

Predicted normal values for maximal respiratory pressures in caucasian adults and children

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ABSTRACT Maximal respiratory pressures at the mouth (PE_{\max} and PI_{\max}) have been measured in 370 normal caucasian children and adults. Age, height, and weight were recorded for all subjects and incorporated in a stepwise multiple regression analysis to determine prediction equations for the maximal respiratory pressures in the children and adults for both sexes. In men PI_{\max} and PE_{\max} were significantly correlated only with age ($p < 0.001$ and < 0.035 respectively), whereas in women they were correlated with height ($p < 0.035$ and < 0.03). In both boys and girls PI_{\max} was related to weight ($p < 0.0001$ and < 0.01 respectively) and PE_{\max} to age ($p < 0.001$ for both). The values for PI_{\max} and PE_{\max} in adults were lower than in previously reported series, but in children the values obtained were similar to those reported for several smaller series.

In recent years interest has been rekindled in methods for measurement of respiratory muscle function in patients with neuromuscular disease. One of the simplest non-invasive measurements is that of maximal pressures, generated at the mouth, after full inspiration and full expiration—that is, maximal expiratory pressure (PE_{\max}) and maximal inspiratory pressure (PI_{\max}).

These pressures have been measured with a mercury manometer¹ and by pressure gauges.² Normal values for adults have been collected by Ringqvist³ and Black and Hyatt² and measurements in patients with neuromuscular disease and obstructive lung disease have also been reported.^{4,5} Inkley *et al*⁶ studied a group of 38 American boys with Duchenne muscular dystrophy and compared the results with values from 66 normal schoolboys (aged 6–14 years), and Cerretelli *et al*⁷ studied a small group of 12 year old children.

As part of the investigation of patients with neuromuscular disease we measured PE_{\max} and PI_{\max} in a group of normal subjects and noted a wide range of normal values from these pressures in published reports. In addition, since there are limited data on PI_{\max} and PE_{\max} values in children, a larger and more comprehensive group of normal subjects

was studied in an attempt to determine normal values for British caucasian adults and children. The age range of our subjects was 7–70 years.

Methods

MEASUREMENTS

Apparatus

The apparatus was based on that used by Black and Hyatt.² Two bronze Bourdon type gauges, one with a pressure range of 0–380 cm H₂O for expiratory pressures and one with a vacuum range of 0–250 cm H₂O for inspiratory pressures, were connected via a brass E tube. The central limb of this E tube was connected to a copper tube 3 cm in diameter and 30 cm in length, with a rigid plastic flanged mouthpiece (Airmed Ltd) and a small air leak 15 cm from the mouthpiece. The outside limbs of the E tube each incorporated a brass tap, proximal to the gauge, so that each gauge could be used independently. The gauges were manufactured for our specific purpose and medically cleaned and calibrated over the range –200 to +250 cm H₂O in the factory before despatch. The calibration was linear over the whole of the working range and pressures were checked regularly with standard water manometers over the range –150 to +220 cm H₂O.

All pressures were measured without a nose clip and with the subject seated. PI_{\max} was measured at residual volume after maximal expiration and PE_{\max} at total lung capacity after maximal inspiration. The

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Accepted 7 December 1983

manoeuvre was repeated at least three times and until two identical readings were obtained. Pressures had to be maintained for at least one second. An interval of about one minute occurred between these efforts. A small leak in the circuit was necessary during both manoeuvres to prevent generation of high buccal pressures and in addition the subject held the cheeks with one hand during the manoeuvre. Children from 7 years were capable of performing the correct manoeuvre with ease.

Age, height and weight were also recorded for each subject.

SUBJECTS

We studied 135 caucasian adults aged over 18 years (table 1). All were volunteers; many were recruited from hospital staff. None had a history of chest disease or any chronic illness and none was having any regular treatment. A few were cigarette smokers and some ex-smokers, but no distinction was made between smokers and non-smokers. We also studied 235 children (distribution shown in table 1) from several schools. They were selected by teachers and all parents were informed of the tests and gave informed consent on behalf of their children. No child had any history of any chronic illness, in particular asthma, and none was having any regular medication.

STATISTICAL METHODS

In all subjects the values for the maximum respiratory pressures were plotted against the three variables measured (height, age, and weight), a stepwise multiple regression analysis⁸ being used. This analysis was used to obtain prediction equations for the maximum respiratory pressures. The three variables were included in the multiple regression

analysis for all groups but a variable was included in the prediction equation only if the multiple correlation coefficient was significant ($p < 0.05$).

The overall accuracy of the prediction equation was reflected by the square of the multiple correlation (R^2). R^2 is the proportion of variation explained by variables included in the regression equation and is an index of the strength of the relationship. Student's unpaired t test was also used for comparisons between groups of subjects.

Results

From a comparison of the group mean values (table 2) men can be seen to have generated higher pressures than women; for PE_{max} the female value was 60% of the male value, for the PI_{max} 69%. These differences were significant ($p < 0.001$), whereas there was no significant difference between the age of the groups. Both PE_{max} and PI_{max} were significantly lower in girls than in boys, the means being respectively 83% and 83% of the boys' values ($p < 0.001$: table 2). In both adults and children, values were lower for PI_{max} than for PE_{max} (on average overall PI_{max} was 79% of PE_{max}). Repeated measurements carried out in five subjects over five days gave a coefficients of variation for PE_{max} of 7.1% and for PI_{max} of 10.2%.

Table 3 shows the regression equations for prediction of PE_{max} and PI_{max} in adults and children, calculated by stepwise multiple regression analysis. The complete data with values of R^2 are given in table 4. For example, if we take the variables included in the multiple regression analysis for PI_{max} in men (table 4), only age has a significant correlation coefficient and addition of the other variables, height and weight, does not result in significance or increase R^2

Table 1 Age distribution of the subjects

Age (y)	Children			Adults			
	7-9	10-14	15-17	18-29	30-39	40-49	≥50
Males (n)	38	75	24	14	18	8	8
Females (n)	22	60	16	30	21	18	18

Table 2 Significance of the sex differences in mean maximum respiratory pressures in adults and in children (values are means with standard deviation in parentheses)

Group (n)	Age (y)	Height (cm)	Weight (kg)	PE_{max} (cm H_2O)	PI_{max} (cm H_2O)
Men (48)	34.7 (14)	179 (6)	74.5 (8.5)	148 (34)	106 (31)
Women (87)	36.8 (13)	163 (7)	61.4 (9)	93 (17)	73 (22)
Significance of t	NS	$p < 0.01$	$p < 0.01$	$p < 0.001$	$p < 0.001$
Boys (137)	11.1 (2.2)	149 (15)	41 (12)	96 (23)	75 (23)
Girls (98)	11.6 (2.5)	147 (16)	40.5 (12)	80 (21)	63 (21)
Significance of t	NS	NS	NS	$p < 0.001$	$p < 0.001$

Table 3 Prediction equations for maximal respiratory pressures in adults (over 18 years) and children (7-17 years)

Group	PI_{max} (cm H ₂ O)	PE_{max} (cm H ₂ O)
Men	$142 - (1.03 \times \text{Age}^*)$	$180 - (0.91 \times \text{Age}^*)$
Women	$-43 + (0.71 \times \text{Ht}^\dagger)$	$3.5 + (0.55 \times \text{Ht}^\dagger)$
Boys	$44.5 + (0.75 \times \text{Wt}^\ddagger)$	$35 + (5.5 \times \text{Age}^*)$
Girls	$40 + (0.57 \times \text{Wt}^\ddagger)$	$24 + (4.8 \times \text{Age}^*)$

*Age in years.
 †Height in centimetres.
 ‡Weight in kilograms.

by a significant amount. The multiple correlation squared (table 4) represents the cumulative "weight" each variable exerts on the regression equation for the prediction of PE_{max} and PI_{max} for each group.

Discussion

In view of the very wide range of maximal respiratory pressures reported in several small studies, we set out to obtain a set of prediction values for maximal respiratory pressures in both adults and children so that PE_{max} and PI_{max} could be used to assess respiratory muscle function in adults and children with neuromuscular disease. As these patients often present in their teens it was also important to obtain data for this age range. No reference values have

previously been available which fully covered the age range in which clinical measurement would be valuable.

Our measurements of maximal respiratory pressures in adults are lower than many previously published values^{2,3} (see also table 5). The reason for the differences in values obtained in the adult groups is not clear. Black and Hyatt,² whose results were lower than those of Ringqvist,³ thought it might have been because the latter used the best of many attempts, sometimes more than 20, while they used the best of two. Ringqvist³ also used a group of military conscripts. In fact, the subjects in Ringqvist's study were pushed to such great lengths that some suffered from spontaneous nose bleeding and conjunctival haemorrhages as a result of their efforts. Gibson *et al.*,⁹ using identical methods to those of this study, collected data from a small group of 10 normal caucasian women and obtained a range considerably lower than those of Ringqvist³ and Black and Hyatt² (PE_{max} 67-140 cm H₂O and PI_{max} 35-95 cm H₂O), but very similar to our results.

Our values for boys and girls are similar to those for the two groups of twenty 12 year old boys and girls of Cerretelli *et al.*⁷ (table 5). As in adults, the equivalent values for PE_{max} and PI_{max} were lower in girls than in boys. The only other study in children⁶ included 66 normal boys aged 6-14 years. No mean data were provided but the range was similar to that

Table 4 R² and significance values of each additional variable used to predict maximum respiratory pressures in a stepwise multiple regression analysis

	Step	Variable	R ² expressed as a cumulative percentage	Significance
MEN	PI_{max}	1 Age	21	0.001
		2 Height	22	0.434
		3 Weight	25	0.152
	PE_{max}	1 Age	14	0.009
		2 Weight	15	0.532
		3 Height	15.5	0.568
WOMEN	PI_{max}	1 Height	5.1	0.035
		2 Weight	6.4	0.270
		3 Age	9.8	0.084
	PE_{max}	1 Height	5.4	0.031
		2 Age	6.2	0.392
		3 Weight	8.0	0.209
BOYS	PI_{max}	1 Height	15.8	<0.0001
		2 Age	16.2	0.399
		3 Height	16.3	0.740
	PE_{max}	1 Age	35.6	<0.0001
		2 Weight	37.1	0.077
		3 Height	37.5	0.584
GIRLS	PI_{max} *	1 Weight	10.8	0.01
	PE_{max} *	1 Age	34.6	<0.0001
		2 Weight	34.9	0.495

*The significance of a variable was not calculated if it improves R²% by less than 0.1.

Table 5 Normal ranges of maximum respiratory pressures in adults and children in different studies

n	Mean age (y)		PE_{max} Mean (SD) (cm H ₂ O)	PI_{max}	Source
	Mean	Range			
MEN					
100		18-83	237 (46)	130 (32)	Ringqvist ³
60		20-54	233 (42)	124 (22)	Black and Hyatt ²
48	34.7	19-65	148 (34)	106 (31)	Present series
WOMEN					
100		18-83	165 (30)	98 (25)	Ringqvist ³
60		20-54	152 (27)	87 (16)	Black and Hyatt ²
87	36.8	18-65	93 (17)	72.9 (22)	Present series
BOYS					
66		6-14	70-201*	20-123*	Inkley <i>et al</i> ⁸
20	12	12†	96.3 (23.3)	76.5 (17.4)	Cerretelli <i>et al</i> ⁷
137	11.1	7-17	95.7 (23)	75.4 (23)	Present series
GIRLS					
20	12	12†	88.0 (16)	66.5 (19.6)	Cerretelli <i>et al</i> ⁷
98	11.6	7-17	80.3 (21)	63.1 (21)	Present series

*No mean data given in paper.

†All children studied aged 12 years.

of Cerretelli *et al*⁷ and of the present series (table 5).

Cook *et al*¹⁰ have shown the difficulty of preventing air leaks at the mouth when pressures of more than 150 cm H₂O are produced and conventional mouthpieces are used. We found the rigid plastic flanged mouthpieces were comfortable for the subjects, and by creating pressure on the cheeks during the manoeuvre high pressures could be maintained without evidence of leaks. The coefficient of variation of PE_{max} and PI_{max} obtained with our technique and apparatus in normal subjects was similar to that recorded by Black and Hyatt.²

Our results show that respiratory pressures in men are related to age; for women, however, a significant relationship was shown only with height. This may be explained by the fact that muscle mass and therefore strength fall with increasing age in men, their peak being in the second and third decade, while in women overall strength may not be related to age to such an extent. In children PI_{max} was correlated with weight and PE_{max} with age.¹

The measurement of maximal respiratory pressure allows a simple, reproducible, and rapid assessment of respiratory muscle function which is extremely useful in following the progression of respiratory weakness in patients with neuromuscular disease.^{2,6} The prediction values from this study allow interpretation of serial measurements of PE_{max} and PI_{max} in patients with neuromuscular disease from presentation, often as teenagers, through adult life.

SHW had a research fellowship from Sandoz Ltd and NTC a research fellowship from the Sir Jules

Thorn Charitable Trust. We are grateful to Miss A Betchley for typing the manuscript.

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