

Lung Function Testing in Preschool Children

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The accumulating evidence of increased incidence of asthma in early childhood and the possible impact of early environment on pulmonary function outcome justify the development of reliable lung function tests to evaluate airway obstruction and reactivity in the preschool child. Ideally, the subject is required to be either fully cooperative - for measurements such as vital capacity and forced expiratory volume in one second (FEV1) - or completely passive, i.e. asleep, for measurements of spontaneous breathing. Daytime sleep is difficult to obtain in the 3-6 year old, at least in the laboratory environment, and measurements must be done during sedation. Some methodological issues related to lung function in preschool children will be reviewed briefly, particularly spirometry and respiratory mechanics and how they apply to the identification of airway reactivity.

Spirometry may occasionally be performed in preschool children. The validity of VC and FEV1 was thoroughly studied in a population of 3-5 year old children at first visit. Reproducibility of FEV1 was found to meet ATS criteria, i.e., a difference within 5% or 100 ml between the two best maneuvers, in 56% of baseline - and 39% of postbronchodilator measurements.¹ This illustrates the difficulty in keeping the child's attention and cooperation throughout a testing session. In another study, children aged 7-10 years were shown to have an increased reliability in FEV1 at subsequent visits.² The underlying respiratory disease also was an important determinant and poor reproducibility of FEV1 was associated with shortness of breath, wheezing, diagnostic of asthma and airway hyperreactivity.² These findings are in keeping with the well-known association between severity of asthma and peak flow variability. Forced expiratory flow at functional residual capacity has also been proposed to assess airway obstruction in preschool children. This parameter appears to be subjected to the additional variability of end expiratory lung volume.

Spirometry could therefore be helpful in some but not all preschool children to estimate the degree of airway obstruction, but not to assess bronchomotor responses that require repeated measurements. However, training may improve the reliability of FEV1. The development of

spirometry in the preschool child also requires proper normative data, as well as an adaptation of quality control. Particularly, the end of test criteria should take into account the fact that young children may empty their lungs in one second or less, a possible indication of the relatively lower specific airway resistance (sRaw) in early childhood compared to adulthood.

Non invasive measurements of respiratory mechanics that minimally interfere with the child's behavior and impose little constraint have gained popularity with the development of digital, easy-to-use equipment, although the principles of these methods have long been described. Airway or respiratory resistance reflects the caliber of the entire airways. The larynx and upper airways contribution to increased airway resistance with lower airway obstruction will be included in either of these measurements. These parameters are thus likely to be more sensitive - and to show more variability - than FEV1 which more specifically expresses flow limitation associated with alteration in small airways.

Airway resistance is calculated as the product of sRaw by thoracic gas volume. The latter requires a high degree of understanding and cooperation that may not be obtained in the preschool child. sRaw, on the other hand, may be measured from the relationship between airway flow and plethysmographic volume. However, a great part of this signal is related to change in temperature and humidity of the respired gas, which may be minimized by panting through a dead space or breathing a gas conditioned to BTPS (e.g., 4). Alternatively, an electronic compensation, based on the assumption that the thermal effect is entirely in phase with tidal volume, has been introduced in some plethysmographs and used for measurements in preschool children. However, since the change in condition of the respired gas is not

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instantaneous, the "electronically corrected sRaw" shows substantial frequency dependence.⁶ In order to ensure meaningful within and between subjects comparison, measurements should thus be performed in a narrow range of frequencies. Finally, the interpretation of an increased sRaw should take into account the fact that it may correspond to an increase in airway resistance or thoracic gas volume or both. This may be particularly relevant when sRaw is the only parameter measured during airway challenge.

The interrupter and the forced oscillation techniques are increasingly used to measure respiratory resistance (Rrs). Both require the measurement of flow, and transrespiratory pressure (Prs), *i.e.*, pressure at the airway opening minus pressure around the chest. The interrupter technique is based on the assumption that the change in Prs observed immediately after a sudden occlusion of the airways at their opening, is entirely explained by the cessation of flow. Rrs may then be obtained by relating the change in Prs to the flow value immediately preceding the occlusion. The technique gives consistent results in normal subjects⁷ and has been shown to detect airway response to bronchomotor agents.^{8,9} A potential limitation is related to the fact that in the presence of mechanical inhomogeneity of the lung, pressure may not equilibrate instantly along the airways after interruption. The forced oscillation technique allows the calculation of Rrs by varying Prs in a frequency domain radically different from the subject's breathing, and relating Prs to the corresponding flow changes. It is also possible to calculate respiratory reactance, the out of phase component of respiratory impedance. Respiratory reactance reflects - to a certain extent - the apparent elasticity of the respiratory system which may be altered when the lung becomes heterogeneous or when the bronchial obstruction predominates in peripheral airways. Promising reports of the use of a variant of this technique to diagnose airway response to methacholine in small children have been published.¹⁰ However, the upper airway shunt may represent a significant limitation in young children¹¹ and this artifact may be minimized quite efficiently by varying pressure around the head rather than directly at the airway opening.¹²

The analysis of breath sounds has been applied to the detection of bronchial responsiveness in young children^{13,14} A change in their frequency distribution has been shown to be associated with a change in FEV1. A weaker association was also found between the reduction in breath sound intensity and FEV1.¹³ Finally, some physiological measurements have little to do with

quantification of airway obstruction and have yet proven valuable in identifying bronchoconstriction, since they are affected by alteration of the intra- but not extrathoracic airways. These measurements would be expected to show less sensitivity but more specificity than conventional respiratory mechanics. For instance, the decrease in transcutaneous PO₂ (PtcO₂) occurring in response to methacholine probably indicates an alteration in the ventilation - perfusion relationship. This measurement is attractive because it requires no cooperation and is proving increasingly helpful in this age range.¹⁵ Further studies may show the development of other noninvasive tests such as the change in profile of expired CO₂.

Lung function is increasingly studied in preschool children, with special interest in airway reactivity. There is a need for a general agreement on the respective value of the various techniques currently in use. It may be expected that the diagnosis of bronchial hyperreactivity in preschool children, for instance, will improve by combining an index of the primary airway response (*e.g.* Krs) with one estimating an effect of the bronchoconstriction (*e.g.*, alteration in PtcO₂). The ultimate validation of such tests includes an evaluation of how well the measurements predict asthma later in childhood.

REFERENCES

1. Kanengiser S, Dozer AJ. Forced expiratory maneuvers in children aged 3 to 5 years. *Pediatr Pulmonol.* 1994; 18:144-149.
2. Studnicka M, Frischer T, Neumann M. Determinants of reproducibility of lung function tests in children aged 7 to 10 years. *Pediatr Pulmonol.* 1998; 25:238-243.
3. Taussig LM. Maximal expiratory flows at functional residual capacity: a test of lung function for young children. *Am Rev Respir Dis.* 1977; 116:1031-1038.
4. Haluszka J, Willim G, Cutrera R, Ronchetti R, Filtcher S. A correction formula for computing specific airway resistance from a single-step measurement. *Pediatr Pulmonol.* 1989; 6:118-121.
5. Klug B, Bisgaard H. Measurement of the specific airway resistance by plethysmography in young children accompanied by an adult. *Eur Respir J.* 1997; 10:1599-1605.
6. Peslin R, Duvivier C, Malvestio P, Benis AR, Polu JM. Frequency dependence of specific airway resistance in a commercialized plethysmograph. *Eur Respir J.* 1996; 9:1747-1750.
7. Oswald-Mammosser M, Llerena C, Speich JP, Donat L, Lonsdorfer J. Measurements of respiratory system resistance by the interrupter technique in healthy and asthmatic children. *Pediatr Pulmonol.* 1997; 24:78-85.
8. Phargoo SE, Watson RA, Pride NE, Silverman M. Accuracy and sensitivity of the interrupter technique for measuring the response to bronchial challenge in normal subjects. *Eur Respir J.* 1993; 6:996-1003.

9. Frey U, Kraemer R. Oscillatory pressure transients after flow interruption during bronchial challenge test in children. *Eur Respir J*. 1997; 10:75-81.
10. Bisgaard H, Klug PI. Lung function measurement in awake young children. *Eur Respir J*. 1995; 8:2067-2075.
11. Marchal F, Haouzi P, Peslin R, Duvivier C, Gallina C. Mechanical properties of the upper airway wall in children and their influence on respiratory impedance measurements. *Pediatr Pulmonol*. 1992; 13:28-33.
12. Marchal F, Mazurek H, Habib M, Duvivier C, Derelle J, Peslin R. Input respiratory impedance to estimate airway hyperreactivity in children: standard method versus head generator. *Eur Respir J*. 1994; 7: 601-607.
13. Malmberg LP, Sorva K, Sovijärvi ARA. Frequency distribution of breath sounds as an indicator of bronchoconstriction during histamine challenge test in asthmatic children. *Pediatr Pulmonol*. 1994; 18:170-177.
14. Pasterkamp H, Kramann SS, Wodicka GR. Respiratory sounds. Advances beyond the stethoscope. *Am J Respir Crit Care Med*. 1997; 156:974-987.
15. Wilts M, Hop WCJ, Van der Heyden GHC, Kerrebijn KF, De Jongste JC. Measurement of bronchial responsiveness in young children: comparison of transcutaneous oxygen tension and functional residual capacity during induced bronchoconstriction and dilatation. *Pediatr Pulmonol*. 1992; 12:181-185.