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MEASUREMENT OF PULMONARY VENTILATORY FUNCTION IN NORMAL CHILDREN. I. SPIROMETRY -The Shimane Heart Study-

(spirometry/electronic spirometer/normal children)

Nobuo IZUMI, Toshikazu NISHIO, Kei SUZUKI, Akio NAKAMURA, Masakazu SAITO, Noriyuki HANEDA, Yasuhisa KAJINO, and Chuzo MORI

Department of Pediatrics, Shimane Medical University, Izumo 693, Japan

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The normal values of pulmonary ventilatory function were obtained using a computerized hot-wire spirometer in 516 healthy children aged 6, 9 and 12 years. Forced vital capacity(FVC), forced expiratory volume in one second(FEV_1) and FEV_1/FVC ratio were analyzed. Regression equations of FVC and FEV_1 against height could be separated at 140 cm. They were as follows: lower than 140 cm; $FVC=0.0397\underline{X}-3.301$ and $FEV_1=0.0327\underline{X}-2.613$ for boys, $FVC=0.0325\underline{X}-2.538$ and $FEV_1=0.0290\underline{X}-2.240$ for girls; higher than 140 cm; $FVC=0.0556\underline{X}-5.511$ and $FEV_1=0.0469\underline{X}-4.561$ for boys, $FVC=0.0538\underline{X}-5.358$ and $FEV_1=0.0448\underline{X}-4.299$ for girls, where FVC and FEV_1 are in liters and $\underline{X}$ is height(cm). The mean values of the FEV_1/FVC ratio of children aged 6, 9 and 12 years were 91.2%, 88.5% and 87.6% in boys and 90.6%, 89.1% and 89.5% in girls, respectively.

INTRODUCTION

During the past ten years, the interest in pulmonary diseases and the need for pulmonary function tests have markedly increased in the pediatric field (1). And during this same period of time, the conventional water or bellows spirometer has been replaced by the electronic spirometer, one of the modern pieces of equipment for pulmonary testing. Early in this period, it was believed that electronic spirometers were less accurate and reliable than the classic ones (2, 3). However, there are also many reports asserting the good clinical applicability of the electronic spirometer in the case of adults (4-6). The purpose of our study is to obtain normal values of pulmonary ventilatory function and to compare the results with those of previous reports obtained by the conventional method.

Table I. NUMBER OF SUBJECTS BY AGE AND SEX

Age (yrs)	Boys	Girls
6	74	48
9	52	63
12	144	135
Total	270	246
	516	

MATERIALS AND METHODS

Study population

A total of 617 children (317 boys and 304 girls) aged 6, 9 and 12 years were examined. They belong to a primary school and a junior high school in Izumo City, Shimane Prefecture. Their parents were asked to answer the questionnaire about the history of heart disease, asthma and other chronic lung disease in their children. Children with any such history, and children with current respiratory infection were eliminated from the study population. In addition, the children who could not perform the forced expiratory maneuver adequately were also eliminated after checking of the record of flow volume curve and the reproducibility of FVC and FEV_1. The number of children from whom reliable data were obtained was 516(270 boys and 246 girls) as shown in Table I.

Equipment

The pulmonary function data were obtained with a hot-wire spirometer(Autospirometer AS-2000 of Minato Medical Science Co. Ltd.). The flow volume curves were monitored with an oscilloscope(Monitorosillo AS-20M, Minato). A portable two-liter precision calibration pump was used for periodic checking of the spirometer.

Procedure

Following instructions for forced expiratory maneuver, the children were obliged to make maximum exhalations into the transducer in standing position wearing a nose clip. The maneuver was repeated three to five times according to the reproducibility of the flow volume curve monitored on oscilloscope and the FVC values printed on paper.

Analysis

Data obtained by the maximum FVC maneuver were used for analysis. When the flow volume curve was interrupted in the terminal portion of its descending line, the datum was adopted after correction.

Regression equations were calculated by the method of least squares.

Table II. CORRELATION COEFFICIENTS BETWEEN ANTHROPOMETRIC MEASUREMENTS AND FVC AND FEV_1

	Height	Weight	BSA*	Chest Circumference
Boys				
FVC	0.932	0.906	0.936	0.853
FEV_1	0.925	0.886	0.922	0.832
Girls				
FVC	0.927	0.892	0.924	0.879
FEV_1	0.925	0.889	0.922	0.871

*BSA was caluculated using the formula of Dubois.

RESULTS

Table II shows correlation coefficients between the various anthropometric measurements and FVC or FEV_1. Although height and body surface area(BSA) are almost equally reliable parameters, the former was assumed to be somewhat better.

FVC and FEV_1 are plotted against height in both sexes as shown in Figs.1 and 2. The regression equations corresponding to the height of all children tested were as follows, FVC; boys $\underline{Y}=0.0459\underline{X}-4.060$, girls $\underline{Y}=0.0447\underline{X}-4.012$, FEV_1; boys $\underline{Y}=0.0389\underline{X}-3.362$, girls $\underline{Y}=0.0390\underline{X}-3.455$, where $\underline{Y}$ is FVC or FEV_1(both in liters) and $\underline{X}$ is height(cm). The regression lines are shown in Figs.1 and 2 with dotted lines.

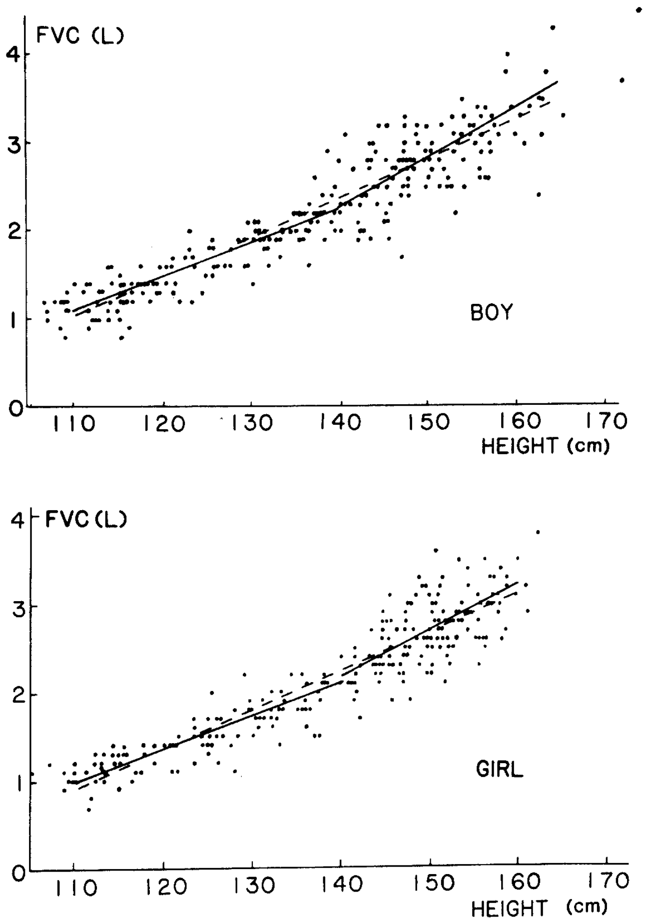

Fig.1. Relationship between FVC and height in each sex. Each value is plotted against height. Two separate regression lines, the breaking point of which is at about 140 cm, are presented with solid line. The dotted line shows the regression equation corresponding to all children examined.

As observed in Figs.1 and 2, the relationship between ventilatory function and height seemed to be curvelinear. There were, at least, two separate regression lines against height, the breaking point of which was at about 140 cm. Therefore, the subjects were separated by height into two groups and the regression equations were calculated in each group considering the continuation of the line(Table III). These regression lines for each group are shown in Figs.1 and 2 with solid lines. The lines against higher height are steeper than those against lower, especially in boys.

These regression equations indicate that FVC in girls is 6.9%, 10.2% and 4.0% lower than that in boys at 120 cm, 135 cm

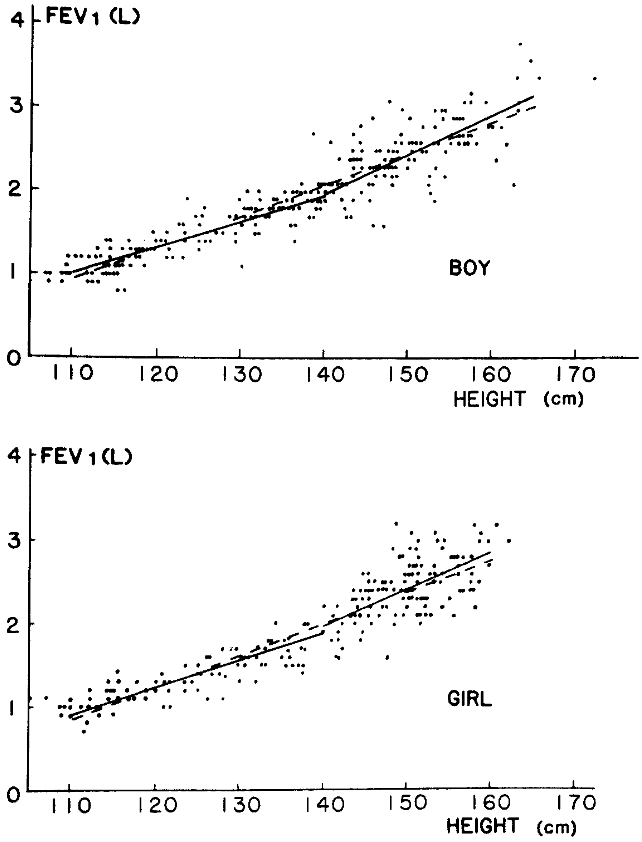

Fig.2. Relationship between FEV_1 and height in each sex.

Table III. REGRESSION EQUATIONS FOR FVC AND FEV_1

Boys	Height	107≦ ≦140 n=146	(r)	140< ≦174 n=124	(r)
	FVC	Y=0.0397X-3.301	(0.902),	Y=0.0556X-5.511	(0.738)
	FEV_1	Y=0.0327X-2.613	(0.894),	Y=0.0469X-4.561	(0.715)
Girls	Height	105≦ ≦140 n=112	(r)	140< ≦162 n=134	(r)
	FVC	Y=0.0325X-2.538	(0.856),	Y=0.0538X-5.358	(0.667)
	FEV_1	Y=0.0290X-2.240	(0.856),	Y=0.0448X-4.299	(0.638)

FVC and FEV_1 (Y) in liters and height (X) in centimeters
r; correlation coefficients

and 160 cm height, respectively. FEV_1 in girls is 5.4%, 7.0% and 2.5% lower than that in boys at 120 cm, 135 cm and 160 cm height, respectively. The relatively more rapid increase of FEV_1 in girls as compared with boys observed in the higher height range is also seen in Table IV which shows the mean and standard deviation of FVC and FEV_1 by age and sex.

Table IV. NORMAL VALUES OF FVC AND FEV_1 BY AGE AND SEX (MEAN±SD)

Age (yrs)	Boys	Girls
FVC		
6	1.29±0.25	1.17±0.17
9	1.96±0.35	1.72±0.26
12	2.76±0.54	2.72±0.40
FEV_1		
6	1.17±0.21	1.06±0.16
9	1.74±0.31	1.55±0.21
12	2.41±0.47	2.42±0.34 (L)

Table V. NORMAL VALUES OF THE FEV_1/FVC RATIO BY AGE AND SEX (MEAN±SD)

Age (yrs)	Boys	Girls
6	91.2±4.1	90.6±4.8
9	88.5±3.9	89.1±8.5
12	87.6±5.4	89.5±4.9
Total	88.8±5.0	89.6±6.0

Table VI. DISTRIBUTION OF THE FEV_1/FVC RATIO BY AGE AND SEX

FEV_1/FVC (%)	Age	≦75	~≦80	~≦85	~≦90	~≦95	95<
Boys	6	0	1(1.4)	8(10.8)	18(24.3)	39(52.9)	8(10.8)
	9	0	2(3.8)	6(11.5)	23(44.2)	19(36.5)	1(1.9)
	12	2(1.4)	16(11.1)	28(19.4)	53(36.8)	39(27.1)	6(4.2)
Girls	6	0	1(2.1)	8(16.7)	12(25.0)	19(39.6)	8(16.7)
	9	0	2(3.1)	10(15.9)	19(30.1)	24(38.1)	8(12.7)
	12	0	8(5.9)	21(15.6)	43(31.9)	52(38.5)	11(8.1)

( ); percentage for each age and sex

Table V shows the mean and standard deviation of the FEV_1/FVC ratio by age and sex. Although the mean values are relatively stable regardless of age and sex, it is somewhat larger in girls than in boys and it seems to have a downward trend with aging. This tendency becomes more apparent in Table VI which shows the distribution of the FEV_1/FVC ratio by age and sex.

DISCUSSION

Through recent advances in electronics, the computerized spirometer has been introduced into pulmonary function testing, and it has been widely used in place of conventional methods

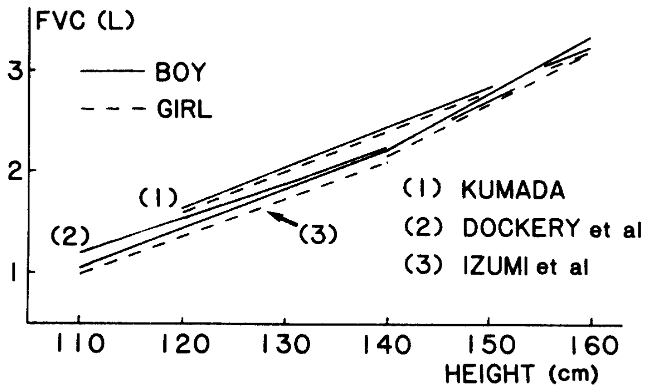

Fig.3. Comparison of FVC regression lines or fifty percentile curve between the present study and those of other authors.

because of its advantages, such as digital display, simple operation, immediate delivery of data and so on (3). But it was pointed out that the electronic spirometer had different performance characterics from those of classical equipment (2).

In Japan, Yoshiya et al. and Yanai et al. (5, 6) measured FVC and FEV_1 in normal adults with a hot-wire spirometer exactly the same as ours and a Benedict Roth spirometer simultaneously. Both authors reported the good coincidence between the two methods and the excellent clinical applicability of the former instrument. The ranges measured by them were from approximately 0.5 to 5 liters which adequately comprised the range of childhood use.

In Fig.3, the regression lines of FVC obtained by us are compared with those by Kumada (7, 8) and the fifty percentile curve for white boys derived by Dockery et al. (9). In the former, measurements were performed using a Benedict Roth spirometer and the Kumada equations have been widely used for the examination of Japanese children. Dockery et al. measured numerous children between 6 and 11 years of age using a Stead Wells spirometer. Although regression lines calculated by us were fairly similar to Dockery's percentile curve, FVC of boys in our study were approximately 10 to 5% lower than those in Dockery's for heights between 110 and 125 cm. On the other hand, our data for FVC in boys were significantly higher than median FVC of black boys in Dockery's sudy. Similar findings were observed in girls and also in FEV_1. These differences might be due to the difference in race rather than equipment (9, 10).

Reviewing numerous pulmonary function studies in the pediatric field, Polgar and Weng (11) recommended the exponential function of height for prediction equations in children. Although it is apparent that the curvelinear expression is ideal, the linear equation is convenient for clinical use. However, it is apparent from Figs.1 and 2 that noticeable errors appear when only one regression equation is applied to all children of various ages. Dickman et al. (12) found in their study for children and adolescents that there were two separate regression lines breaking at 60 inches of height, and the line against the higher height had a much steeper slope. In their figure, the two regression lines had a great gap at the breaking point, and another less prominent break seemed to exist at about 55 inches in the line against the lower height. This point is assumed to correspond to our breaking point in Figs.1 and 2. And if two more separate regression lines were drawn between 42 and 60 inches in Dickman's diagram the observed gap would become small. Burrows et al. (13) attempted a biologically reasonable mathematical analysis of pulmonary function throughout the life. They found that height exponents were derived solely from data for boys and girls aged 6.0 to 11.999 years and, thereafter, effects of age were observed, that is, a rapid increase of FVC up to the age of 18 in boys and up to 16 in girls. Considering the above-mentioned results, it seems proper to provide two linear prediction equations for children and another equation for adolescents. Further examinations are needed for adolescents.

It is generally recognized that the FEV_1/FVC ratio has a downward trend as height or age increases. However, the correlation coefficients are quite low (9, 10, 13), and the use of a regression equation is not justified. Burrows et al. (13) temporarily provided prediction equations of the ratio as follows; male($<$ age 33 years) 90.128-0.2054·age, female ($<$ age 33 years) 91.761-0.1768·age. The ratios derived from these equations are 88.9%, 88.3% and 87.7% in boys and 90.7%, 90.2% and 89.6% in girls aged 6, 9 and 12 years, respectively. These are quite similar to our mean values in Table V. The FEV_1/FVC ratio is also said to correlate most closely with the FVC itself (9, 13). Dockery et al. (9) presented median ratio versus FVC level in diagram and found that, at small lung volumes, there was no difference between sexes (about 90% at 1.2L of FVC) and, for larger values of FVC, boys had a lower ratio than girls (about 83% and 87% at 3.5L of FVC for boys and girls, respectively). They did not report the normal range of the ratio. In Japan, although a ratio less than 85% is regarded as abnormal in children (7), normal range of ratio by age, height or FVC and sex has to be determined in future studies.

In our study, there were some subjects who had low FEV_1/FVC ratio, less than 80%(Table VI). They were healthy and had no history of chronic lung disease. The clinical meanings of the findings are left to be clarified in our next study.

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