Eur Respir J
1988, 1, 368–375

Respiratory muscle force and ventilatory function in adolescents

P.C. Schrader, Ph.H. Quanjer, I.C.W. Olievier*

Respiratory muscle force and ventilatory function in adolescents. P.C. Schrader, Ph.H. Quanjer, I.C.W. Olievier.
ABSTRACT: In 94 girls and 90 boys, aged 12.5–20.3 yr, the relationship of respiratory pressures or forces with lung volumes and ventilatory flows was studied. There was great variability in respiratory muscle performance, which helps to explain differences in lung volumes between individuals. Respiratory muscle force increases almost proportionally with thoracic dimensions, so that inspiratory and expiratory pressures generated at the level of residual volume (RV), functional residual capacity (FRC) and total lung capacity (TLC) are approximately constant with age. In the oldest boys there is evidence that the continued increase in lung volumes when they stop growing is due to a 'muscularity effect'. Boys generate larger pressures than girls at all lung volumes. Thus boys attain a larger TLC, and in spite of narrower airways, the same peak expiratory flow and a larger FIV_1/FVC ratio than girls. Effort independent flows (FEV_1 and MMEF), however, are larger in girls.
Eur Respir J. 1988, 1, 368–375.

* Physiology Department, University of Leiden, Leiden.

Correspondence: P.C. Schrader, Physiology Department, University of Leiden, P.O. Box 9604, 2300 RC Leiden, The Netherlands.

Keywords: Dysanapsis; expiratory pressure; inspiratory pressure; lung growth; lung volumes; muscle force; ventilatory flow.

Received: November 28, 1987; accepted after revision December 14, 1987.

A number of studies seem to indicate that respiratory muscle force plays a role in determining the level of different lung function indices in children and adolescents [1–3]. Schoenberg and co-workers [1] examined the relationship between body mass and ventilatory indices derived from the maximum expiratory flow-volume curve in a large cross-sectional study. They introduced the term 'muscularity-obesity effect' to describe the increase in ventilatory function which parallels the increase in body mass and the subsequent decline in lung function beyond an optimum weight. This was also described in 1846 by Hutchinson [4]. Seely and associates [5] performed a longitudinal study which showed that, in girls, both vital capacity and body mass continued to increase when growth in standing height had stopped. This may be an indication that ventilatory function increases because of an increase in muscle mass and hence in muscle force. The finding was reproduced in other studies [2, 6].

Recently the role of respiratory muscles was addressed more directly. Leech *et al.* [7] studied the relationship between maximum expiratory and inspiratory pressures in young adults who had reached adult height. Gaultier and Zinman [8] tried to quantify the force which respiratory muscles were capable of generating in children from 7 to 13 years of age. Both studies showed the role of the 'respiratory pump' in explaining differences in lung function between children and young adults. No such data are available for adolescents in the pubertal growth spurt; during this period differences in muscular development become apparent [9], resulting in differences in motor performance and physical strength. Cross-sectional studies, in which respiratory pressures were related to age, show conflicting results. Smyth and co-workers could not find any differences between adolescents and adults [10], whereas several others found an age-related trend during this period of life [11, 12]. Interindividual differences in lung function also increase during puberty [5, 13]. The factors which form the basis for these differences are not well documented, but differences in respiratory muscle strength may be relevant.

It is the purpose of the present study to describe the age-related changes in respiratory muscle strength during puberty, and to pay special attention to the differences between boys and girls. Furthermore, we have tried to assess the extent to which the differences between individuals in lung function, obtained from spirometry and residual volume measurements, can be accounted for by differences in the power of the 'respiratory pump'.

Materials and methods

Pupils were recruited from two urban secondary schools in Leiden, The Netherlands. In each school we selected one class at random from each consecutive year; all pupils had been invited to participate in the study. Of the 250 pupils thus selected we obtained informed consent from the parents of 190. The pupil's parents were asked to answer a mailed questionnaire on current and past respiratory symptoms, and on past and present respiratory illnesses in their children. We used the MRC questionnaire [14] as modified for children by Kerrebijn *et al.* [15]. The measurements took place at the schools in Spring 1983, between

9 a.m. and 4 p.m. Before the tests were performed the pupil's age and gender were recorded, and the pupils were asked about their smoking habits, sporting and daily physical activities. On the basis of this information the pupils were categorized into smoking and non-smoking groups, and into three groups on account of the time spent on sporting activities (0–2, 2–6 and 6 or more hours per week). Standing height and body mass were measured to the nearest centimetre and hectogram respectively.

The measurements reported in this study took 15–20 min for each pupil; hence all measurements could be performed in eight days. In 6 of the 190 pupils we were not able to obtain satisfactory tracings for all indices. The data presented here relate to 94 girls (12.5–19.6 yr, mean 15.4, SD 2.1) and 90 boys (12.5–20.3 yr, mean 15.3, SD 2.0).

Chest wall measurements and chest surface areas

Chest wall measurements of the seated subjects were recorded with the Harpenden anthropometer according to the technique described by HOWATT and DEMUTH [16]. One investigator performed all measurements, which were:
1. sternal length, *i.e.* the distance between the xyphoid process and the sternal angle;
2. thoracic width measured at the level of the xyphoid process;
3. thoracic depth, *i.e.* the anteroposterior diameter measured in a horizontal plane at the level of the junction of the manubrium and sternum.

Measurements 2 and 3 were performed at the level of full lung inflation (TLC level), at the end of a normal expiration (FRC level) and at the end of a maximum expiration (RV level). All measurements were made at least in duplicate, *i.e.* until the differences between corresponding recordings were less than 1.5 cm; average values were used for further analyses.

We used the formula of a truncated cone [17] for the computation of chest surface area (A_{cs}):

$$A_{CS} = \pi(r_1^2 + r_2^2) + \pi(r_1 + r_2)\sqrt{h^2 + (r_2 - r_1)^2}$$

In this equation h is the sternal length, r_1 half the thoracic depth, and r_2 half the thoracic width. Chest surface area was computed for the three levels of lung inflation.

Lung volumes, ventilatory flows and respiratory pressures

For measurements of respiratory function the subjects were connected by means of a three-way valve to either a bag-in-bottle system for the measurement of residual volume (RV), a water-sealed spirometer for measurement of other lung volumes and ventilatory flows, or to room air. The airway could be occluded at the mouth for the measurement of respiratory pressures, using an air-driven shutter with remote control. All measurements were performed in a fixed order with the subject comfortably seated upright.

Residual volume

After the subjects had become accustomed to the measuring device they were asked to perform a maximum expiration, after which the tap was switched from room air to the bag-in-bottle system which had been filled with 100% oxygen. RV was assessed by rebreathing at large tidal volume, using lung nitrogen as the indicator gas; the method is described in detail by STERK *et al.* [18] and DEGROODT *et al.* [19]. From this measurement we also obtained total lung capacity (TLC) as the sum of RV and inspiratory vital capacity, and the RV/TLC ratio. Measurements were performed as many times as necessary to obtain technically satisfactory tracings.

Functional residual capacity

The functional residual capacity (FRC) was determined indirectly as the sum of RV and expiratory reserve volume. To that end the subject was connected to a water-sealed spirometer (Lode D53R) and breathed normally for 3 min, performing a maximum expiration at the end of this period. During measurements CO_2 was absorbed, and oxygen supplied to meet the metabolic demands.

Maximum expiratory and inspiratory pressures and forces

Maximum pressures were generated and sustained against a closed tap. Maximum expiratory pressures were recorded at the level of TLC and FRC ($P_{E,TLC}$ and $P_{E,FRC}$ respectively), and maximum inspiratory pressures at the level of FRC and RV ($P_{I,FRC}$ and $P_{I,RV}$ respectively). The pressures were measured at the mouth with a differential pressure transducer (Statham PM5TC). The level of lung inflation was monitored from spirometric recordings. Pressure and volume signals were recorded on an X-Y oscilloscope and a chart recorder.

We tried to prevent air leakage at the mouth by instructing the subjects to support their cheeks firmly during measurements. Also the lips were firmly closed around a ring protruding 1.5 cm from the mouthpiece. To circumvent spurious results due to pressure generated by the cheeks against a closed glottis, a small air leak was created by a gauge (length 28 mm, i.d. 1.2 mm) attached to the tap [20]. We only considered plateau pressures which could be sustained for 2–3 s. At least two reproducible and technically satisfactory sets of pressure tracings were recorded, and the largest values selected for further analyses. The mean coefficients of variation for $P_{I,max}$ and $P_{E,max}$ were 7.8 and 8.5% respectively; this is less than in the study of WAGNER *et al.* [11], where it was 10 and 11% respectively. Respiratory forces were computed from the respiratory pressures and corresponding chest surface areas.

Spirometry

Whilst connected to the spirometer, the subjects were asked to exhale completely and perform a forced inspiratory vital capacity manoeuvre followed by a forced expiratory vital capacity manoeuvre (FVC). This procedure was repeated until three technically satisfactory tracings were obtained. From these recordings we selected the largest values of FVC, forced inspiratory volume in 1 second (FIV_1) and forced expiratory volume in 1 second (FEV_1); similarly the largest value of maximum mid-expiratory flow (MMEF) derived from a curve with an FVC within 95% of the largest FVC is reported [21].

Peak expiratory flow

Peak expiratory flow (PEF) was measured with a mini-Wright peak flow meter. We report the largest values of three reproducible measurements.

Results

Anthropometric data

We divided the boys and girls into five age groups (<13.5, 13.5–15, 15–16.5, 16.5–18, and >18 yr) and determined the median values of age, standing height and body mass for each group. The relationship of age with the two other indices is shown in figure 1. In the two youngest age groups the girls are taller and heavier than the boys as expected, since they enter the growth spurt earlier. The cross-sectional data show that, in girls, standing height and body mass hardly increase on average after the ages of 14 and 17 respectively. In boys, a maximum height of about 180 cm is attained between 16.5 and 18 yr; however, body mass seems to increase beyond this age.

In males and females the relationship of sternal length and thoracic depth with thoracic width is the same up to a thoracic width of about 30 cm when boys attain a wider chest without an increase in the two other chest measurements (figs 2 and 3).

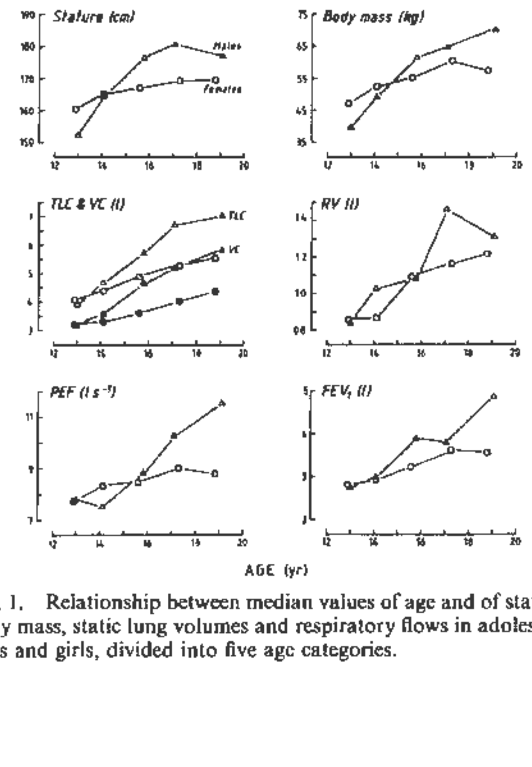

Fig. 1. Relationship between median values of age and of stature, body mass, static lung volumes and respiratory flows in adolescent boys and girls, divided into five age categories.

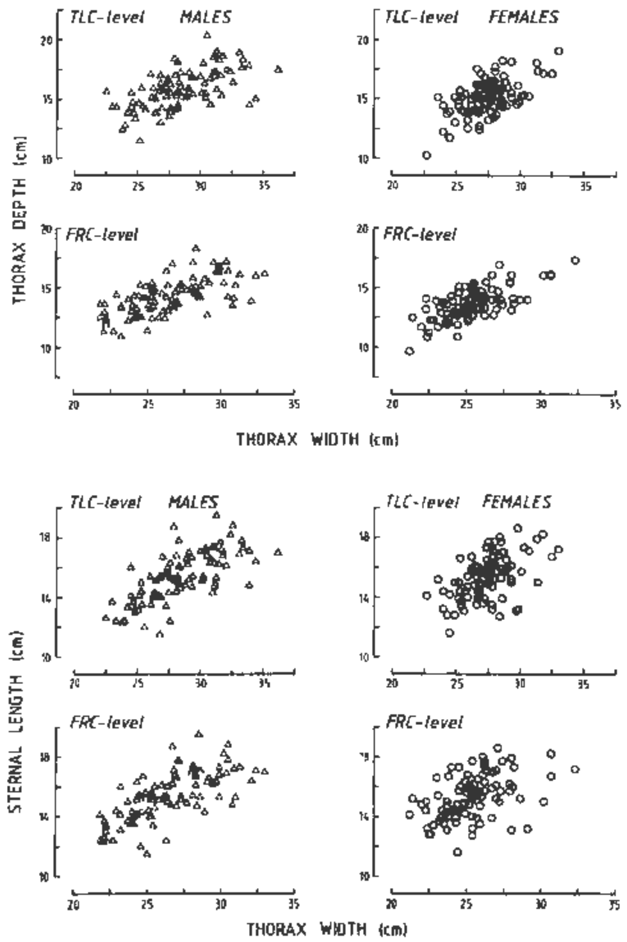

Fig. 2. Cross-sectional relationship in boys and girls between either sternal length or thoracic depth with thoracic width at the level of total lung capacity and functional residual capacity.

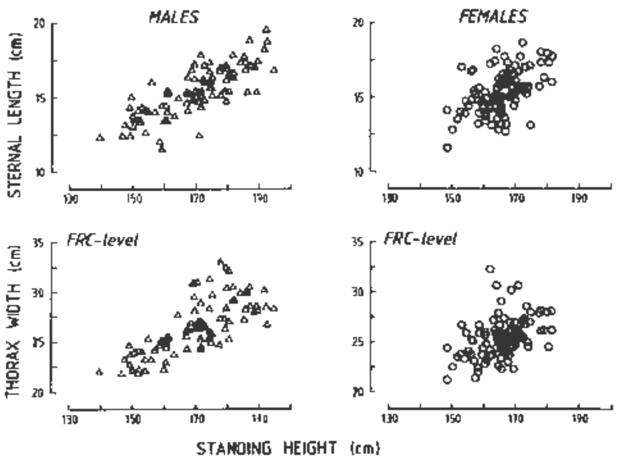

Fig. 3. Relationship of standing height with sternal length and thoracic width in adolescent boys and girls.

Static lung volumes

We determined the median lung volumes for each age group. There are clear trends between lung volumes and age, which are different for boys and girls (fig. 1, lower panels). The pattern of growth is similar for VC and TLC; differences between sexes are slight in the youngest age group, but increase sharply with age. Compared to the median values of TLC in the youngest age group there is a 1.8-fold increase in boys and only a 1.35-fold increase in girls; similar growth figures apply to the FVC. In girls lung volumes continue to increase when standing height has reached adult values (fig. 1). The subdivision of static lung volumes in males and females is unrelated to age; this holds for RV%TLC ($r=0.01$ in males; $r=-0.05$ in females), and FRC%TLC ($r=-0.04$ in males; $r=0.16$ in females). Males and females have comparable resting lung volumes: at age 16 the mean FRC%TLC is 54.7% in males and 54.5% in females. RV%TLC is on average larger in females (mean 22.5; SD 5.83) than in males (mean 20.9; SD 4.76), but the means do not differ ($p>0.5$).

Maximum flows

Maximum inspiratory and expiratory flows increase in proportion to lung volume as judged by FIV_1%IVC and FEV_1%IVC, which are uncorrelated with age and standing height in boys and girls. Figure 1 shows the median values for PEF and MMEF in boys and girls. Slightly higher values are found in girls up to 14 years of age for PEF and up to 17 years of age for MMEF. In table 1 we have tabulated TLC and inspiratory vital capacity (IVC), standardized for a standing height of 165 cm, and FEV_1%IVC, FIV_1%IVC, MMEF and PEF standardized for age 16. Analysis of covariance did not reveal differences between boys and girls for any of the lung function variables after accounting for the standing height and age. Yet there is a pattern: in spite of the lower TLC (table 1) and lower maximum $P_{E,TLC}$ (fig. 4), girls produce the same PEF as boys (table 1). They also have a higher FEV_1%IVC ratio and a higher MMEF (table 1).

Respiratory forces and pressures

Figure 4 shows the median values for maximum inspiratory and expiratory pressures plotted as a function of median age for the five groups of boys and girls; the corresponding relationship for respiratory muscle force is also shown in figure 4. In this age range (13–20 yr), boys are usually capable of generating larger inspiratory and expiratory pressures than girls. As mentioned earlier, we used chest surface areas in the computation of respiratory forces. Since surface area is proportional to L^2 and volume to L^3 (where L=length), if surface areas are correctly estimated they should be proportional to $V^{0.67}$. We checked this by regressing log surface area on log lung volume. Table 2 shows the regression coefficients and their confidence limits. For TLC in both sexes these regression coefficients approximated the expected value of 0.67. Thus we regard the corresponding

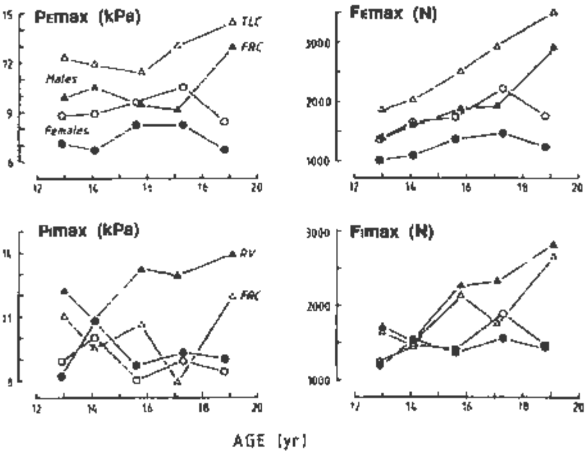

Fig. 4. Maximum respiratory pressures and forces at different levels of lung inflation in adolescent boys and girls. Estimates of thorax surface area (see text), and hence of muscle force, were only valid at the level of TLC.

Table 2. - Regression coefficients and 95% confidence intervals computed from regression of log surface area on log volume

	Boys	Girls
TLC	0.64 (0.57-0.71)	0.50 (0.38-0.62)
FRC	0.48 (0.40-0.56)	0.24 (0.12-0.24)
RV	0.28 (0.20-0.36)	0.06 (–0.03-0.15)

TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume

Table 1. - Comparison of ventilatory indices in boys and girls; values have been standardized for age 16 and a standing height of 165 cm

	TLC ml	IVC ml	MMEF $ml \cdot s^{-1}$	PEF $l \cdot min^{-1}$	FEV_1/IVC %	FIV_1/IVC %
Females	4646	3617	3768	497	87.48	89.90
Males	4832	3828	3478	498	83.85	91.61

TLC: total lung capacity; IVC: inspiratory vital capacity; MMEF: maximum mid-expiratory flow; PEF: peak expiratory flow; FEV_1: forced expiratory volume in one second; FIV_1: forced inspiratory volume in one second.

respiratory forces as acceptable and the respiratory forces computed at the level of FRC and RV as unreliable.

In general respiratory forces increase with age, more so in boys than girls. In girls the forces generated by respiratory muscles change much less, the values stabilizing after age 16. In boys the median value of $F_{E,TLC}$ increases non-linearly with age and nearly doubles. Inspiratory pressures decline at the level of FRC. The expiratory pressures are more or less independent of age, with the possible exception of $P_{E,TLC}$ which increases in the oldest boys.

Since expiratory pressures are almost constant whilst expiratory force increases, it follows that expiratory muscle force and chest surface area increase roughly in the same proportion during adolescent growth.

Relationship between respiratory volumes or flows and respiratory pressures or forces

We have computed separately for boys and girls the partial correlations between ventilatory flows and lung volumes on the one hand, and maximum pressures and forces on the other (table 3). Computations were performed controlling for the effects of age, standing height, body mass, smoking habits, respiratory symptoms and time spent on athletic activities. Smoking habits did not contribute significantly to differences in lung function nor to differences in muscle performance. As in the study of GAULTIER *et al.* [8] athletic performance did not contribute to differences in ventilatory function between individuals nor did smoking habits. The partial correlations in girls are not different from zero; in boys partial correlations are systematically higher than in girls, and nearly half of them are significant (table 3).

Multiple stepwise regression

As the lung grows ventilatory volumes and flows increase. In so far as these changes are due to an increase in the size and number of alveoli, and to an increase in the dimensions of the chest, it is logical to relate such increases to an anthropometric measurement such as standing height. From the neonatal period to adulthood changes occur in the mechanical properties of the lungs and chest [22], and these potentially affect volumes and flows; there is no obvious biological reason why this should be related to body size, instead a relationship with age seems more logical. Body mass is thought to contribute to ventilatory function: in early adolescence an increase in body mass reflects an increase in muscle mass and is positively related to ventilatory function [1], while an increase in subcutaneous fat would be negatively related. Respiratory pressures or forces, the more direct measures of respiratory muscularity, obviously directly affect lung volumes and flows. Hence it is plausible to use these indices as independent variables in a multiple stepwise regression analysis, and lung volumes and ventilatory flows as dependent variables. In view of power relationships between dependent variables and body mass or standing height, the analysis was carried out after log transformation of these indices; this transformation also stabilized the variances. Respiratory forces, unlike respiratory pressures, are correlated with age and standing height, which leads to problems of multicollinearity; hence in regression analyses we only used respiratory pressures. The rank order in which independent variables were included in the equation, and their contributions to the explained variance, are listed in table 4.

For all indices but RV the explained variances are higher in boys than in girls; as a rule they are higher for volumes than for flows (table 4). There is no common sequence in which the independent variables are entered into the equation, but there are some trends. Log weight and log height are chosen in the first step in boys and girls respectively. Age is selected next in nine of the twelve regressions.

Differences in respiratory muscle strength contribute more to differences in lung function amongst boys than girls; for all indices but RV, respiratory pressures (mostly inspiratory) were included in the equations in boys. However, the increase in explained

Table 3. - Partial correlation coefficients (controlling for standing height, age, body mass) between respiratory volumes or flows and respiratory muscle performance

	Males			Females		
	$P_{E,TLC}$	$P_{I,RV}$	$F_{E,TLC}$	$P_{E,TLC}$	$P_{I,RV}$	$F_{E,TLC}$
RV	0.09	–0.05	0.06	–0.14	–0.04	–0.15
TLC	0.22*	0.17	0.23*	0.00	0.04	0.07
FRC	0.14	0.02	0.13	0.13	–0.14	–0.10
FVC	0.20*	0.26*	0.24*	0.06	0.09	0.15
RV%TLC	0.02	–0.14	–0.01	–0.15	–0.07	–0.20
FEV_1	0.18	0.37*	0.24*	0.06	0.09	0.15
MMEF	0.13	0.33*	0.17	0.19	0.11	0.22*
PEF	0.29*	0.35*	0.36*	0.12	0.16	0.16

*$p<0.05$; $P_{E,TLC}$: maximum expiratory pressure at total lung capacity; $P_{I,RV}$: maximum inspiratory pressure at residual volume; $F_{E,TLC}$: forced expiratory pressure at total lung capacity. For other abbreviations see tables 1 and 2.

Table 4. - Contribution of various indices to explained variance (r^2) in ventilatory volumes and flows

	Males		Females	
Dependent variables	Independent variables	r^2	Independent variables	r^2
ln TLC	ln weight	0.826	ln height	0.526
	age	0.856	age	0.650
	ln height	0.870	ln weight	0.659
ln RV	ln height	0.368	ln height	0.240
	age	0.386	ln weight	0.328
			age	0.400
			PE,TLC	0.417
ln FVC	ln weight	0.842	ln weight	0.411
	age	0.871	age	0.557
	ln height	0.876	ln height	0.590
	PI,FRC	0.881		
ln FEV_1	ln weight	0.730	ln height	0.376
	age	0.773	age	0.464
	PI,FRC	0.793	ln weight	0.514
ln PEF	ln weight	0.610	ln height	0.280
	age	0.684	age	0.345
	PI,FRC	0.715	ln weight	0.371
ln MMEF	ln height	0.372	ln weight	0.143
	PI,FRC	0.416	PE,TLC	0.179
	age	0.461		

See other tables for abbreviations.

variance is modest, 4% at the most. Also the regression coefficients relating to pressures were low: the coefficients for PI,FRC are −0.0041, −0.0086, 0.0082, −0.0159 for FVC, FEV_1, PEF and MMEF respectively. Thus for a boy who generates a PI,FRC of −10 kPa the FVC would be 2.07% larger than for a boy with a PI,FRC of −5 kPa, other factors such as body mass, age and standing height being equal. For FEV_1, PEF and MMEF the corresponding figures would be 4.39, 4.19 and 8.27% respectively.

Discussion

The measurement of respiratory pressures was rather demanding on the subjects. This was because it was difficult to sustain a pressure that was generated for some length of time, and because the pupils had to cope with the compliance of the cheeks and with potential leaks at the mouth. This may explain the considerable spread in the pressures generated by boys and girls of comparable age, stature and body mass; however, the coefficient of variation of about 8% for the two best attempts is satisfactory. The maximum inspiratory and expiratory pressures that we obtained are comparable in level and in spread to those published by Cook *et al.* [20], Gaultier and Zinman [8] and Leech *et al.* [7]. These are less than the figures reported by Black and Hyatt [6], but considerably higher than those reported by Smyth *et al.* [10] and Wilson *et al.* [12].

The difficulty in generating pressures will have led to measurement errors and thus underlying relationships with ventilatory function will have been obscured. Even so the pattern that emerges from this study is clear. Boys have greater respiratory muscle force and, accordingly, are capable of generating systematically higher pressures at all lung volumes than girls. In general, differences in maximum pressures and in respiratory muscle force do help to explain differences in ventilatory function between individuals of the same sex, and between males and females. However, the reduction in residual variance is modest to small, indicating that other important determinants of differences in ventilatory performance between individuals have not been considered. In girls, lung volumes still increase when standing height, maximum respiratory pressures and forces have settled at adult values (figs 1 and 4); this is compatible with the fact that both the onset and the end of the growth spurt in standing height occur earlier than for thoracic dimensions [9, 13, 23]. In boys, however, the increase in lung volumes and ventilatory flows in the oldest boys (fig. 1) can be accounted for by increased effective muscle force (fig. 4, table 4), suggesting that there is a 'muscularity effect'.

By and large differences in respiratory muscle performance do not affect residual volume after accounting for stature, body mass and age (table 3). Residual volume is determined by the elastic recoil pressure of the chest and lungs, the occurrence of airway closure, and by the transmission of respiratory muscle force to the lung via a curved surface area. Little is known about chest recoil in adolescents.

There is no evidence from the present study to suggest that the balance between lung and chest recoil is altered during growth. On the contrary, the fact that the FRC/TLC ratio is independent of age suggests that changes, if any, are well balanced. This is compatible with the findings of SHARP *et al.* [24], who studied the pressure-volume curve of the respiratory system in anaesthetized subjects. They found that between the ages 10–18 yr the shape of the curve remained the same, and that differences in the position of the curve were slight after standardizing for volume.

The increase of residual volume may be affected by changes in airway closure. Closing volume as a percentage of the VC declines in adolescents [23, 25], and this could be associated with more complete lung emptying. Since it requires administration of a relatively large bolus of tracer gas to demonstrate airway closure in children, the volume of trapped gas involved is probably small, as will be the effect on residual volume. Hence the constant RV/TLC ratio signifies that the increase in expiratory muscle force at low lung volumes is apparently proportional to the increase in lung surface area.

As has been shown frequently in adults, but also in adolescents [26–29], girls on average generate larger expiratory flows than boys of the same age and stature (table 1). In fact, even though in boys the TLC is 5% larger than in girls, the peak expiratory flow is the same on average. The peak expiratory flow is not governed by wave speed limitation. It depends on effort, the speed of muscle shortening, and on the diameter of large intrathoracic airways. Since maximum expiratory pressures at the level of TLC and FRC are consistently less in girls than in boys, girls apparently have wider airways for a given lung volume than boys. This is in agreement with the findings of DUIVERMAN *et al.* [30] that, between 2.3–12.5 yr (with the exception of 8 yr) during quiet breathing, the resistance of the respiratory system to airflow is larger in boys than in girls. The fact that girls, but not boys, decrease airway tone after a deep inspiration may also contribute to the sex-related differences in expiratory flow [31]. The FEV_1/FVC ratio is composed of an effort-independent and an effort-dependent portion; it can be thought of as a mean expiratory flow in the first second of expiration divided by volume, when it has the dimension of t^{-1}, *i.e.* the reciprocal of the time constant of the lung. Girls exhibit the smaller time constants. The same reasoning applies to the MMEF, a mean expiratory flow which is entirely governed by wave speed limitation and hence an indirect measure of the airway area at the choke point. Due to the higher alveolar pressures generated by boys than by girls, some of the differences in FEV_1 and MMEF can be accounted for by intrathoracic gas compression. To some extent the data are also confounded by the fact that the RV/TLC ratio in girls is about 1.5% higher than in boys, so that for the same total lung capacity they have a smaller FVC; this would artificially inflate the FEV_1/FVC ratio and MMEF in girls, but the difference from boys remains if one corrects for this bias.

These observations lead to the question of whether there is dysanaptic growth, *i.e.* whether the relationship between the growth of lung and airway dimensions is different for boys and girls. This question can only be answered if in the two sexes the volumes attained are comparable. The TLC and RV are effort-dependent lung volumes which are governed by the elastic properties of the chest and lung and by respiratory muscle force. We have no information about the elastic properties but the FRC/TLC ratios are hardly different and there is no evidence from the literature of differences in lung elastic recoil between adolescent girls and boys [32–35]. It is unlikely that the properties of the chest wall differ much between sexes. The study of DUIVERMAN *et al.* [30], who employed forced oscillations applied at the mouth, did indicate, however, that between 2.3 and 12.5 yr boys have the stiffer respiratory system and this may also apply to the adolescent age. As regards respiratory muscle force and inspiratory and expiratory pressures, boys can stretch the lungs further at the level of TLC and also attain a smaller residual volume. Hence the systematically higher RV/TLC ratio in girls fits in with their lower respiratory muscle performance, as do the smaller VC and TLC. The relationship between thoracic width, sternal length and chest depth is very similar in boys and girls (figs 2 and 3). Hence all the evidence is that boys start forced expiration from a higher level of lung inflation than girls; this is associated with greater lung elastic recoil and airway distending pressure which would help to generate larger forced expiratory flows. Yet the peak expiratory flows are no different, so that the relationship between airway and lung dimensions seems to be basically different between boys and girls. Interestingly, THURLBECK [36] found in infants that boys had larger alveoli than girls; apparently then males have the narrower airways. During a forced inspiration, the greater muscle power in boys more than compensates for the larger flow resistance leading to a greater FIV_1/FVC ratio in boys than in girls.

References

1. Schoenberg JB, Beck GJ, Bouhuys A. – Growth and decay of pulmonary function in healthy blacks and whites. *Respir Physiol*, 1978, 33, 267–293.

2. Rea H, Becklake MR, Ghezzo H. – Lung function changes as a reflection of tissue ageing in young adults. *Bull Eur Physiopathol Respir*, 1982, 18, 5–19.

3. Burrows B, Cline MG, Knudson RJ, Taussig LM, Lebowitz MD. – A descriptive analysis of the growth and decline of the FVC and FEV_1. *Chest*, 1983, 5, 717–724.

4. Hutchinson J. – On the capacity of the lungs and on the respiratory functions, with a view of establishing a precise and easy method of detecting disease by the spirometer. *Tr Med Chir Soc London*, 1846, 29, 137–252.

5. Seely JE, Guzman CA, Becklake MR. – Heart and lung function at rest and exercise during adolescence. *J Appl Physiol*, 1974, 36, 34–40.

6. Black LF, Hyatt RE. – Maximal respiratory pressures: normal

values and relationship to age and sex. *Am Rev Respir Dis*, 1969, 99, 696–702.
7. Leech JA, Ghezzo H, Stevens D, Becklake MR. – Respiratory pressures and function in young adults. *Am Rev Respir Dis*, 1983, 128, 17–23.
8. Gaultier C, Zinman R. – Maximal static pressures in healthy children. *Respir Physiol*, 1983, 21, 45–61.
9. Tanner JM. – Growth in adolescents. Blackwell, Oxford, 1978.
10. Smyth RJ, Chapman KR, Rebuck AS. Maximal inspiratory and expiratory pressures in adolescents. *Chest*, 1984, 4, 569–572.
11. Wagner JS, Hibbert ME, Landau LI. Maximal respiratory pressures in children. *Am Rev Respir Dis*, 1984, 129, 873–875.
12. Wilson SH, Cooke NT, Edwards RHT, Spiro SG. – Predicted normal values for maximal respiratory pressures in Caucasian adults and children. *Thorax*, 1984, 39, 535–538.
13. Schrader PC, Quanjer PhH, van Zomeren BC, Wise ME. – Changes in the FEV_1-height relationship during pubertal growth. *Bull Eur Physiopathol Respir*, 1984, 20, 381–388.
14. Medical Research Council. – Definition and classification of chronic bronchitis for clinical and epidemiological purposes. A report to the Medical Research Council by their committee on the aetiology of chronic bronchitis. *Lancet*, 1965, 1, 775–779.
15. Kerrebijn KF, Hoogeveen-Schroot HCA, van der Wal MC. Chronic nonspecific respiratory disease in children, a five year follow-up study. The Netherlands Asthma Fund, Leusden, 1977.
16. Howatt WF, DeMuth GR. – Configuration of the chest. *Pediatrics*, 1965, 35, 177–184.
17. Diem K, Lentner C (ed). – Wissenschaftliche Tabellen, 7. Auflage. Documenta Geigy, J.R. Geigy S.A., Basle, 1968.
18. Sterk PJ, Quanjer PhH, van der Maas LLJ, Wise ME, van der Lende R. – The validity of the single breath nitrogen determination of residual volume. *Bull Eur Physiopathol Respir*, 1980, 16, 195–213.
19. DeGroodt EG, Quanjer PhH, Wise ME. – Influence of external resistance and minor flow variations on single breath nitrogen test and residual volume. *Bull Eur Physiopathol Respir*, 1983, 19, 267–272.
20. Cook CD, Mead J, Orzalesi MM. – Static volume-pressure characteristics of the respiratory system during maximal efforts. *J Appl Physiol*, 1964, 19, 1016–1022.
21. Quanjer PhH (ed). – Standardized lung function testing. Report Working Party 'Standardization of Lung Function Tests', European Community for Coal and Steel. *Bull Eur Physiopathol Respir*, 1983, 19 (suppl. 5), pp. 1–95.
22. Agostoni E, Mead J. – Statics of the respiratory system. *In*: Handbook of Physiology, Sect. 3, Vol 1. American Physiological Society, Washington, pp. 387–409.
23. DeGroodt EG, Quanjer PhH, Wise ME, van Zomeren BC. Changing relationships between stature and lung volumes during puberty. *Respir Physiol*, 1986, 65, 139–153.
24. Sharp JT, Druz WS, Balagot RC, Bandelin VR, Danon J. Total respiratory compliance in infants and children. *J Appl Physiol*, 1970, 29, 775–779.
25. Mansell A, Bryan C, Levison H. – Airway closure in children. *J Appl Physiol*, 1972, 33, 711–714.
26. Cotes JE, Dabbs JM, Hall AM, Heywood C, Laurence KM. – Sitting height, fat free mass and body fat as reference variables for lung function in healthy British children; comparison with stature. *Ann Hum Biol*, 1979, 6, 307–314.
27. Dockery DW, Berkey CS, Ware JH, Speizer FE, Ferris BG Jr. – Distribution of forced vital capacity and forced expiratory volume in one second in children 6 to 11 years of age. *Am Rev Respir Dis*, 1983, 128, 405–412.
28. Leeder SV, Swan AV, Peat JK, Woolcock AJ, Blackburn CRB. – Maximum expiratory flow-volume curves in children: changes with growth and individual variability. *Bull Eur Physiopathol Respir*, 1977, 13, 249–260.
29. Quanjer Ph.H, Polgar G, Wise ME, Karlberg J, Borsboom G, Stocks J. Compilation of reference values for lung function testing in chidren. *In*: Standardized Lung Function Testing in Paediatrics. PhH Quanjer *et al.* eds. *Eur Respir J*, in press.
30. Duiverman EJ, Clement J, van de Woestijne KP, Neijens HJ, van der Bergh ACM, Kerrebijn KF. – Forced oscillation technique. Reference values for resistance and reactance over a frequency spectrum of 2–26 Hz in healthy children aged 2.3–12.5 years. *Bull Eur Physiopathol Respir*, 1985, 21, 171–178.
31. Taassig LM, Cota K, Kaltenborn W. Different mechanical properties of the lung in boys and girls. *Am Rev Respir Dis*, 1981, 123, 640–643.
32. Baran D, Yernault JC, Paiva M, Englert M. – Static mechanical lung properties in healthy children. *Scand J Respir Dis*, 1976, 57, 139–147.
33. De Troyer A, Yernault JC, Englert M, Baran D, Paiva M. – Evolution of intrathoracic airway mechanics during lung growth. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1978, 44, 521–527.
34. Mansell AL, Bryan AC, Levison H. Relationship of lung recoil to lung volume and maximum expiratory flow in normal children. *J Appl Physiol: Respirat Environ Exercise Physiol*, 1977, 42, 817–823.
35. Zapletal A, Paul T, Samanek M. – Pulmonary elasticity in children and adolescents. *J Appl Physiol*, 1976, 40, 953–961.
36. Thurlbeck WM. – Postnatal human lung growth. *Thorax*, 1982, 37, 564–571.

RÉSUMÉ: Nous avons étudié, chez 94 filles et chez 90 garçons, dont l'âge se situe entre 12.5 et 20.3 années, la relation des pressions ou forces respiratoires, avec les volumes pulmonaires et les débits ventilatoires. On a noté une grande variabilité des performances musculaires respiratoires, ce qui aide à expliquer les différences de volumes pulmonaires entre les individus. Les forces des muscles respiratoires augmentent environ de façon proportionnelle avec les dimensions du thorax, de telle sorte que les pressions inspiratoires, qui sont générées au niveau du volume résiduel, de la capacité résiduelle fonctionnelle, et de la capacité pulmonaire totale, sont approximativement constantes avec l'âge. Chez les garçons les plus âgés, il apparaît que l'augmentation continue des volumes pulmonaires, à un moment où la taille debout cesse d'augmenter, est due à un effet de muscularité. Les garçons sont capables de générer des pressions plus fortes que les filles à tous les volumes pulmonaires. Donc, les garçons arrivent à un plus grande capacité pulmonaire totale et, en dépit de bronches plus étroites, arrivent au même débit expiratoire maximum et à un rapport FIV_1/FVC supérieur à celui des filles. Toutefois, les débits indépendants de l'effort (FEV_1 et MMEF), sont les plus élevés chez les filles