Plethysmographic specific airway resistance

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child; preschool; specific airway resistance

Summary sRaw measurements are feasible in children from 2 years of age. sRaw allows clinical monitoring and research during this critical period of growth and development in early life. sRaw measurements promise to bridge the gap of lung function measurements between infancy and school age.

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Plethysmographic specific airway resistance (sRaw) have been successfully adapted for use in children from 2 years of age.1,2

Plethysmographic measurement of airway resistance was introduced by DuBois in 1956.3 Alveolar pressure is reflected by minute changes in plethysmographic volume (using Boyle’s Law) during inspiration and expiration and airflow is measured with a pneumotachograph. In DuBois’ original method Raw is calculated from dividing sRaw by the thoracic gas volume at functional residual capacity (FRC). First, sRaw was measured from simultaneous recording of airflow and plethysmographic volume changes during tidal breathing and second, FRC was determined from recording of plethysmographic volume changes and the corresponding mouth pressure changes during tidal inspiratory and expiratory efforts against a closed shutter. Young children do not tolerate the latter. A simple algebraic manipulation of the formulas which precluded the separate measurements of Raw and FRC omitting this latter step, provided measurements of sRaw, which greatly facilitates the procedure even in young children.4,5

sRaw reflects the overall dimensions of the airways, including the effect of lung expansion on the caliber of the airways. Since sRaw is the product of Raw and FRC, it cannot distinguish if improvements or deteriorations are due to either or both of its two components.

sRaw measurements employ a constant volume whole-body plethysmograph (body-box), which in principle is a sealed cabin built for use in adults. The cabin is equipped with a pressure transducer that records pressure changes.1,2

PRACTICAL ASPECTS

Flow (V) in the airways and variations of the pressure in the box are simultaneously measured as the child breathes through the pneumotachograph using a mouthpiece and nose clip or specially adapted face-mask with a large cushion and a built-in flexible tube, while seated inside the box. Volume and pressure in the box are calibrated routinely before measurements whereby changes in box volume (∆Vbox) are measured through changes in box pressure.1 The simultaneous recordings of V and ∆Vbox are depicted as the specific resistance loop and the inserted straight parameter line from which sRaw is calculated as:

\[ sRaw = \left( \frac{\Delta V_{\text{box}}}{\Delta V} \right) \times (P_{\text{amb}} - P_{H_2O}) \]

where Pamb is ambient pressure, PH2O is the pressure of water vapor at body temperature, and Pamb – PH2O is the approximate thoracic gas pressure.4,5

To ensure slight neck extension and thereby preventing airway compression from the neck as well as to improve the co-operation, a monitor showing video cartoons is placed in front and above the subject during all measurements.1 Communication via microphone and loudspeaker ensures instruction of the child and adult during testing. Since sRaw measurements are now routinely performed...
with automatic electronic BTPS compensation, which has been shown to exhibit positive frequency dependency\(^6,7\) all measurements should be made at recommended breathing frequencies from 30 to 45\(^7\) as a standard procedure to minimize the influence of breathing frequency in the measurements. If the child refuses to enter the box alone or is otherwise uncooperative, measurements can be attempted with an adult person accompanying the child inside the plethysmograph.\(^7,8\) Such measurements exhibit good correlation with values obtained from the child alone.\(^7,8\) The adult performs a constant slow expiratory maneuver for a period of 20 s thereby allowing sufficient time for measurement of \(sR\) of the child. Such maneuvers gives rise to a slight continuous drift of the signal measuring changes of plethysmographic volume, which is corrected for by the data processing software together with any drift from temperature build-up, both of which are easily separated from the more rapid pressure changes from the child’s breathing.

### QUALITY CONTROL OF MEASUREMENTS

On-line display of the loops allows detection of artifacts. The decision whether to accept or reject a measurement can be made during and after the measurements. \(sR\) is usually reported as the mean of the median from at least two sets of at least 5 consecutive and technically satisfactory loops.

### RELIABILITY

The standard deviation of \(sR\) has been reported as 0.20 kPa s and the within-subject SD (SDw) as 0.11 kPa s. CVw% is 8–11%.\(^4,7,9\) Repeatability appears to be independent of age\(^9\) and measurements of \(sR\) with and without an accompanying adult do not alter repeatability.\(^7\)

### NORMATIVE DATA

\(sR\) is independent of height, age and gender,\(^9\) provided it is calculated as pressure/flow changes between points of maximum pressure (\(sR_{TOT}\)). Considerable caution is required when interpreting results in young children, since prediction equations in commercially available equipment usually default to values based on historic data collected at least 20 years ago with heated rebreathing systems. These tend to give predicted values approximately half those obtained when using electronic ‘thermal compensation’ to correct for phase lags between box pressure and flow\(^7\) such that even a healthy subject will appear to have abnormally elevated results. An international initiative to collate \(sR\) data in healthy preschool children from various labs around the world will address this problem within the next few years. In the meantime, normative ranges between approximately 0.9 to 1.7 kPa s,\(^9\) using facemask with mouthpiece.

### ACCEPTANCE

Measurement is accepted in >80% of healthy 2–7 year old children, but success rate increases by age.\(^9\) In a birth cohort study of 766 children, 66% completed measurements at age 3.\(^10\)

### CLINICAL APPLICATION

#### Asthma: discrimination between health & disease

\(sR\) was significantly increased in selected groups of preschool asthmatics compared to healthy controls and in randomly selected groups of preschool asthmatics.\(^1\) In fact, \(sR\) discriminated more accurately between healthy and asthmatics than Raw.\(^11\) \(sR\) was significantly higher in 3 year old children who wheezed at least once during the first 3 years of life than in those who had never wheezed.\(^10\)

#### Asthma: bronchial challenge & Bronchial Hyperresponsiveness (BHR)

Cold air challenge (CACH) is feasible in 2 to 5 year old children.\(^2,12\) BHR to CACH, defined as an increase in \(sR\) of >20% was found in 68% of asthmatics and 7% of controls and may serve as an adjunct to diagnosis.\(^12\) Hyperventilation with dry room temperature air may function as an alternative.\(^3,14\)

#### Asthma: efficacy of asthma medication

The ability of \(sR\) to discriminate between patients and control subjects as reflected by bronchodilator responsiveness (BDR) was assessed in 55 asthmatics and 37 healthy preschool children.\(^15\) A greater BDR was found in patients attesting to the increased bronchomotor tone in asthmatics. A BDR of >25% increase in \(sR\) may be a helpful indicator of asthma in young children. BDR and broncho-protective efficacy of the long-acting \(\beta_2\)-agonist formoterol was studied in 12 preschool asthmatics and a consistent 80% protection against CACH for at least 8 hours post-dose was demonstrated.\(^16\) A significant bronchoprotective action of Leukotriene Receptor Antagonists (LTRA) was shown in a DBPC crossover study in 13 preschool asthmatics.\(^17\) CACH produced a 46% increase in \(sR\) after placebo, and a 17% increase after 2 days of LTRA.

In an explorative study in 38 preschool asthmatics it was assessed whether lung function measures, including BHR to CACH, could serve as supplementary tools in assessing response to ICS therapy.\(^18\) ICS improved BHR to CACH in addition to conventional symptom-scores.

#### Cystic fibrosis

\(sR\) may be a useful tool in CF during early childhood. Reduced lung function was documented in a cross sectional...
and from consistently abnormal levels of SRaw and FEV₁ in a longitudinal study. BDR and response to CAC were normal.20

REFERENCES