ORIGINAL ARTICLE

Reference Value of Impulse Oscillometry in Taiwanese Preschool Children

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Received Jan 9, 2014; received in revised form Aug 25, 2014; accepted Sep 8, 2014
Available online 8 November 2014

Key Words
impulse oscillometry; preschool children; reference value; Taiwanese

Background: Impulse oscillometry is a potential technique for assessing the respiratory mechanism—which includes airway resistance and reactance during tidal breathing—in minimally cooperative young children. The reference values available in Asian preschool children are limited, especially in children of Chinese ethnicity. This study aimed to develop reference equations for lung function measurements using impulse oscillometry in Taiwanese children for future clinical application and research exploitation.

Methods: Impulse oscillometry was performed in 150 healthy Taiwanese children (aged 2–6 years) to measure airway resistance and reactance at various frequencies. We used regression analysis to generate predictive equations separately by age, body height, body weight, and gender. The stepwise regression model revealed that body height was the most significant determinant of airway resistance and reactance in preschool young children.

Results: With the growth in height, a decrease in airway resistance and a paradoxical increase in reactance occurred at different frequencies. The regression curve of resistance at 5 Hz was comparable to previous reference values.

Conclusion: This study provided reference values for several variables of the impulse oscillometry measurements in healthy Taiwanese children aged 2–6 years. With these reference data, clinical application of impulse oscillometry would be expedient in diagnosing respiratory diseases in preschool children.

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http://dx.doi.org/10.1016/j.pedneo.2014.09.002
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1. Introduction

The measurement of respiratory function has a key role in diagnosing and monitoring respiratory diseases. However, lung function testing is limited in the preschool population because of the poor performance and lack of cooperation by children. The impulse oscillometry system (IOS) is a simple and noninvasive technique for measuring lung mechanics during tidal breathing. Its use of external pressure signals and the resultant flows are calculated to determine lung impedance. The lung impedance is a complex sum of lung resistance (Rrs) and reactance (Xrs). The resistive component of impedance (i.e., Rrs) includes the resistance of the whole airway, lung tissue, and chest wall. The reactance component of impedance (i.e., Xrs) comprises the mass-inertive forces in phase of air volume and the elastic property of the lung periphery. Compared to spirometry, the IOS is able to offer more specific information with regard to the resistive and elastic properties of the respiratory system. Resistance derived from the IOS is strongly correlated with resistance, as measured by plethysmography and interrupter. Furthermore, through measurements obtained from bronchodilator and provocation tests, the IOS can also provide helpful information in the diagnosis and monitoring of asthma status in young children.

Several studies have recently reported the reference values of the IOS in Caucasian children. Reports also have addressed such measurements in Korean children. However, no data have been available for children of Chinese ethnicity. The aim of this study was to create comprehensive reference values and equations using the IOS in healthy Taiwanese children aged 2–6 years for future clinical application.

2. Materials and methods

2.1. Participants

This is a cross-sectional study performed in kindergarten children from northern Taiwan. The Ethics Committee of the Chang Gung Memorial Hospital (Taoyuan, Taiwan) approved the study. Informed consent was obtained from the parents or legal guardians of the children. A short questionnaire was mailed to the parents prior to the examinations. The questionnaire was designed in accordance with the GAP (Global Academic Program) conference criteria and excluded children with ineligible conditions such as premature birth with a gestational age of <36 weeks, chronic respiratory diseases, physician-diagnosed asthma, and respiratory infection during the preceding 4 weeks. Among the 181 children initially recruited, a total of 150 children were enrolled in the study. Thirty-one children were excluded because of physician-diagnosed asthma (n = 10), recent respiratory infection (n = 8), premature birth (n = 3), or inability to cooperate during the test (n = 10). The uncooperative children were all <3 years old. The age of enrolled children ranged 29–76 months and their body height ranged 86–123 cm.

2.2. Procedures

The measurements were performed using a commercially equipped impulse oscillometer (MasterScreen; Jaeger, Würzburg, Germany), and conformed to the recommendations of the American Thoracic Society/European Respiratory Society on the forced oscillation technique. In brief, during the measurements, the children were seated, breathed through a mouthpiece, and wore a noseclip with cheek and mouth floor firmly supported. The computer-generated oscillatory signal was delivered to the participant via a pneumotachometer and a low-resistance filter connected to the mouthpiece. The output pressure and flow signals were analyzed for their amplitude and phase difference to determine the components of the respiratory impedances, which were the resistance (Rrs) and reactance (Xrs). During the measurements, the flow signal was monitored for signs of glottis closure and air leakage. The measurements were considered acceptable only when the time segment chosen for analysis lasted for at least 20 seconds. For most children, two measurements were sufficient to obtain useful readouts; a maximum of nine measurements were nonetheless needed in eight children. The Rrs and Xrs were recorded at 5 Hz, 10 Hz, 15 Hz, 20 Hz, 25 Hz, and 35 Hz. The resonance frequency was also recorded. The area of the reactance curve below zero was subsequently computed. The average Rrs between 5 and 20 (mean, R5–20) was also calculated.

2.3. Statistical analysis

Stepwise multiple linear regression was performed to identify the best predictor among various parameters of the IOS by using height, age, body weight, and gender as potential independent variables. The 5th percentile and 95th percentile were calculated using parametric methods. All statistical analyses were performed using IBM SPSS Statistics version 20 (IBM, Armonk, NY, USA).

3. Results

Table 1 summarizes the demographic data of the participants. Fifty-four percent were boys. There were no differences between boys and girls in age, body height, body weight, and body mass index.

In stepwise regression analysis (which included the variables age, body height, body weight, and gender), body height was the strongest independent variable for all parameters of the IOS. Except for Xrs at 35 Hz (X35) and resonance frequency, all IOS parameters were significantly dependent on the standing body height. Table 2 summarizes the linear regression equations and residual standard deviations for all the variables. Figure 1A and B show Rrs at 5 Hz (R5) and 20 Hz (R20) versus the standing body height of all participants. Figure 1C and D show the mean Rrs between 5 Hz and 20 Hz (R5 and R20) and the difference between Rrs 5 Hz and Rrs 20 Hz (R5–R20). The relationship between age and R5 is further illustrated in Figure S1 in the supplementary material online. Figure S2 in the
Table 1  Demographic data of children participating in the study.

<table>
<thead>
<tr>
<th>Demographic data</th>
<th>Boys (n = 81)</th>
<th>Girls (n = 69)</th>
<th>Total (n = 150)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mo)</td>
<td>55.0 ± 12.6 (31–76)</td>
<td>54.0 ± 13.8 (29–75)</td>
<td>54.6 ± 13.1 (29–76)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>106.0 ± 7.9 (90–123)</td>
<td>105.0 ± 9.7 (86–123)</td>
<td>105.1 ± 8.8 (86–123)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>18.0 ± 3.8 (11–28)</td>
<td>18.0 ± 3.8 (10–28)</td>
<td>18.6 ± 3.8 (10–28)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.7 ± 2.0 (11.9–24.0)</td>
<td>16.5 ± 2.0 (10.4–25.4)</td>
<td>16.7 ± 2.0 (10.4–25.4)</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD (range).

BMI = body mass index.

Table 2  Regression equations for all variables.

<table>
<thead>
<tr>
<th>Parameters (Kpa/L/s)</th>
<th>Coefficient of height (SE)</th>
<th>Intercept (SE)</th>
<th>R²</th>
<th>RSD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>R5</td>
<td>−0.0134 (0.0022)</td>
<td>2.4395 (0.2283)</td>
<td>0.280</td>
<td>0.211</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R10</td>
<td>−0.0103 (0.0016)</td>
<td>1.9250 (0.1732)</td>
<td>0.222</td>
<td>0.165</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R15</td>
<td>−0.0079 (0.0015)</td>
<td>1.5680 (0.1598)</td>
<td>0.201</td>
<td>0.160</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R20</td>
<td>−0.0069 (0.0015)</td>
<td>1.3888 (0.1556)</td>
<td>0.150</td>
<td>0.148</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R25</td>
<td>−0.0067 (0.0014)</td>
<td>1.3653 (0.1480)</td>
<td>0.139</td>
<td>0.145</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R35</td>
<td>−0.0079 (0.0015)</td>
<td>1.6104 (0.1542)</td>
<td>0.181</td>
<td>0.149</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>X5</td>
<td>0.0036 (0.0014)</td>
<td>−0.6408 (0.1504)</td>
<td>0.100</td>
<td>0.152</td>
<td>0.009</td>
</tr>
<tr>
<td>X10</td>
<td>0.0048 (0.0011)</td>
<td>−0.7383 (0.1189)</td>
<td>0.139</td>
<td>0.120</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>X15</td>
<td>0.0041 (0.0009)</td>
<td>−0.6087 (0.0913)</td>
<td>0.143</td>
<td>0.091</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>X20</td>
<td>0.0026 (0.0006)</td>
<td>−0.3542 (0.0668)</td>
<td>0.147</td>
<td>0.066</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>X25</td>
<td>0.0014 (0.0006)</td>
<td>−0.1033 (0.0599)</td>
<td>0.100</td>
<td>0.061</td>
<td>0.002</td>
</tr>
<tr>
<td>X35</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
</tr>
<tr>
<td>Rf</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
<td>NS</td>
</tr>
<tr>
<td>AX</td>
<td>−0.0686 (0.0163)</td>
<td>10.4286 (1.7161)</td>
<td>0.139</td>
<td>0.163</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>mean R5–20</td>
<td>−0.0102 (0.0017)</td>
<td>1.9152 (0.1774)</td>
<td>0.229</td>
<td>0.179</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>R5–R20</td>
<td>−0.067 (0.0015)</td>
<td>1.0656 (0.1604)</td>
<td>0.180</td>
<td>0.162</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

AX = the area of reactance curve less than zero; mean R5–20 = mean resistance in the range of 5–20 Hz; R5, R10, R15, R20, R25, and R35 = respiratory resistance (Rrs) at 5 Hz, 10 Hz, 15 Hz, 20 Hz, 25 Hz, and 35 Hz, respectively; R5–R20, difference between R5 and R20; Rf = resonance frequency; RSD = residual standard deviation; SE = standard error; X5, X10, X15, X20, X25, and X35 = respiratory reactance (Xrs) at 5 Hz, 10 Hz, 15 Hz, 20 Hz, 25 Hz, and 35 Hz, respectively.

Figure 1  The respiratory resistance (Rrs) at (A) 5 Hz and (B) 20 Hz versus standing height in all participating children (n = 150). The mean Rrs between 5 Hz and 20 Hz versus (C) height. The difference between Rrs at 5 Hz and Rrs at 20 Hz versus (D) height is also shown. Curves indicated the regression line ±2 residual standard deviation (RSD).
supplementary material online shows the regression curves and coefficients of equations for boys and girls. Among the four body height ranges (86–95 cm, 96–105 cm, 106–115 cm, and 116–125 cm), the resistance decreased gradually with increasing body height (excluding R35). With the exception of X25, the reactance increased proportionally with increasing frequency (Figure 2A and B).

4. Discussion

This study is the first to report impulse oscillometry measurements in preschoolers of Chinese ethnicity. Our report showed that the variables of IOS, especially Rs, were closely associated with body height. In a stepwise multiple regression analysis model, gender, body weight, and age did not improve prediction. Figure 3 shows a comparison of the reference ranges of resistance at 5 Hz from our study and other previous studies.2–4,10–13 Except for the outliers of two studies,2,11 our regression curve was comparable to most curves of other studies in the body height range of 90–120 cm. The variations between these studies may be because of differences in equipment, measurement protocol, and study population (e.g., population cohort or kindergarten). However, the regression curve of Taiwanese children was very close to the curves of children in Poland and children of preschool age in Finland.4,13

Owing to significant variations of reference values among different studies and populations (Figure 3), comparison is difficult when only the mean predicted curve was associated, and more so if variability is not taken into consideration. Considering the outlier spread of the observed value, it is better to express the observed data by the z-score.14 The value of the z-score [i.e., (the observed value – the predicted value)/residual standard deviation] can measure how an observed result lying from that expected in the population. Table 2 shows the values of the residual standard deviation of the variables, which are necessary for calculating the z-scores. The result facilitated the interpretation and comparison of results between different laboratories.

Because of poor cooperation and performance in unseated preschool children, it is difficult and time-consuming to obtain reliable values using spirometry and body plethysmography. To date, the IOS is apparently the only technique to measure respiratory mechanism without much difficulty in preschool young children. In this study, only 56% (13/23) of children younger than 3 years old were willing to cooperate, which allowed acceptable values to be collected. The number was sufficient for statistical analysis. With regard to children older than 3 years, consistent and reliable values were obtained after several trials of practicing. Thus, the IOS can be a useful tool to study the development of lung mechanics in healthy and diseased children aged 3–6 years.

The reference values of IOS should ideally be based on unbiased sampling so that the results can represent the whole population. Ethnicity, socioeconomic status, and air pollution exposure are factors that affect respiratory development and lung function.15,16 Because nearly all Taiwanese are of Chinese ancestry, ethnic differences were few in this study population. However, because of the study design, it was difficult to control the socioeconomic status and pollution exposure in this study. The enrolled children...
should similarly have been healthy. However, it was difficult to define health and select the appropriate participants. In this study, we applied the minimal exclusion criteria to exclude children with obvious clinical risk factors for respiratory developmental anomalies and children with illnesses that may affect test performances. This was performed to minimize the differences between the predicted value in the study and the predicted value of the selected sample of the general population.

In this study, Rrs and Xrs at different frequencies were analyzed for different body height ranges. According to previous reference data, Rrs was inversely related to body height, and this correlation was most noticeable at 5 Hz (R5), which demonstrated the deepest regression curve. Some studies have shown that resistance measured at 5 Hz offered more useful clinical information than measurements at higher frequencies when assessing bronchodilatation or the methacholine challenge test in preschool children with asthma.16

In our pilot study of bronchodilator testing in preschool children with mild to moderate asthma, a strong correlation existed between alterations at R5 and alterations of spirometric parameters, especially in FEV1 and FEF25–75 (see Figure S3 in the supplementary material online). Shi et al18 also recently showed that R5, the difference between R5 and R20 (R5 − R20), and the area of reactance curve less than zero were able to predict loss of asthma control in children with mild to moderate asthma.

In this study, Xrs appears to be positively associated with height at lower frequencies (i.e., 5–15 Hz). At higher frequencies, Xrs is essentially independent of height. This trend is similar to the findings in previous reports.9,12,17 Because Xrs reflects the elastic and mass-inertial properties of the respiratory system, Xrs at lower frequencies (which reflect the peripheral lung compartment) gradually increase as the number of alveoli grows. Recent studies show that X5 is sensitive to the correlation with the change in FEV1, while a patient performs exercise and the methacholine challenge test.19,20

In summary, this study reported reference values of respiratory resistance and reactance using impulse oscillometry in Taiwanese preschool children. Our study showed that the IOS has a great prospective utilization for measuring lung mechanics in children 3–6 years of age. Because the IOS is of clinical value in children with respiratory disease, the reference data from this study will be helpful in the clinically applying the IOS in small young children of the Chinese ethnicity.

Conflicts of interest

The authors have no conflicts of interest to declare relevant to this article.

Acknowledgments

This study was sponsored by CMRPG2B0061-3 of Chang Gung Memorial Hospital (Taoyuan, Taiwan). The authors thank Chien-Ting Shen for technical assistance.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.pedneo.2014.09.002.

References


