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Predicted normal values for maximal respiratory pressures in children

Valores preditos para as pressões respiratórias máximas em crianças

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Abstract

Introduction: Reference equations are used to predict normal values for maximal respiratory pressures. **Objectives:** To develop predictive equations for maximal respiratory pressure in children. **Methods:** A total of 144 healthy children, aged between 7 and 11 years, were assessed. Maximal inspiratory and expiratory pressures were assessed with a digital manovacuometer on top of residual volume and total lung capacity, respectively. **Results:** The variables sex, age and weight showed association with maximal inspiratory pressure, while maximal expiratory pressure, in addition to the aforementioned variables, also showed association with height. After regression analysis, only sex and age had an influence on the variability of inspiratory and expiratory pressures. **Conclusions:** The present study provides reference values and proposes two equation models that predict maximal respiratory pressure values among children aged between 7 and 11 years.

Key words: Child; Respiratory function tests; Respiratory muscles; Reference values; Muscle strength.

Resumo

Introdução: Equações de referência são utilizadas para predizer valores de normalidade de pressões respiratórias máximas. **Objetivo:** Elaborar equações preditivas para as pressões respiratórias máximas de crianças. **Métodos:** Um total de144 crianças saudáveis, com idade entre 7 e 11 anos, foram avaliadas. As pressões inspiratória e expiratória máximas foram avaliadas utilizando um manovacuômetro digital a partir do volume residual e da capacidade pulmonar total, respectivamente. **Resultados:** As variáveis sexo, idade e peso apresentaram associação com a pressão inspiratória máxima, enquanto que a pressão expiratória máxima, além das variáveis anteriormente citadas, também mostrou associação com a altura. Após a análise de regressão, apenas o sexo e a idade permaneceram exercendo influência sobre a variabilidade das pressões inspiratória e expiratória máximas. **Conclusões:** Este estudo disponibiliza valores de referência e propõe dois modelos de equação que predizem o valor das pressões respiratórias máximas de crianças entre 7 e 11 anos.

Descritores: Criança; Força muscular; Músculos respiratórios; Testes de função respiratória; Valores de referência.

Introduction

Research aimed at determining normal values and predictive equations for maximal inspiratory and expiratory pressures (MIP and MEP, respectively) in adults began in the 1960s. One of the most cited studies in the literature was carried out by Black and Hyatt[1] in 1969. Since then, several authors[2-15] have determined normal values and/or predictive equations for many populations and age groups. Despite the visible increase in the amount of research on this topic, there are still few studies regarding reference equations and normal parameters for assessing respiratory muscle strength in children.

In 1984, Wilson et al.[9] evaluated 235 British Caucasian children of both sexes, between 7 and 17 years old. For boys and girls, weight and age explained the variability of MIP and MEP. Later, Domènech-Clar et al.[10] studied 392 Spanish children aged between 8 and 17 years. For this study, independent variables explaining variability in MIP (boys and girls) and in MEP (boys) were weight, height and age.

Moreover, specific reference values are needed to assess maximal respiratory pressures in the Brazilian population. In an earlier study, Neder et al.[3] analyzed a sample of healthy adults and compared the measures obtained for maximal respiratory pressures with those predicted by equations proposed for other nationalities. These authors concluded that these equations[1,6,9,16] were unable to predict respiratory muscle strength in Brazilian adults. Two subsequent studies[2,4] found that even the equations proposed by Neder et al.[3] could not predict maximal respiratory pressures values for samples of adults from two Brazilian states. The authors attributed these differences not only to the physical traits of the samples assessed, but also to discrepancies observed between the methodologies used in the studies.

Studies have been performed with pediatric populations in several countries[9-15]. Nevertheless, in Brazil there is still a lack of studies with children and adolescents[7,15]. Heinzmann-Filho et al.[15] assessed preschool children and children aged between 3 and 12 years old and proposed predictive equations for maximal respiratory pressures of boys and girls. However, there is still a need for performing more studies with subjects of specific age groups, such as schoolchildren. Thus, this study aims to propose predictive equations and determine reference values and lower limits for maximal respiratory pressures for healthy children aged between 7 and 11 years.

Material and methods

This is a cross-sectional study[17],approved by the Research Ethics Committee at the Federal University of Rio Grande do Norte and conducted in accordance with the Declaration of Helsinki. All parents or legal guardians gave their informed consent.

Participants

A sample calculation was conducted according to the formula for estimating the mean supplied by the Laboratory of Epidemiology and Statistics of the Dante Pazzanese Institute, according to Lima et al.[18]. For the calculation, a 95% confidence level was considered (z-value = 1.96). The standard deviation and error estimate values used were those proposed by Wilson et al.[9]. The error estimate was calculated from the difference between mean MIP between the groups of boys and girls. The calculation was carried out discriminating by sex, resulting in 14 boys and 12 girls for each age group, totaling a minimum sample of 130 children. The sample included healthy children of both genders aged from 7 to 11 years old.

The following list of diagnoses and conditions were adopted as exclusion criteria: chronic lung, chronic lung, cardiovascular or neuromuscular disease; history of recent upper airway, chest or abdominal trauma; reports/history of fever (three previous weeks) and flu or a cold in the week prior to the procedure; history of smoking; obvious chest deformity; acute middle ear problems; abdominal hernia; glaucoma or retinal detachment; neurological damage; reported use of medication such as inhaled or systemic glucocorticoids, mineralocorticoids, central nervous systems stimulants, barbiturates or muscle relaxants; percentile less than 5 and greater than or equal to 85 on the body mass index (BMI) curve in relation to age and sex, as proposed by the National Center for Health Statistics[19]; evidence of acute respiratory tract disease in the period between questionnaire completion by parents and the day of data collection; alterations in respiratory or heart rate, blood pressure, and peripheral oxygen saturation (monitored during evaluation) according to normal predicted values for their age. We also excluded children who missed class; who could not perform the necessary procedures; who refused to participate; or who were unable to understand the guidelines for using the manovacuometer.

Instruments and procedures

Body weight was determined using a digital balance (Personal Scale – QIE 2003B, China), with a 150 kg capacity and accuracy of 100 g. Height was measured with a 150 cm metric tape measure, fixed to the wall 50 cm above the ground[20].

The weight/height^2 formula was applied to calculate BMI. This was then plotted on a gender-specific BMI chart for age in order to obtain the percentile value[19].

Maximal respiratory pressures were measured using an MVD300 digital manovacuometer (Globalmed®, Porto Alegre, RS, Brazil), with an operating range from -300 to +300 centimeters of water (cmH_2O), accurate to 1 cmH_2O. A flattened mouthpiece of rigid plastic was attached (Globalmed®, Porto Alegre, RS, Brazil) with a hole 2 mm in diameter on top to dissipate additional pressure caused by the contraction of facial muscles and the oropharynx[1,13,21]. A nasal clip was used for all measurements. Children received visual and auditory feedback through MVD300 data acquisition software (version 1.5).

Maximal respiratory pressure was measured by two trained evaluators according to the method proposed by both the American Thoracic Society and the European Respiratory Society[22]. Initially, subjects selected (by draw) which maximal respiratory pressure would be assessed first. Maneuvers were then demonstrated and verbally explained. When measuring MIP, children were instructed to breathe normally (at tidal volume level) for three respiratory cycles, followed by one maximal expiration (approximately up to the residual volume) at the rater's command, and then maximal inspiration (until approximate total lung capacity). Instructions were similar for MEP assessment, except that participants first performed a maximal inspiration and then maximal expiration following occlusion of the orifice[22]. The rater manually supported the subjects' cheeks during measurement. During the entire duration of the test, the children remained seated with their hips at a 90º angle and their backs against the chair. A one-minute rest was allowed between each maneuver[9,10] and five minutes between MIP and MEP assessments[12]. A maximal of nine maneuvers were performed for each maximal respiratory pressure assement[10]. Of these, at least three acceptable maneuvers were obtained (without leaking, with a duration of at least 2s[21], and sustained for 1s[22]), of which at least two were reproducible (with a difference between them of no more than 10% of the highest value). The maneuver with highest value was recorded. However, an additional measurement was taken if the final measurement was the highest[21]. Maximal respiratory pressures were evaluated in accordance with the participant's school schedule (morning or afternoon) considering that, according to Aguilar et al.[23], there is no performance variation in maximal respiratory pressures assessed at different times on the same day

Statistical analysis

Sample data were analyzed with SPSS 17.0 software (Statistical Package for the Social Sciences) at a 5% significance level.The Kolmogorov-Smirnov test was used to verify data normality. For subsequent analyses, two age groups were used, one aged 7-8 years and the other 9-11 years.

Predictive equations were constructed by multiple linear regression analysis[24]. Prior to this, Pearson's correlation was used to assess associations between the independent variables sex (0= female; 1= male), age (0= 7-8 years; 1= 9-11 years), weight and height, and maximal respiratory pressures in order to determine the order of entry for independent variables into the regression model. Variables with p values < 0.05 were added to the regression model one at a time, in descending order of the correlation coefficient and according to significance level (stepwise forward). Residual analysis was carried out to confirm normality, linearity, and equality of variance for the regression model. Lower limits of normal (LLN) for MRP were determined by subtracting the product from the value predicted with the proposed equation [1.645 x standard error of estimate (SEE)][21].

Results

From the 331children that agreed to participate in the study, 174 did not meet inclusion criteria established for this research. Thus, 157 children were included in the study. Four were excluded for refusing to participate, five for not understanding instructions, three who were unable to perform acceptable and reproducible maneuvers within the maximum number of measurements established for the study, and one for presenting a fever.Thus, the final sample was composed of 144 subjects, including 63 boys and 81 girls (mean age of 9.0 ± 1.2 years and 8.7 ± 1.2 years, respectively,and p=0.25).

Table 1 shows sample characterization through means and standard deviations of the variables weight, height, and BMI for each sex and age range. An intersex comparison of these variables for the 7 to 8-year age group showed no significant difference (weight: p=0.86; height: p=0.79 and BMI: p=0.75). A similar result was found in the 9 to11-year age group (weight: p=0.15; height: p=0.62 and BMI: p=0.05). The mean percentile was 44±24 for girls from both age groups, 58±25 for boys in the 7 to 8-year age group and 47±28 for those aged 9-11 years.

Table 1: Sample characterization as mean and standard deviation of the variables weight, height and BMI for each sex and age range

	Females (n=81)		Males (n=63)	
	7 – 8 (n=36)	9 – 11 (n=45)	7 – 8 (n=27)	9 – 11 (n=36)
Weight (kg)	26±4	33±6	27±3	33±4
Height (cm)	128±7	140±9	129±5	140±7
BMI (kg/m²)	15.7±1.4	16.7±1.6	16.4±1.2	16.8±1.5

BMI: Body mass index.

Table 2 displays the normal values and LLN for maximal respiratory pressures, expressed by sex and age range as well as the comparisons for these variables between boys and girls.

Table 3 shows the correlation matrix used to determine significant correlation between MIPand sex, age, and weight. In addition to the variables, MEPwasalso significantly correlated with height. At the end of regression analysis, weight was excluded from the MIP model and weight and height from the MEP model. Only the variables sex and agecontributed significantly to MIP (R^2=15%) and MEP (R^2=18%) (Table 4). After regression analysis, the equations were constructed as follows: MIP = 62.1 + 15.4 x Sex + 7.3 x Age and for MEP = 73.7 + 16.5 x Sex + 9.5 x Age.In the equations, girls and boys were categorized as 0 (zero) and 1 (one), respectively. The age group between 7 and 8 years old corresponds to 0 (zero), and the age group between 9 and 11 years old corresponds to 1 (one).

Table 2: Normal and lower limit values for maximal respiratory pressure as mean and standard deviation (±), by sex and age range

	Females (n=81)		Males (n=63)	
	7 – 8 (n=36)	9 –11 (n=45)	7 – 8 (n=27)	9 – 11 (n=36)
MIP (cmH_2O)	64.2 ±21.7	67.7 ±17.6	74.7 ±19·7#	86.9 ±19.2†£
MEP (cmH_2O)	77.9 ±22.8*	79.8 ±17.1*	84.6 ±15.2*	103.9 ±21.3*†£
LIN MIP (cmH_2O)	30.02	37.32	45.42	52.72
LIN MEP (cmH_2O)	41.13	50.63	57.63	67.13

MIP: maximal inspiratory pressure; MEP: maximal expiratory pressure; LLN MIP: Lower limit of normal for maximal inspiratory pressure; LLN MEP: Lower limit of normal for maximal expiratory pressure;
* p≤ 0.05 – Comparison of MIPwith MEPbetween the same sex and age subgroup;
#p< 0.05 – Comparison of MIPbetween sexes, in the same age subgroup;
† p≤ 0.0001 – Comparison of MEPbetween sexes, in the same age subgroup;
£ p≤ 0.05 – Comparison of MIPand MEPbetween age subgroups for the same sex.

Table 3: Correlation matrix between maximal respiratory pressures and anthropometric variables (sex, age, weight and height)

	MIP		MEP	
	R	p-value	R	p-value
Sex	0.37	0.0001	0.38	0.0001
Age (years)	0.18	0.02	0.22	0.004
Weight (kg)	0.16	0.03	0.19	0.01
Height (cm)	0.08	0.16	0.18	0.02

MIP: maximal inspiratory pressure; MEP: maximal expiratory pressure; r: correlation coefficient.

Discussion

Findings in this study suggest that boys 7 to 11 years old have greater MIP than girls of the same age. However, this difference is only recorded among 9 to 11-year-old boys when assessing MEP. In contrast, Gaultier and Zinman[11] found that only MEP was higher for boys in the 7 to 8-year age range. More recent research showed greater maximal respiratory pressures in boys and girls from all age groups studied, although this difference was more pronounced in children 11 years and older. Outcomes in the present study are closer to those of Domènech-Clar et al.[10] This difference in results might be related to the distribution in the number of children in each age group in the different studies[11,12]. It may also be due to the methods employed, since the two studies with discrepant results were conducted in the 1980s and important changes may have occurred in the measuring instruments used.

Although some authors[11,12] have stated that girls achieve adult

Table 4: Multiple linear regression models (stepwise forward) used to construct predictive equations for maximal inspiratory and expiratory pressures

	R^2 adjusted	Coefficient (β)	SE	95% CI	p value
MIP	0.15				
Intercept		62.108	2.840		
Sex (categorized)		15.378	3.288	8.877-21.879	0.0001
Age (categorized)		7.317	3.288	0.816-13.818	0.028
MEP	0.18				
Intercept		73.672	2.879		
Sex (categorized)		16.505	3.334	9.914-23.096	0.0001
Age (categorized)		9.523	3.334	2.932-16.113	0.005

MIP: maximal inspiratory pressure; MEP: maximal expiratory pressure; Intercept: a mathematical constant; R^2: adjusted coefficient of determination; Coefficient (β): the mathematical weightings of the explanatory variables in the equation; SE: estimated precision of the coefficients; 95% CI: 95% confidence intervals for the coefficients.

values for maximal respiratory pressures-sooner than boys, the present study recorded a significant increase with advancing age only among boys. These results corroborate those of Szeinberg et al.[14], who found that the effect of age on maximal respiratory pressure was more evident in males.

Comparative analysis of MIP and MEP demonstrated that MEP was always 12% to 15% higher than MIP, regardless of the subject's sex and age. Wilson et al.[9] found that MEP for the sample studied was 21% greater than MIP. This outcome may be due to the fact that inspiratory maneuvers are considered more difficult to perform, primarily for children[13]. This is likely due to greater difficulty in coordinating and activating respiratory muscles[25]. Curiously, Tomalak et al.[13] recorded lower values for MEP than MIP in both sitting and standing positions, although the authors did not discuss this finding.

Findings in this study indicate a small, but significant correlation between sex, age, and weight with MIP. Regarding MEP, in addition to these variables, a correlation was also observed with height. Most research with children[9-11,13,14] also refers to the correlation of these pressures with sex and age, although there is no consensus regarding correlation with anthropometric data. Other authors have also stated that forced vital capacity[14,15] and muscle area[12] may interfere with maximal respiratory pressures. This lack of consensus is also observed in studies of other age groups[3-6]. However, discussion of these correlations was hindered by insufficient detail regarding the behavior of these variables prior to presenting the predictive equation models proposed in most studies.

Multiple linear regression analysis is the most commonly used predictive mathematical model, in addition to the coefficient of determination (R^2), which is generally applied to assess the model's predictive power[24]. In the present study, the explicative power of multiple linear regression indicated that sex and age explained only 15% and 18% of inspiratory and expiratory muscle strength, respectively, in the proposed model. Previous research evaluating samples of children[9,10]also provided mathematical models for predictive equations with similar values ofR^2. In a study by Wilson et al.[9], predictive power for MIP in boys was 15.8% and 10.8% among girls, whereas values recorded by Domènech-Clar et al.[10] for girls and boys were 21% and 40%, respectively. In the study of Arnall et al.[8], performed with children, the R^2varied from 8%to 26% for girls and boys, respectively. Despite establishing age as a predictive variable for MEP in boys and girls, Wilson et al.[9] determined weight as the only variable that influenced MIP in both sexes. Recently, Domènech-Clar et al.[10] also found that age interferes with MIP and MEP among boys and girls. However, the current study demonstrated that interaction between weight and height is also a determinant in MIP variability for both sexes and in MEP among boys. By contrast, Heinzmann-Filho et al.[15] observed that height and weight were able to predict MIP for both sexes, while MEP was influenced by age and weight for both boys and girls.

Gaultier and Zinman[11] assessed maximal respiratory pressuresfrom residual volume, residual functional capacity, and total lung capacity. The authors determined that the best multiple regression analysis model for MEP included age and sex for all lung volumes. In regard to MIP based on residual volume and total lung capacity, the predictor model included only sex and height, whereas in MIP-based on residual functional capacity, age was added to these two variables. For these authors, the fact that age increased prediction of maximal respiratory pressure suggests that maturation or growth factors interfere with respiratory muscle strength.

Given the substantial variation of normal values recorded in studies evaluating respiratory muscle strength, LLN has been used to identify whether an individual exhibits respiratory muscle weakness[26], thereby avoiding a false positive result[27]. Despite their significant clinical usefulness, little research has been conducted to provide LLN for maximal respiratory pressures[3,5,28]. The nonexistence of these parameters for children is an aggravating factor and emphasizes the need for comparative studies.

The present study sought to extrapolate findings from other investigations that also propose lower limits of normal for maximal respiratory pressures in children. Thus, for each parameter, if the measured value is less than the proposed LLN, probability of respiratory muscle weakness is 95%[21]. The primary relevance of this parameter may be during evaluation of children with neuromuscular disorders,since loss of muscle strength occurs before reduced lung volume is detected[29].

One of the limitations in this study was the failure to assess spirometry variables. However, families were questioned on the presence of respiratory symptoms in children. Furthermore, the independent variables studied were able to predict only part of the variability of maximal respiratory pressures. Thus, it is suggested that future studies investigate the possible existence of other predictor variables (such as body surface, regular sports activities, or forced vital capacity) for MIP and/or MEP of children, including those of other age groups.

Conclusions

This study allowed us to conclude thatonly age and sex explained variability in maximal respiratory pressures. It was therefore possible to provide reference values and two models of predictive equations for maximal respiratory pressure of Brazilian children aged from 7 to 11 years, as well as lower limits of normal for MIPandMEPin this age range.

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