A STUDY OF RESPIRATORY FUNCTION IN NORMAL SCHOOL CHILDREN

THE PEAK FLOW RATE

BY

JEAN R. NAIRN, A. J. BENNET, J. D. ANDREW and P. MACARTHUR

From the Paediatric Department, Raigmore Hospital, Inverness

(RECEIVED FOR PUBLICATION OCTOBER 4, 1960)

A simple, but reliable, method of measuring the ventilatory function of the lungs has long been sought. With increasing experience of spirometry in clinical medicine it was realized that the measurement of vital capacity is of limited value because the rate of movement of air in and out of the lungs is not taken into account in this test. In 1933, Hermannsen devised the test of maximum breathing capacity (M.B.C.), which does measure this dynamic factor and which, as recently as 1953 (Kennedy) has been considered the best single index of ventilatory function. Unfortunately, it is time consuming, fatiguing for both patient and observer, and is unsuitable for use with seriously ill patients or young children. Several workers have devised tests based on the rate at which air can be forcibly exhaled, usually by measuring, with a spirometer, the volume breathed out during a timed interval of a forced expiration (Roche and Thivollet, 1949; Tiffeneau, Bousser and Drutel, 1949; Kennedy, 1953). These have become standardized as the forced expiratory volume for a stated interval, usually one second (F.E.V._{1.0}). This measurement of the rate of respiratory air flow is accepted as a test of respiratory function particularly useful in the study of obstructive airway disease, and gives consistent results in individuals (Strang, 1959; Miller, Johnson and Wu, 1959), and a fairly close correlation with clinical grades of exercise tolerance due to obstructive airway disease (Capel and Smart, 1959). While many instruments are available for measuring the rate of expiratory flow, their size and complexity render them more suitable for use in the laboratory than at the bedside, consulting room or clinic. The anxiety caused in children and even adults by the bulk and appearance of most spirometers, and by the use of nose clips, increases considerably the time required to carry out the test and adds yet another variable to the factors influencing the result.

When the peak flow meter (Wright and McKerrow,

1959), designed for the Pneumoconiosis Unit of the Medical Research Council, became available, it was welcomed by us as a simple instrument, measuring an aspect of ventilatory function similar to that estimated by the F.E.V., and likely to prove of assistance in the assessment of patients, particularly children with obstructive respiratory disorders. In use in the ward, out-patient clinic and school, we have found this instrument robust, portable and easy to use. As with all such instruments, the patient's full co-operation is essential and has been obtained without difficulty from normal children aged 5 years and over. As part of our study it was necessary to establish the peak flow in normal children. It has been shown (Strang, 1959, 1960; Needham, Rogan and McDonald, 1954) that the ventilatory function of normal children varies with age and stature. The peak flow rate (P.F.R.) is here correlated with age and various anthropometric parameters; the effects of exercise and of sex are considered; a chart has been constructed from which we can predict the range of P.F.R. in normal children of known height.

Material

Subjects were obtained by random selection from the records of two secondary schools and three primary schools in Inverness, a non-industrial town with approximately 30,000 inhabitants. Any child whose school medical report noted significant disease or abnormality was excluded. The sample comprises 421 children between the ages of 6 and 18 years, and is considered to constitute a representative cross-section of normal school-children in this area. Permission for testing was obtained from the parents of each child and the few refusals and absentees were replaced by children from a reserve list.

Method

Testing was carried out in the medical room of each school. Each child was weighed and the height measured, without shoes but with normal

light clothing. The surface area in each case was calculated by means of a Dubois nomogram using the directly measured height and weight readings. The object of the test was explained simply and the method of blowing the flow meter was demonstrated to the children in groups of six. Each subject then held the instrument and had several trial blows, under close supervision, until it was clear that he was using the meter properly and comfortably; this usually required two to four blows. Six successive readings of the peak flow were then recorded, excluding only the occasional faulty attempt when the subject coughed or failed to close the lips around the mouthpiece. A separate mouthpiece was used for each individual in the group. Exhortation, encouragement and small prizes were used to ensure enthusiasm, competition, maximum expiratory effort and proper recording.

Following this initial test, each child ran rapidly a distance of approximately 150 yards and, immediately on return, while still panting, recorded another six readings on the meter.

Results

Consistency of Individual Readings. From the set of six readings of peak flow rate taken from each

child the average of the three maximum readings and the absolute maximum reading were compared and the difference did not exceed 5% in 96.4% of boys and 95% of girls. It was therefore considered justifiable to use the absolute maximum peak flow rate reading in each subject for the purposes of calculation and correlation.

Interrelation between Peak Flow Rate and Anthropometric Measurements. Scatter diagrams of peak flow rates in relation to height, surface area and weight are shown in Figs. 1, 2 and 3 respectively. By calculation the correlation coefficient for height and peak flow rate (r_h) = 0.930. Similarly, the correlation coefficient for surface area and peak flow rate (r_a) = 0.769. As r_a is derived from measurements of height and weight and shows inferior correlation to that of height alone, the correlation coefficient for weight need not be considered. The superiority of the correlation coefficient for height is confirmed by simple inspection of the scatter diagrams in Figs. 1, 2 and 3.

A regression or estimating equation has been employed to compare the peak flow rate firstly with height and again with surface area. In each case the sexes are considered separately and to-

FIG. 1.—Scatter diagram showing peak flow rates in relation to height.

FIG. 2.—Scatter diagram showing peak flow rates in relation to surface area.

gether, giving three equations for each anthropometric measurement. The standard error of estimate which measures the scatter index is $\pm 13.4\%$ for height and $\pm 14.4\%$ for surface area. By means of the estimating equation and the standard error of estimate for the height values a range of normal values has been prepared in Fig. 4. This chart is based on the boys' equation. Height values were chosen in preference to surface area values as they show a lower scatter index, a higher correlation coefficient and height is easier to measure in everyday clinical work. In Fig. 4 the centre line represents the mean trend and is based on the regression equation. The scatter is depicted by the two lines on each side of the mean trend line and includes 70% of normal children within the limits of the lines marked A and 95% of normal children within the lines marked B. An estimation of the peak flow rate can be read from Fig. 4 for any desired height in children within the limits of the height of the young people investigated. The expected peak flow rate of children of known height or surface area can also be found by calculation from the regression equation $y = a + bx$, where

y = estimated or computed peak flow rate in litres per minute, x = anthropometric measurement in inches or square metres, and a and b are constants which vary in accordance with the anthropometric measurement and whether boys, girls or adults are under consideration. The constants a and b are shown in the Table.

Sex Difference in Peak Flow Rate. Fig. 5 shows the mean trend lines based on the regression equation according to height for boys and girls. This test reveals no significant difference between the sexes.

Exercise Difference in Peak Flow Rate. Figs. 6 and 7 show the difference in peak flow rate before and after exercise of girls and boys respectively. These diagrams are based on the means of 12 height groups and not on a regression equation. A test of significance was applied to this increase in peak flow rate and it was found to be highly significant (i.e. $p = < 0.01$) in children up to 55.5 in. in height, significant (i.e. $p = < 0.05$ but > 0.01) in children between 55.5 in. and 61.5 in. in height, but not definitely significant in children above that height.

FIG. 3.—Scatter diagram showing peak flow rates in relation to weight.

Age and Peak Flow Rate. Fig. 8 shows the peak flow rate in boys and girls in age groupings. The points in the lines in the Table represent means in each group. There was a wide variation in height and weight within age groups, particularly in the boys aged 11-13 years, and this is a possible explanation for the lag in the curve at these ages.

Discussion

Using the peak flow meter in normal adults, Lockhart, Smith, Mair and Wilson (1960) found satisfactory consistency in the readings from each individual, with a variation of 6% during one period of testing compared with a variation of 11.5% in estimating F.E.V._{0.75}. Strang (1959) estimating

FIG. 4.—Range of normal values; peak flow rate in relation to height.

FIG. 5.—Regression lines of peak flow rates in relation to height in both sexes.

FIG. 6.—Peak flow rates in girls in relation to height before and after exercise.

spirometrically the F.E.V._{1.0} in children, based his results on the three maximum readings from each subject and found that 95% of the readings were within 3.8% of the individual means. Wright and McKerrow (1959), using the peak flow meter, also averaged each individual's three maximum results. As we are recording maximum rate of flow we feel it is more logical to base our calculations on the highest of the individual's six efforts. The concordance of our results is such that, had we used the mean of the top three, there would have been little difference in our conclusions as, in 95% of all children tested, and in 100% of those over 11 years old, these means were within 5% of the peak value.

Analysis of the results shows a positive correlation of P.F.R. with height, weight, surface area and age. The P.F.R. correlates most closely with height and surface area and much less closely with weight. There is considerable variation in height in each age group so it is not surprising that the correlation of P.F.R. with age is much less close. Even when the effect of individual variation is diminished by considering the mean P.F.R. for each age group, the resultant diagram, Fig. 8, demonstrates that the increase of P.F.R. with age is somewhat irregular and varies in the two sexes, the difference being striking after the age of 14 years and similar to that noted by Strang (1959) in his study of F.E.V._{1.0}. The

FIG. 7.—Peak flow rates in boys in relation to height before and after exercise.

FIG. 8.—Mean peak flow rate in relation to age group.

apparent fall in P.F.R. in 11-year-old boys is possibly associated with the extreme variation of height among our subjects in this particular age group and may not be a true reflection of the population at this age. As height is the parameter which correlates most closely with the P.F.R., the relationship between these two factors is further established for each sex by the drawing of regression lines (Fig. 5) which show that, for practical purposes, the sexes may be considered together. We are thus able to draw a chart (Fig. 4) showing the mean

TABLE

	Height Groupings			Surface Area Groupings		
	Girls	Boys	Persons	Girls	Boys	Persons
a	-441.24	-476.24	-460.286	-52.635	-62.376	-57.895
b	+13.527	+14.203	+13.893	+307.363	+323.81	+315.8

trend line for normal school-children, and the range into which fall 70% of normal children ($\pm$ standard error) and 95% of normal children ($\pm$ twice the standard error). Correlation of P.F.R. with the logarithm of height is even closer ($r = 0.935$), but the difference is exceedingly small and does not, in practice, justify the extra calculation involved in what is intended to be a useful clinical index.

That the better performance of the older boys than of girls of the same age (Fig. 8) was not solely due to the boys' greater increase in height in adolescence, was demonstrated by dividing the children into four groups by height with equal weighting for the two sexes and comparing the performance of boys with girls in each group. The difference was not significant in the shortest, of moderate significance in the second group and of higher significance in the two tallest groups. It is probable that the variation between older boys and girls is associated with the onset of puberty and the different rate and manner in which the sexes reach physical maturity. No inquiry was made as to the onset of puberty in our subjects and further study will be required to clarify this point.

It has been claimed by Capel and Smart (1959) that normal adults show no change in the F.E.V. after exercise, although adults with obstructive airway disease show significant improvement. In this study, improvement in the P.F.R. occurred in every group after exercise (Figs. 6 and 7). That this improvement does not result from practice has been demonstrated by retesting a proportion of subjects after a lapse of several hours. When the effect of exercise is considered in the four height groupings already mentioned, it is found to be highly significant in the two smallest groups, of less significance in the third group, and not statistically significant in the tallest group. It is indeed apparent from the Figs. 6 and 7, and surprising to us, that the increase in P.F.R. after exercise has about the same absolute value (15 to 25 litres per minute) in all groups of children irrespective of their size. The increase is therefore relatively much larger in small children with low P.F.R.'s than in big children with big P.F.R.'s and, if the same findings continue into adult life, our results would confirm Capel and Smart's (1959) claim that normal adults, when the P.F.R. is greater still, show no significant change in F.E.V. after exercise. We can offer no explanation

for this apparent effect of exercise upon the P.F.R. in normal children, but believe that it is important to take it into account when analysing the effect of therapeutic measures in obstructive airway disease.

Summary

Experience in the use of the peak flow meter of Wright and McKerrow is described.

Peak flow rates were estimated in 421 normal boys and girls and a chart was constructed from which the peak flow rate could be predicted from the child's height. The range of values found in normal children was included in this chart.

The effect of sex and exercise upon the peak flow rate in normal children was studied and the results discussed.

We wish to acknowledge our indebtedness to Dr. W. D. Wilson, Medical Officer of Health of Inverness, and his staff for a great deal of assistance in organizing our visits to the schools. We are also very grateful to Dr. J. A. MacLean, Director of Education for Inverness, and to the Headmasters and School Nurses of the schools where we studied pupils, for their assistance throughout our tests.

Dr. D. G. MacKay, Medical Statistician to the Northern Regional Hospital Board, gave generously of his time and advice in the statistical treatment of our results and we thank him for his very valuable help.

REFERENCES

- Capel, L. H. and Smart, J. (1959). The forced expiratory volume after exercise, forced inspiration and the valsalva and Müller manoeuvres. *Thorax*, **14**, 161.
- Hermannsen, J. (1933). Untersuchungen über die maximale Ventilationsgrösse (Atemgrenzwert). *Z. ges. exp. Med.*, **90**, 130, (cited by Kennedy, M. C. S., 1953).
- Kennedy, M. C. S. (1953). A practical measure of the maximum ventilatory capacity in health and disease. *Thorax*, **8**, 73.
- Lockhart, W., Smith, D. H., Mair, A. and Wilson, W. A. (1960). Practical experience with the peak flow meter. *Brit. med. J.*, **1**, 37.
- Miller, W. F., Johnson, R. L., Jr. and Wu, N. (1959). Relationships between fast vital capacity and various timed expiratory capacities. *J. appl. Physiol.*, **14**, 157.
- Needham, C. D., Rogan, M. C. and McDonald, I. (1954). Normal standards for lung volumes, intrapulmonary gas-mixing and maximum breathing capacity. *Thorax*, **9**, 313.
- Roche, L. and Thivolle, J. (1949). Exploration fonctionnelle du poumon dans l'expertise de la silicose. *Arch. Mal. prof.*, **10**, 448.
- Strang, L. B. (1959). The ventilatory capacity of normal children. *Thorax*, **14**, 305.
- (1960). Eosinophilia in children with asthma and bronchiectasis. *Brit. med. J.*, **1**, 167.
- Tiffeneau, R., Bousser, J. and Drutel, P. (1949). Capacité vitale et capacité pulmonaire utilisable à l'effort. Critères statique et dynamique de la ventilation pulmonaire. *Paris méd.*, **137**, 543.
- Wright, B. M. and McKerrow, C. B. (1959). Maximum forced expiratory flow rate as a measure of ventilatory capacity, with a description of a new portable instrument for measuring it. *Brit. med. J.*, **2**, 1041.