Impulse Oscillometry*

Reference Values in Children 100 to 150 cm in Height and 3 to 10 Years of Age

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Objectives: **To generate reference equations in North American children to be used for assessing respiratory function through the forced oscillation (Rfo) technique, and to determine the changes in oscillatory resistance, reactance, and resonant frequency (Fres) in relation to age, body height, and weight.**

Design/setting: **A prospective cross-sectional study performed on healthy children selected according to strict criteria of American Thoracic Society and European Respiratory Society recommendations.**

Measurements: **Triplicate measures were obtained of resistance and reactance at 5, 10, 15, 20, 25, and 35 Hz as well as Fres through the impulse oscillometer (MasterScreen IOS; Jaeger/Toennies; Höchberg, Germany). Two hundred twenty-two white children—normally distributed within the 3- to 10-year age range and 100 to 150 cm in height—were recruited in Montreal, Canada. We used regression analysis to generate multiple predictive equations separately per gender and frequency on age, height, and body weight.**

Results: **Stepwise multiple regression in both natural and logarithmic forms for height, weight, age, and gender showed that standing height was the only significant predictor for all variables. Minimal variability was noted in each subject among the triplicate measurements ($p = 0.68$ to 0.96). Coherence was > 0.9 at all oscillating frequencies except 5 Hz (< 0.72), with tendencies to lower values in young children.**

Conclusions: **Resistance and Fres decrease by height, but also by age; and reactance increases. As opposed to our past experience with spirometry in compatible age groups, the Rfo technique was well accepted by preschool children.** ***(CHEST 2005; 128:1266–1273)***

Key words: children; pulmonary function; reference values; regression

Abbreviations: ATS = American Thoracic Society; AX = area of the reactance curve less than zero; ERS = European Respiratory Society; Fres = resonant frequency; Rfo = forced oscillation

As a noninvasive and effort-independent technique, respiratory resistance obtained by the forced oscillation (Rfo) technique is well suited for lung function measurement in young children.[1–5] Previous publications[1,6–8] in adults have confirmed the strong correlation between airway resistance measured by body plethysmography and respiratory resistance measured by forced oscillation, thus attesting to the validity of this technique. We and others[4,7–9] have demonstrated the general applicability of this Rfo technique in previously untrained asthmatic children aged > 3 years and tested during an acute exacerbation but using a different device. Rfo measurements depend on reproducible tidal breathing. Children of preschool age can better adhere to this test in contrast to spirometry/pulmonary function testing, which, albeit established, requires the subject to perform a more difficult maneuver. Indeed, we have demonstrated that children at the age of 3 years can perform Rfo at a 50% success rate.[4,9]

Reference values have been published previously

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for children using random frequency[10] and fixed frequency (6 to 10 Hz). Several commercial devices for the measurement of oscillatory resistance at multiple frequencies have become generally available (MasterScreen IOS; Jaeger/Toennies; Höchberg, Germany; and Vmax System R.O.S. Oscilink; SensorMedics; Yorba Linda, CA),[9,11,12] superseding previous equipment at fixed frequencies. Nevertheless, reference values specific for this measurement technique are required to interpret resistance measurements obtained in children for whom no prior best values are available. The only reference values that have previously been reported using an Rfo technique were limited to children from 3 to 6 years old.[7,13] Furthermore, there are no published reference values obtained with the Rfo system for North American children.

The selection of a normal population to establish reference values has been carefully defined by the European Respiratory Society (ERS) and the American Thoracic Society (ATS).[14,15] Only healthy children free from conditions known to adversely affect ventilatory function should be considered, with adherence to these strict recommendations being documented. Furthermore, although the strongest determinant of lung function parameters is height, models have also occasionally included age and/or weight.[16] It is also well recognized that gender and/or race frequently influence the relationship between these determinants and lung function parameters.[17] Nevertheless, the purpose of this study was to elaborate specific reference values of Rfo and concomitant variables for North American children using the ATS and ERS recommendations.

Materials and Methods

We conducted a cross-sectional study of patients and/or accompanying siblings, aged 3 to 10 years, who presented at the Ophthalmology or General Surgery Clinics of the Montreal Children Hospital. Patients were accrued over two consecutive summers, at a time when viral infections were minimal. The protocol was reviewed and approved by the Institutional Review Board, and informed consent for participation was obtained for each subject from parents or guardians.

Study Subjects

In accordance with the ATS and ERS recommendations for the selection of healthy subjects,[14,15] exclusions occurred for the following reasons: (1) personal or family history (including parents and siblings) of wheezing or asthma[18,19]; (2) personal history of allergic rhinitis[20,21] or eczema[22,23]; (3) low birth weight ($< 1{,}500$ g)[24,25]; premature birth (< 37 weeks), neonatal mechanical ventilation, or bronchopulmonary dysplasia[26,27]; (4) passive smoking in the house[28,29]; (5) obesity (weight for height $> 95\%$ of predicted)[30]; (6) concurrent upper respiratory tract infection[31–33]; (7) dyspnea, cough, wheezing, accessory muscle use, or an abnormal ($< 95\%$) oxygen saturation level as measured by pulse oximetry (Nellcor N10; Nellcor; Hayward, CA); or (8) any other contraindication in obtaining respiratory resistance measurement (such as a significant facial or oral abnormality). Subjects could be enrolled only once in the study to ensure independence of participants and of the pertinent recorded data.

Procedures

Assessment of respiratory function through the Rfo technique is used on a daily basis in our clinic. In 2003 only, of a total of 3,997 children evaluated for pulmonary function, the Rfo technique was employed in 761 children, the majority of whom were of preschool age. However, for the purposes of the current study, potentially eligible subjects visiting the Ophthalmology or General Surgery Clinics were approached and initially screened by questionnaire. The 12-item questionnaire, extracted from the International Study of Asthma and Allergies in Childhood questionnaire,[19,34] screened for a personal and family history suggestive of asthma, eczema, and rhinitis. Moreover, we added three questions related to exposure to cigarette smoke (current smoking by the immediate family, regular exposure to secondhand smoke, and regular exposure to active or passive smoking in the preceding year).

A trained researcher (J.F. or J.J.) approached all subjects, and measurements were obtained independent of the results of the screening questionnaire. This study reports only the data for subjects who were retained after analysis of the questionnaire. Demographic data, including age, gender, race, and medical history, were recorded, along with height by stadiometer (Holtain Ltd; Crymych; Dyfed, UK) and weight by an electronic scale (Ancaster Scale; Brantford, ON, Canada). The absence of respiratory symptoms as well as the normality of oxygen saturation ($> 95\%$) was documented by the interviewer.

For all assessing subjects, three replicate measurements of oscillatory resistance (Rfo) were obtained using the system software (MasterLab, Version 4.53; Jaeger/Toennies). Resistance measurements were retained for analysis if reproducible, that is, if the coefficient of variation between replicate measurements was < 0.15.[35–37] Furthermore, we aimed for a coherence measurement of > 0.9 at all frequencies in all children.

For measurement of respiratory resistance, the standing child was asked to breathe quietly for 15 to 20 s using a rigid oval mouthpiece with a tongue guard, with the head in a neutral position, nose clips in place, and while supporting both cheeks. This Rfo technique has been described in detail elsewhere.[7]

Briefly, small, square-wave pressure oscillations (< 0.1 kPa) were superimposed on the spontaneous breathing pattern of the child, with pressure and airflow variations measured by a pneumotachograph-transducer system at the mouthpiece. The magnitude and phase of the flow oscillations resulting from the pressure fluctuations are dependent on the total impedance of the respiratory system. Through the phase relationship between pressure and flow, the impedance is then partitioned into the resistance and the imaginary portion, the reactance. For the respiratory system, resistance represents the effective resistance of lungs and chest wall, whereas reactance is the net effect of the two opposite (a compliant and an inertial) components. Each recording on the MasterScreen IOS assessment yielded both the expiratory resistance and reactance at different oscillatory frequencies between 5 Hz and 35 Hz within the flow range of normal tidal breathing. In addition, the resonant frequency (Fres) [*ie*, the frequency at which the reactance was zero] and the area of the reactance curve less than zero (AX) were also computed. All computations occur automatically with the MasterLab software.

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