Spirometric, body plethysmographic and flow volume reference values for male and female children aged 5 to 18 years

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Abstract

The objective of the study was to obtain reliable reference values for spirometric, body plethysmographic and flow volume parameters in male and female children aged 5 to 18 years.

Vital capacity (VC) and its subdivisions (IC and ERV) as well as total lung capacity (TLC), residual volume (RV), peak flow (PEF), forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), maximum flow volume curve (MEF_{75}, MEF_{50}, MEF_{25}, MMEF, FEF_{75-85}), airway resistance (R_{tot}) and the thoracic gas volume at resting expiratory position (FRC) were measured in 452 girls and 641 boys aged 5 to 18 years. The measurements were carried out one after the other on the same subjects in the morning using a volume-constant plethysmograph (MasterLab, E. Jaeger; programs: body plethysmography, spirometry and flow volume).

Using multiple regression analysis the best fitting curves for the prediction of normal values for boys and girls were selected and are presented here. Analyses of covariance were performed to compare the adjusted means of the spirometric and body plethysmographic variables of the male and female subjects.

As expected we found higher static and dynamic (FVC, FEV_1, PEF) lung volumes in boys than in girls relating to height. On the other hand, the flows (MMEF, MEF_{50}, MEF_{25}, FEF_{75-85}) were significantly lower in the male than in the female subjects of the same age justifying separate prediction equations for boys and girls. However, the same equation for both genders may be used for the prediction of the resistance variable R_{tot}. Our results are compared with those of previous studies in the pediatric literature.

Key words: Asymptomatic children
reference values
sex–related differences
spirometry
body plethysmography

1 Introduction

Lung function testing by whole body plethysmography can easily be applied also to children aged five years and older. But, although this method is becoming widely used in pediatrics, no reliable reference values based on large populations are available. Only few of the published studies have taken age and weight of the children in addition to body size into account and separated boys and girls [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12].

Unlike whole body plethysmography many reports on reference values for static and dynamic lung volumes measured by spirometry have been published [13]. They are based on sizeable populations. However, most measurements of the flow volume curves have been carried out only for small groups of children and adolescents. Thus, the results of the studies referring to normal values for MEF_{75}, MEF_{50}, MEF_{25}, MMEF and FEF_{75-85} vary considerably and most of these investigations use rather simple regression models as prediction equations of the parameters [2, 5, 7].

In order to obtain more reliable prediction equations, body plethysmographic, spirometric and flow volume measurements of 1093 children and adolescents have been analysed by regression models that deliver adequate descriptions of the data. Among the possible regression equations those consistent within groups of lung function parameters were selected and are presented here. In particular, we considered for which parameters it is justified to use different prediction equations for male and female children and adolescents.

2 Materials and Methods

2.1 Subjects

From January 1989 to July 1993 combined spirometric and body plethysmographic lung function tests were carried out on 4714 children during their six–week stay at *"Seehospiz Kaiserin Friedrich"*, a big rehabilitation center on Norderney, an island off the coast of Northern Germany. Its intake is primarily for patients suffering from chronic diseases of the respiratory system, the skin or from psychosomatic disorders. A large number of its patients are convalescents or subjects suspected of allergic diseases. However, most of them are healthy subjects tested routinely also by spirometry and body plethysmography. From this subpopulation 1093 subjects (641 males, 452 females) aged 5 to 18 years were the basis for modelling dynamic lung volumes and flows. Out of those 1093 subjects a portion of 1068 (632 males, 436 females) remained as reference subjects for static lung volumes and airway resistance.

All of them were of Caucasian origin. Only those subjects were included who showed no signs of respiratory dysfunction on the day of lung function testing. Taking the medical history into account the selection criteria were nearly the same as those recommended by the GAP conference [12], i.e.: (1) No presence of acute, and no past chronic disease of the respiratory system; (2) no major respiratory disease, such as congenital anomalies, destructive type of pneumonia or thoracic surgery; (3) no systemic disease which may directly or indirectly influence the respiratory system; (4) no more than incidental smoking; (5) no treatment with drugs. Furthermore, subjects were excluded according to the following statistical criteria: (i) If any of the combined lung function tests were missing; (ii) if there were outliers according to standardized residuals below -4.5 or above $+4.5$ of the regression model.

Body size was measured as standing height in m, weight was registered in kg. Age was recorded as the difference between day of measurements and birthday in years. Each age group in table 1 includes children up to the next highest age, e.g. age group 7 includes children between 6 and 7 years (7^{th} year of age). The age distributions of our male and female subjects were relatively homogeneous between 6 and 16 years of age showing low quota only in the tails for the age groups 5, 17 and 18.

Table 1. — Distribution of age in females and males.

	Year of age														
Sex	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
f	4	25	48	30	39	37	59	41	36	43	34	28	19	9	452
m	8	45	54	45	66	52	75	80	62	65	43	32	11	3	641

2.2 Lung function testing

Whole body plethysmography and spirometry were performed one after the other on the same subject in the morning using a volume–constant plethysmograph connected to a pneumotachograph and a pressure recorder (completely computerized MasterLab–body with electronic BTPS-compensation, Erich Jaeger, Würzburg).

During the breathing manoeuvres the subjects were sitting in an upright posture wearing a noseclip. The specific plethysmographic variables, i.e. airway resistance and functional residual capacity (FRC_{box}), were measured first. Immediately after the assessment of FRC an inspiratory capacity manoeuvre (IC) was performed to determine the total lung capacity (TLC = IC + FRC) followed by the measurements of ERV and IVC. After a short rest, maximal expiratory flow volume curves were recorded. All measurements and curves were stored and the best of them obtained from 3 to 5 technically satisfactory manoeuvres were chosen for analysis using a special MasterLab–data recording system.

The resistance was taken as a slope of the total flow–pressure loop (R_{tot}), read at the flow level of 0.5 l/s. Likewise FRC was measured at the volume level of 0.5 l. The best of the registered loops were chosen for analysis and all measurements were carried out by the same technicians.

2.3 Statistical analysis

Multiple regression analysis

The stored data were exported as ASCII files, analysed once more and processed using the SAS statistical software program [14], version 6.08 under MS-Windows.

Complex regression equations were chosen as adequate models to predict the reference values. The lung function measurements except FEV_1%FVC and FEV_1%IVC were transformed into logarithmic units (ln = natural logarithm) and described as functions of height (H), age (A) and weight (W) terms where the pool of variables included also logarithmic, reciprocal, square–root, quadratic and cubic transformations as well as interaction terms (e.g. $A{\cdot}H$, H/W, $A\sqrt{W}$, $IND = H/\sqrt[3]{W}$ = index of body mass).

In the stepwise analysis using forward and/or backward selection, terms were added to or removed from the equation using the following criteria: (1) All independent variables were to contribute significantly ($p < 0.01$, t–test) to the regression. (2) All regressors combined were to have a significant influence on the lung function variable ($p < 0.01$, F–test). (3) The addition of an individual independent variable was to increase the *coefficient of determination* R^2 by at least 0.01 and hence to decrease the *residual standard deviation* RSD, i.e. the deviation around the regression line.

Each model was explored by different graphical techniques. Residual plots allowed us (i) to check the linear relationship between dependent and independent variables, (ii) to evaluate the assumption of homoscedasticity (constant variance) and (iii) to investigate that there are no systematic patterns or trends. Normality of residuals (observed values – predicted values) were assessed by normal plots. The adequacy of prediction equations was re-examined by so-called median plots where the medians of observed values are compared with the medians of corresponding predicted values by plotting the medians against the grouping variable height or age. Whenever different models gave similar results, we selected the simplest one, consistent within groups of lung function parameters. Details on the procedures are reported in Kühnel [15] and Seidel [16]. The lower 5 percent limit of predicted normal values is obtained by subtracting 1.645 RSD from the predicted value (in logarithmic units). To obtain the *lower limit* in untransformed units exponentation has to be used. E.g. the 5^{th} percentile for FVC in girls (see table 2) results in $\exp(\ln(FVC) - 1.645 \cdot 0.121) = \exp(-0.199)FVC = 0.82 \cdot FVC$.

Covariance analysis

Analyses of covariance [17, 18] were performed to compare the adjusted means of the spirometric (body plethysmographic) variables obtained from 641 (632) males and 452 (436) female subjects. The covariates in the analyses were age and height. We grouped the data by height (age) and calculated the median of the predicted values of individuals in each group. The corresponding median plots of males and females were checked for differences in slope. Whenever the difference was constant on a logarithmic scale, the t–test of adjusted means was applied [18].

Robust regression and outlier detection

The assessment of RV, RV%TLC and FIV_1 may be inaccurate and high leverage points may have an adverse effect on the regression slope.

In order to eliminate such outliers a robust regression method (Least Trimmed Squares) was applied to lung function variables RV, RV%TLC and FIV_1 using the reweighted least squares method rather than the least squares method [19]. On the average, five percent of these data were weighted to zero and so excluded from the analysis.

3 Results

3.1 Dynamic lung volumes and flows

Table 2 contains the prediction equations for dynamic lung volumes and flows derived from 452 girls aged 5 to 18 years and table 3 those derived from 641 boys. Furthermore, the coefficient of determination R^2, the residual standard deviation RSD and the proportion p_5 of subjects with values below the 5^{th} normal percentile are listed there. Most prediction equations are multiple regression equations with functions of height and age. It should be mentioned that no weight terms are included, because they contributed less than 0.01 to R^2, when added to height and age terms. (It is well known [13] that the transition from childhood to adolescence changes the relationship between lung volume parameters and height which has been a challenge for modellers over the years.) We experimented with models suggested by Kristufek [4], Neuberger [6], Schoenberg [11] and Quanjer [13] and compared them with equations based on our own pool of variables. In girls we settled for the choice height and ln(age) leading to explained variances from 71% to 92%. In boys the characteristics between lung volumes and height changed more dramatically. Among the eligible models the simplest one was chosen, whereby height and age^2 delivered a good fit without systematic errors, having explained variances from 67% to 92% (table 3).

Most of the ventilatory flows in girls are related to the variables height and ln(age) whereas $\ln(MEF_{25})$ and $\ln(FEF_{75-85})$ depend only on $height^3$. In boys most parameters are satisfactory described by simple regressions with height; only ln(PEF) and $\ln(MEF_{75})$ call for two variables, height and ln(age), the same combination as for girls. The explained variances are of the same order in girls and boys ranging from 47% to 84%. As expected the indices FEV1%FVC and FEV1%IVC were rather weakly related to age and height terms. We chose only 1/age as independent variable, which accounted 5% to 19% of the variance. The addition of a height term in the model did not increase R^2 significantly.

Table 2. — Prediction equations for lung volumes (l) and ventilatory flows (l/s) measured by pneumotachograph spirometry in 452 female children aged 5 to 18 years.

Prediction Equations		R^2	RSD	p_5
$\ln(FVC)$	$= -1.928 + 1.410H + 0.339\ln(A)$	0.901	0.121	4.6
$\ln(FEV_1)$	$= -1.902 + 1.394H + 0.302\ln(A)$	0.917	0.106	4.9
$\ln(FIV_1)^1$	$= -1.922 + 1.128H + 0.395\ln(A)$	0.706	0.214	6.9
$\ln(IVC)$	$= -1.967 + 1.428H + 0.330\ln(A)$	0.905	0.119	4.6
$FEV_1\%FVC$	$= 88.022 + 39.758/A$	0.071	5.140	6.6
$FEV_1\%IVC$	$= 90.779 + 43.547/A$	0.054	6.538	3.8
$\ln(PEF)$	$= -1.278 + 1.436H + 0.325\ln(A)$	0.834	0.163	4.2
$\ln(MEF_{75})$	$= -1.176 + 1.359H + 0.284\ln(A)$	0.809	0.164	4.4
$\ln(MEF_{50})$	$= -1.368 + 1.337H + 0.232\ln(A)$	0.735	0.191	3.5
$\ln(MEF_{25})$	$= -0.368 + 0.262H^3$	0.610	0.238	5.1
$\ln(MMEF)$	$= -1.505 + 1.385H + 0.214\ln(A)$	0.750	0.186	3.3
$\ln(FEF_{75-85})$	$= -0.645 + 0.267H^3$	0.543	0.279	4.2

[1] Reweighted least squares: $n = 416$.

R^2, explained variance; RSD, residual standard deviation.

p_5, proportion of subjects below the 5^{th} normal percentile.

Table 3. — Prediction equations for lung volumes (l) and ventilatory flows (l/s) measured by pneumotachograph spirometry in 641 male children aged 5 to 18 years.

Prediction Equations		R^2	RSD	p_5
$\ln(FVC)$	$= -1.736 + 1.806H + 0.00059A^2$	0.911	0.117	5.1
$\ln(FEV_1)$	$= -1.660 + 1.685H + 0.00050A^2$	0.924	0.100	4.5
$\ln(FIV_1)^1$	$= -1.579 + 1.456H + 0.00093A^2$	0.666	0.232	7.3
$\ln(IVC)$	$= -2.002 + 2.009H$	0.904	0.123	5.0
$FEV_1\%FVC$	$= 82.168 + 74.212/A$	0.191	5.464	6.1
$FEV_1\%IVC$	$= 84.062 + 95.369/A$	0.171	7.516	3.1
$\ln(PEF)$	$= -1.140 + 1.223H + 0.412\ln(A)$	0.844	0.152	3.9
$\ln(MEF_{75})$	$= -0.987 + 1.277H + 0.251\ln(A)$	0.800	0.157	4.7
$\ln(MEF_{50})$	$= -1.193 + 1.562\,H$	0.742	0.173	4.1
$\ln(MEF_{25})$	$= -1.687 + 1.441\,H$	0.552	0.244	4.1
$\ln(MMEF)$	$= -1.318 + 1.571\,H$	0.729	0.180	3.9
$\ln(FEF_{75-85})$	$= -1.960 + 1.440\,H$	0.473	0.286	4.1

[1] Reweighted least squares: $n = 614$.

Analyses of covariance revealed statistically significant differences of the flow reference values for girls and boys. By analysing the median plots of predicted values in the male and female subjects for each flow variable we could observe differences in the two curves. For instance, the prediction equations of ln(FVC) are listed in table 4.

Table 4. — Prediction equations for ln(FVC) in both genders based on 1093 children: 452 females (sex = 0) and 641 males (sex = 1).

both genders	$\ln(FVC)$	$=$	$-1.949 + 0.275\ln(A) + 1.528\,H$	
(f: sex = 0, m: sex = 1)			$+0.0341\,H\cdot sex$	$R^2 = 0.91$, $RSD = 0.12$
female	$\ln(FVC)$	$=$	$-1.949 + 0.275\ln(A) + \mathbf{1.528}\,H$	
male	$\ln(FVC)$	$=$	$-1.949 + 0.275\ln(A) + \mathbf{1.562}\,H$	

The increase of the curve FVC for the male subjects is, on average, 4% higher than that of the female subjects (fig. 1). We found some differences relating to body size, namely significant higher means of FEV_1 and PEF and significant lower means of $FEV_1\%FVC$, $FEV_1\%IVC$, MMEF,MEF_{50} and MEF_{25} in boys than girls. Likewise the prediction curves of MEF_{75} varied in different ways being lower for boys taller than 1.5 m.

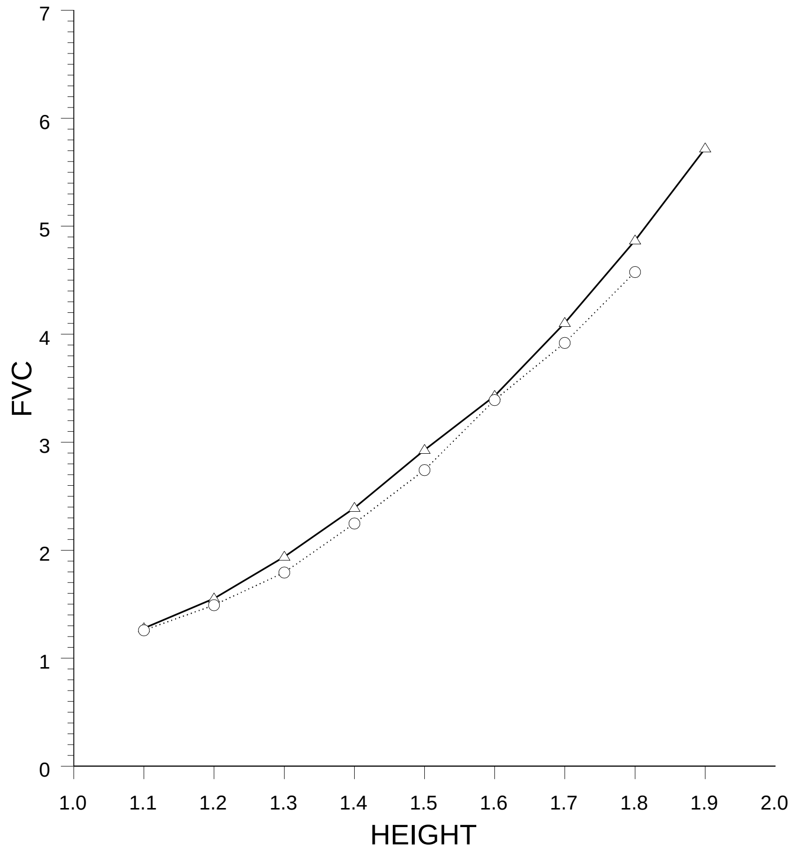

Fig. 1. – Medians of FVC–reference values (derived from table 4) obtained from female (○) and male (△) individuals grouped in 0.1m height blocks.

3.2 Static lung volumes and airway resistance

The prediction equations for total lung capacity (TLC), functional residual capacity (FRC), expiratory reserve volume (ERV) and residual volume (RV) for male and female children and adolescents are listed in table 5. They are based on observations of 632 male and 436 female children and adolescents. RV was assessed as the difference TLC – IVC. Its residual standard deviation is relatively high and the coefficient of determination relatively low ($R^2 = 0.178$ and 0.189, respectively), although extreme outliers had been eliminated using robust regression analysis. This indicates some difficulties with respect to the accuracy in estimating this lung function variable. There were satisfactory coefficients of determination (from 0.73 to 0.90) and relatively small RSD for the other lung volumes requiring no robust regression analysis. Moreover, we calculated FRC%TLC. Apparently, it does not change during childhood and adolescence, whereas RV%TLC shows a slight decrease. As expected, analyses of covariance yielded significant lower lung volumes for girls than for boys of the same height.

Table 5. — Prediction equations for lung volumes (l) measured by whole body-plethysmography for male and female children aged 5 to 18 years

Sex	n	PREDICTION EQUATIONS	R^2	RSD	p_5
f	436	$\ln(TLC) = -1.114 + 1.423H + 0.019A$	0.882	0.116	7.1
m	632	$\ln(TLC) = -1.332 + 1.747H$	0.897	0.111	5.2
f	436	$\ln(FRC) = -1.778 + 1.510H + 0.016A$	0.852	0.135	5.5
m	632	$\ln(FRC) = -1.896 + 1.728H$	0.859	0.131	4.7
f	436	$\ln(ERV + 1) = -1.152 + 0.798H + 0.294\ln(A)$	0.727	0.145	5.3
m	632	$\ln(ERV + 1) = -1.125 + 0.978H + 0.186\ln(A)$	0.727	0.145	5.9
f	419	$\ln(RV) = -1.203 + 0.209\,H^3 + 3.002/A$	0.178	0.325	7.4
m	598	$\ln(RV) = -1.078 + 0.180\,H^3 + 2.513/A$	0.189	0.324	6.4
f	436	$FRC\%TLC = \; 56.83 \pm 7.02$ (mean ± 1 SD)			
m	632	$FRC\%TLC = \; 55.77 \pm 6.90$			
f	436	$\ln(RV\%TLC) = \; 2.576 + 5.953/A$	0.264	0.348	5.7
m	596	$\ln(RV\%TLC) = \; 2.582 + 5.609/A$	0.312	0.297	6.7

Contrary to the lung volumes and flows the airway resistance variable R_{tot}, measured during quiet breathing does not differ significantly between girls and boys so that the same prediction equation can be used for both genders, and no separate ones are mandatory. For $\ln(R_{tot})$ we have

$$\ln(R_{tot}) = 2.078 - 1.866\,H\,, \quad R^2 = 0.766,\; RSD = 0.191\,.$$

The specific airway resistance ($SR_{tot} = R_{tot} \cdot FRC_{box}$), however, does not change during childhood and adolescence. The difference between girls $SR_{tot} = 0.971 \pm 0.198$ and boys $SR_{tot} = 1.007 \pm 0.195$ is statistically not significant.

4 Discussion

The statistical evaluation of our data was similar to the procedure described in Crapo et al. 1981 [20] and Gore et al. 1995 [17]. By stepwise analysis we were able to identify regression models that describe the data adequately. The median values of grouped data served as reference curve for the regression line of the medians of predicted values. Robust regression analyses were applied to some lung function variables (FIV_1, RV, RV%TLC) with extreme outliers in order to eliminate leverage points. Therefore, the corresponding equations are based on a reduced number of subjects. Using analyses of covariance we were able to compare the adjusted means of the spirometric measurements derived from 641 male and 452 female subjects and body plethysmographic measurements obtained from 632 male and 436 female children and adolescents.

As expected [2, 3, 4, 5, 8, 21, 22, 23] we found higher static lung volumes (IVC, FRC, TLC, ERV, RV, FVC) in boys than in girls relating to height. After correcting for body size we also detected significantly higher dynamic lung volumes (FVC, FEV_1, PEF) in boys than girls. However, the flows (FEV_1%IVC, MMEF, FEF_{75-85}, MEF_{50}, MEF_{25}) were significantly lower in the male than in the female subjects of the same age justifying separate prediction equations for boys and girls. Consequently the same applies to all flow variables. Only the prediction curve for MEF_{75} is nearly identical for both genders. In clinical practice separate prediction equations for male and female children (tables 3, 4 and 5) may be used. Our results support the hypothesis that girls have higher expiratory flows than boys [2, 12] and, in particular, our findings confirm the measurements of Merkus et al. [24] and Hibbert et al. [25]. On the other hand, boys have higher dynamic lung volumes [24, 25, 26, 27]. The small difference of $SR_{tot} = 0.971 \pm 0.198$ (females) and 1.007 ± 0.195 (males), respectively, accounts for significant higher FRC in boys.

The main reason for higher flows in girls may be that boys, generally, exert higher efforts at the forced expiration manoeuvres. Thus, the stronger thoracic compression may reduce the rate of air emptying out of the lung (effort dependence of maximal expiratory flows). Furthermore, gender differences in growth of lung function, with girls generating greater volume–standardized maximal expiratory flows until age 18.5 years could be documented independently from two papers ([24], [25]). Using TLC and not FVC as an estimate for lung size Merkus et al. [24] found that the growth of airways relative to volume is greater in males than in females during adolescence, overtaking that of females when TLC is > 5 liter. Generally, growth in flow lags behind that in volume [25].

Our FVC– and FEV_1–reference values are similar to those from the recent Austrian spirometric studies by Kummer [26] and Rapatz [27] (see table 6). Likewise, the FVC and FEV_1 values derived by Polgar and Promadhat [8] from several published studies and those calculated by Quanjer et al. [13] from spirometric data sets collected in 6 different European Centres deviate slightly from our values. Latter study comprised 2269 girls and 3592 boys aged 6 – 21 years. Although the number of subjects is larger than in our study the standard deviation of the FVC prediction equation is only slightly lower and that of the FEV_1 equation even slightly higher. The coefficients of determination (R^2) are nearly the same in both studies. These statistical characteristics seem to indicate that our population represents a reliable one.

Table 6. — Flow–volume reference values in boys aged 8, 12 and 16 years. Comparison of the predicted values of our study with those of other authors. Absolute differences: present model - published model.

			FVC l	FEV_1 l	PEF l/s	MEF_{75} l/s	MEF_{50} l/s	MEF_{25} l/s
A(yr)	H(m)	W(kg)	**predicted values** of present model (table 3)					
8	1.33	29	2.02	1.85	3.83	3.43	2.42	1.26
12	1.56	45	3.21	2.83	6.00	5.10	3.47	1.75
16	1.77	65	5.01	4.27	8.73	7.17	4.82	2.37
			difference: present model – published model					
Neuberger [6]			0.06	0.04	- 0.01	0.04	0.01	0.04
6 – 16 years			0.12	0.07	0.23	0.26	0.03	0.05
Austria 1994			0.59	0.41	0.19	0.34	-0.06	0.02
Rapatz [27]			-0.01	0.00	-0.40	-0.30	-0.14	0.02
6 – 17 years			0.05	0.01	-0.51	-0.29	-0.24	-0.07
Austria 1995			0.00	-0.12	-1.18	-0.57	-0.54	-0.28
Kristufek [4]			0.08	0.13	0.24	—	-0.19	-0.20
6 – 81 years			-0.04	0.06	0.48	—	-0.40	-0.30
Slovakia 1988			0.35	0.42	1.26	—	-0.06	-0.19
Zapletal [23]			—	0.12	-0.18	-0.19	-0.13	-0.05
6 – 17 years			—	0.11	0.17	-0.01	-0.15	-0.11
Czech Rep. 1977			—	0.35	0.90	0.47	0.06	-0.09
Schoenberg [11]			0.13	0.18	0.66	—	0.10	0.07
7 – 17 years			0.21	0.32	1.55	—	0.24	0.12
USA 1978			0.47	0.43	2.01	—	-0.06	-0.29
Polgar [8]			-0.07	0.00	-0.70	—	—	—
6 – 18 years			0.00	-0.05	-0.54	—	—	—
USA 1971			0.52	0.16	0.36	—	—	—

On the other hand, the predicted values of PEF, MEF_{75}, MEF_{50}, MEF_{25} vary considerably among the different reference populations (table 6). Our values are comparable with those of the Austrian study by Neuberger [6].

As already mentioned, many studies on reference values of flow–volume testing have been published, but there are only a few valid studies on body plethysmographic reference values based on sufficiently large samples. That is why summarized equations composed of data, compiled from several authors, are being used in the US [2, 7, 8]. In Europe the prediction equations for TLC, FRC_{box} and RV according to Zapletal et al. [23] are mainly recommended for use. However, their reference population comprises a rather small sample of 174 males and females only.

A comparison of the reference values of our own study with those of Zapletal et al. [23] reveals that, on average, TLC is 5% lower and FRC 8% higher in our studied population. Thus, FRC%TLC is higher too, i.e. $56.2 \pm 6.9\%$ versus $49.2 \pm 3.5\%$. Dab and Alexander [3] calculated the mean and maximum tolerated ratios with respect to FRC/TLC (0.50 and 0.60) and to RV/TLC (0.23 and 0.39). Likewise, the reference values of FRC derived from other authors are lower or even considerably lower than ours (table 7). RV%TLC in children and adolescents aged 10 to 18 years was nearly the same as in the recent study of Hibbert et al. [25]. Note that younger children were not investigated by these authors.

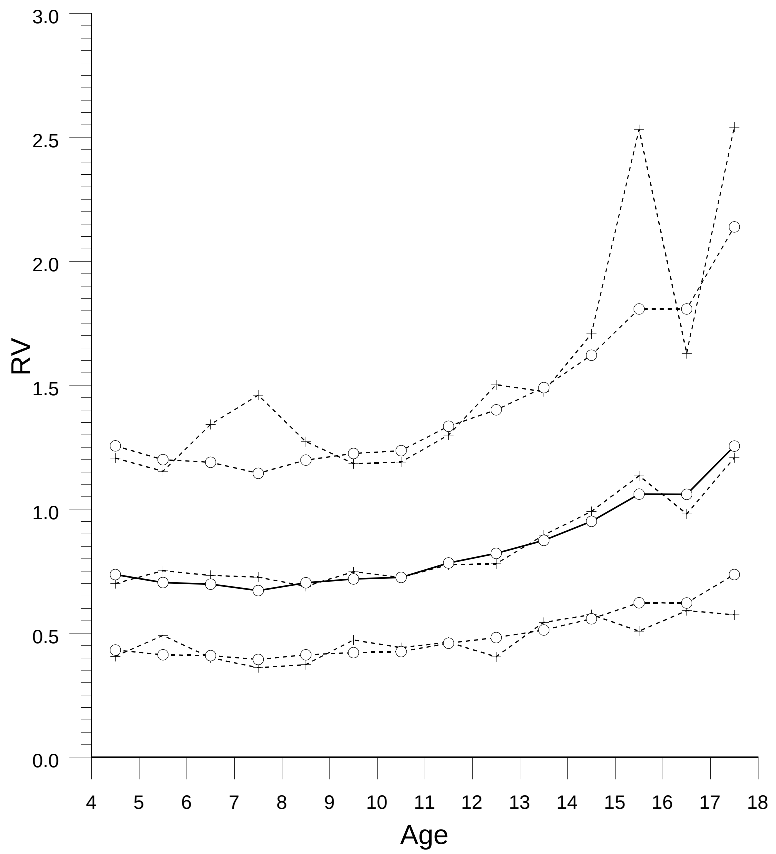

Fig. 2. – Median (med) of RV–data in males with proportional standard deviation med$\times$ exp($\pm$1.645 SD) for each 1 year–age group (+) and median (med_p) of the corresponding predicted values with upper and lower normal limits $med_p \times \exp(\pm 1.645$ RSD) ($\circ$) derived from table 5.

In agreement with all authors performing body plethysmographic measurements we found RV (= TLC − IVC) to be the lung volume with the greatest relative variability. This might be due to the combination of three separate measurements, i.e. IC, FRC and IVC. Moreover, boys and girls at ages 5 to 9 seem to have by nature a relative high RV, as demonstrated by our reference values (fig. 2), and may be also derived from the regression equation of Zapletal [23]. However, at least two important facts may account for those discrepancies. Firstly, our data contain much more children aged 5 to 9 years (146 girls, 218 boys) than any other study (e.g. [4] reports 17 girls and 22 boys between 6 and 9 years) influencing the prediction model to be more accurate, in particular, in its initial part. Secondly, the prediction equations of Dab [3], Michaelson [5], v. d. Hardt [22] and Zapletal [23] are simply based on height, neglecting the possibly negative impact of age.

In this respect our prediction equations for body plethysmographic variables might be superior to those related only to height and calculated from populations with a small proportion of young children. Nevertheless, RV remains the least reliable of all static spirometric variables and "*in clinical practice one single abnormal value should be interpreted with due care*" [3]. If necessary the measurement should be repeated several times.

Zapletal et al. [23] did not publish reference values concerning the total airway resistance measured by whole body plethysmography. Similarly, there do not seem to exist any adequate reference values in the Angloamerican literature [2]. Prediction equations for R_{tot} are proposed only by the German authors v. d. Hardt and Leben [22] and the Belgian authors Dab and Alexander [3]. Our reference values are lower than those of [3], but higher than and closer to those of [22]. There were no significant differences of the observed measurements between boys and girls in all three studies (table 8), so that the same prediction equations may be used for both genders. Moreover, our resistance values, which are not higher than those reported in former studies [8], suggest a reliable sample.

In summary, we are able to provide new spirometric and body plethysmographic reference values for 17 different lung function parameters. All prediction equations were derived from the same set of individuals constituting a large population of children and adolescents of Caucasian origin. The results encourage the use of separate prediction equations for boys and girls for all static and dynamic lung volumes as well as for flows, but it is recommended to use the same prediction equations for both genders only with respect to airway resistance variables.

Table 7. — Lung volumes measured by whole body plethysmography in boys (m) and girls (f) aged 8, 12 and 16 years. Comparison of the predicted values of our study with those of other authors. Absolute differences: present model - published model.

			TLC (l)		FRC (l)		RV (l)	
			m	f	m	f	m	f
A(yr)	H(m)	W(kg)	**predicted values** of present model (table 5)					
8	1.33	29	2.70	2.54	1.50	1.43	0.71	0.71
12	1.56	45	4.03	3.80	2.22	2.16	0.83	0.85
16	1.73/1.63	61/57	5.42	4.52	2.98	2.55	1.01	0.90
			difference: present model − published model					
Zapletal [23]			-0.16	-0.17	0.11	0.10	0.00	0.01
6 – 17 years			-0.28	-0.29	0.11	0.14	-0.16	-0.14
Czech Rep. 1977			-0.20	-0.05	0.20	0.30	-0.23	-0.20
Dab [1] [3]			0.14	-0.02	0.21	0.14	0.08	0.09
3 – 22 years			0.08	-0.16	0.27	0.20	-0.14	-0.12
Belgium 1979			-0.04	0.01	0.33	0.34	-0.34	-0.22
Kristufek [4]			0.07	-0.09	0.10	0.00	0.05	-0.02
6 – 81 years			-0.15	-0.25	0.06	0.04	-0.07	-0.13
Slovakia 1987			-0.14	-0.31	0.18	0.16	-0.11	-0.25
v. d. Hardt [22]			0.01	0.00	0.21	0.25	0.09	0.13
6 – 15 years			0.13	-0.02	0.36	0.37	0.03	0.03
Germany 1976			0.46	0.25	0.62	0.55	0.07	-0.01
Michaelson [5]			0.14	-0.02	0.29	0.23	0.06	0.07
6 – 18 years			0.08	-0.16	0.32	0.25	-0.08	-0.06
USA 1978			-0.04	0.01	0.31	0.37	-0.17	-0.12

[1] Same model for boys and girls.

Table 8. — R_{tot} (kPa/l/s) in boys and girls aged 6, 10 and 14 years. Predicted values of our study and those of von der Hardt [22] and Dab [3].

Age in years	Own study	v. d. Hardt	Dab
(Height in m)	children	children	children
6 y (1.20 m)	0.88	0.73	0.91
10 y (1.42 m)	0.59	0.52	0.66
14 y (1.63 m)	0.39	0.39	0.47

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