objective assessment of the action of bronchodilator drugs in a child with asthma, can be determined by the measurement of the $FEV_{.75}$[8-11] or the FEV_1. Leuallen and Fowler[12] came to the conclusion that in adult patients with chronic bronchitis and emphysema the expiratory retardation was found to be more pronounced during the mid-part of a forcible expiration. Measurement of the $FEV_{.25-.75}$ or FEV_A in asthmatic patients and a comparison with normal predicted values may well prove to be a more sensitive index of obstruction to airflow than the $FEV_{\cdot 75}$ or FEV_1.

The shape of the pattern of expiratory flow as recorded by a spirometer has been variously described. The FES has been described as a straight line followed by a curve, the two parts being demarcated by a critical point.[13-15] Bernstein, who used a spirometer similar to ours, found the record to be a smooth curve, concave upwards. A straight line on a spirometric record implies that the rate of flow is constant, but Leuallen and Fowler[12] showed with pneumotachographs of normal people that the rate of flow is not constant and they demonstrated the presence of large accelerations of airflow during the initial period of forced expiration. In all the spirograms studied in the present series, the spirogram could be separated into two distinct phases by following the procedure described for the measurement of the FEV_A. No pneumotachographic studies were carried out, but it is suggested that measurement of the FEV_A, because of its high correlation with standing height ($r = 0 \cdot 833$ in boys and $r = 0 \cdot 731$ in girls), may well prove to be a useful index of normality in the reconstruction of the predicted FES of a given patient.

SUMMARY

Spirometric investigations, employing a Bernstein spirometer, were carried out on 122 normal boys and 55 normal girls. Forced expiratory spirograms were recorded and their characteristics were investigated.

The spirograms recorded were found to be remarkably uniform in shape and almost specific for any particular occasion in a given individual. The first phase of expiration was always recorded by the spirometer as an almost straight line, but as the speed of expiration lessened, the curve deviated more and more. The angle at which the second phase began was designated as FEV_A.

The $FEV_{\cdot 25-\cdot 75}$ and FEV_A were measured in 122 boys and 55 girls, and the FEV_1 in 116 boys and 51 girls. These values were statistically analysed and correlated with standing and sitting height.

Prediction formulae were calculated using the single anthropometric index of standing or sitting height for the prediction of the $FEV_{\cdot 25-\cdot 75}$, FEV_A and FEV_1. Prediction formulae for the $FEV_{\cdot 75}$ and FVC calculated from the same spirograms measured in the present series[1] have also been given so as to facilitate the reconstruction of the predicted 'normal' FES for any given child.

It is suggested that in a child suffering from asthma, measurement of the $FEV_{\cdot 25-\cdot 75}$, FEV_A and a reconstruction of the 'normal' predicted FES for the given child, may prove to be more useful indices than the measurement of the $FEV_{\cdot 75}$ or FEV_1 in the assessment of the severity of the obstruction to airflow or the response to bronchodilator drugs or steroids.

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