Plethysmographic Measurements of Specific Airway Resistance in Young Children*

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Validated methods for lung function measurements in young children are lacking. Plethysmographic measurement of specific airway resistance (sRaw) provides such a method applicable from 2 years of age. sRaw gauges airway resistance from the measurements of the pressure changes driving the airflow during tidal breathing. These measurements require no active cooperation and are therefore feasible in children from 2 years of age. The within-observer and between-observer variability of sRaw in young children compare favorably with alternative methods. Reference values are available for sRaw and have allowed discrimination of young children with respiratory disease. Bronchial hyperresponsiveness can be determined with acceptable short-term and long-term repeatability and provides good discrimination between asthmatics and healthy young children. The effects of the major antiasthmatic therapies have also been documented by this technique, and sRaw has recently been used in longitudinal studies of young children with chronic pulmonary diseases. Future developments should provide improved algorithms for thermal correction of the respired volumes and adapt the equipment to the special needs of young children. This article reviews the method, and proposes a protocol and criteria for quality assurance for assessment of sRaw in preschool children from 2 years of age. sRaw measurements offers a method for clinical monitoring and research during this critical period of growth and development early in life. ***(CHEST 2005; 128:355–362)***

Key words: airway resistance; child; method; preschool; specific airway resistance

Abbreviations: BTPS = body temperature and pressure, saturated; ICC = intraclass correlation coefficient; Pamb = ambient pressure; PH_2O = pressure of water vapor at body temperature; Raw = airway resistance; SDb = between-subject SD; SDw = within-subject SD; sRaw = specific airway resistance; sRawTOT = parameter line connecting the flow points at maximum change in plethysmographic volume (pressure); sRawVmax = parameter line connecting the maximum flow points; $sRaw_{0.2}$ = parameter line connecting the points where the flow reaches 0.2 L/s; $sRaw_{0.5}$ = parameter line connecting the points where the flow reaches 0.5 L/s; $sRaw_{50\%}$ = parameter line connecting the points where the flow is 50% of the maximal flow; TGV = thoracic gas volume; $\dot{V}$ = air flow; Vpleth = plethysmographic volume; ΔVpleth = change in plethysmographic volume

Longitudinal cohort studies[1,2] suggest that outcomes in older children and adults with asthma may be determined primarily in early childhood. Measurement of lung function such as spirometry plays a key role in the management of children with chronic lung diseases such as asthma and cystic fibrosis, while such objective parameters are difficult in the age group < 6 years old. There are some measurements of lung function available for infants, while methods for measurements in the period between infancy and school children are sparsely reported. Whole-body plethysmography has been documented for measurements of airway resistance (Raw) in young children from 2 years of age.

Plethysmography was introduced by DuBois et al[3] in 1956 for the assessment of Raw. The measurement of Raw requires a two-step procedure, with initial appraisal of the specific Raw (sRaw) through simultaneous recording of air flow and plethysmographic volume (Vpleth) swing during tidal breathing, and subsequent measurements of the thoracic gas volume (TGV) through recording of Vpleth swing and the corresponding mouth pressure swing while the subject performs tidal inspiratory and expiratory breathing (panting) against a closed shutter. Raw is

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then calculated as the ratio of sRaw/TGV. The procedure for measurement of TGV is poorly tolerated by young children, who often refuse or who perform the breathing maneuver against the closed shutter unsatisfactorily. Omitting this latter step provides measurements of sRaw and greatly facilitates the procedure allowing its use even in young children as suggested in 1976 by Dab and Alexander,[4,5] but was not assessed until the recent decade.

Plethysmographic measurements of sRaw have lately been successfully adapted and approved for use in children from 2 years of age.[6–23] Appropriate use of an adapted facemask, and an adult accompanying the child in the box has increased acceptance of this method.[8] The approach to measurements of flow and pressure swing in a plethysmograph during tidal breathing is noninvasive and acceptable for use in awake young children from 2 years of age. The technique allows measurements during normal tidal breathing and requires only the passive cooperation of the child, independent of the child's ability to follow verbal instructions.

It is the aim of this article to further a wider dissemination of measurements of sRaw in young children in research as well as in clinical practice. With this aim, this article explains the simple principles of sRaw measurements, reviews the data on the validity of the method in young children, proposes a protocol for assessing sRaw, and suggests areas for future research.

Physics

sRaw is a measure of airway caliber-comprising effects of lung size. sRaw reflects the overall dimensions of the airway, including the effect of lung expansion on the caliber of the airway. Since sRaw is the product of Raw and TGV, it cannot distinguish if improvements are due to either of its two components. Breathing at different levels of lung volume might give the same sRaw, although the relationship between Raw and TGV differs. Likewise, other principles of lung function measurements do not distinguish the effect of lung volume on the flow or resistance.

Any increase, however, of Raw or increase of TGV or both results in an elevated sRaw. Similarly, sRaw will decrease if either Raw or TGV or both are minimized, and a normal sRaw would indicate that both Raw and TGV must be in a normal range. That is why sRaw is the more dynamic parameter, as supported in empiric data comparing sRaw and Raw in asthmatics and healthy children.[24] In summary, sRaw is always reflecting the complete respiratory tract, consisting of both resistive and volume properties.

Measurements of sRaw

The child breathes though a flowmeter (pneumotachograph) recording the flow ($\dot{V}$) while seated inside a sealed, volume-constant box equipped with a pressure transducer that records changes of pressure inside the plethysmograph (Fig 1). This enables the measurement of the variations of the pressure in the plethysmograph due to the compression of the lung gas volume during expiration and decompression during inspiration through the breathing cycle, *ie*, the effort driving the flow is reflected as the pressure swing within the box. Calculating the Raw from pressure difference and flow is analogous with Ohms law of resistance in an electric circuit.

Volume and pressure in the plethysmograph is calibrated before measurements, whereby the change in Vpleth (ΔVpleth) is measured through the change in box pressure. The simultaneous recordings of $\dot{V}$ and ΔVpleth are depicted as the specific resistance loop and the inserted straight parameter line from which sRaw is calculated (Fig 2):

$$\text{sRaw} = (\Delta\text{Vpleth}/\Delta\dot{V}) \times (\text{Pamb} - PH_2O)$$

Figure 1. A 3-year-old child in the whole-body plethysmograph. ΔV indicates the volume (pressure) swing caused by the child's thoracic excursions during tidal breathing as measured by pressure transducers in the box. $\dot{V}$ indicates the respiratory flow during tidal breathing as measured by the pneumotachograph. sRaw is assessed from the ratio $\Delta V/\dot{V}$.