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ASSESSMENT OF PULMONARY FUNCTION IN PRESCHOOL CHILDREN

S. Sonnappa and P. Aurora

Pulmonary function tests (PFT) are increasingly used in preschool children for clinical assessment and monitoring early childhood respiratory diseases. However, objective assessment of pulmonary function in children aged 2–6 yrs represents a major challenge. Children in this age group are too old to sedate but are unable to cooperate actively in many of the physiological manoeuvres required for the PFT. They need to be constantly engaged and encouraged by the operator to participate in the test and produce technically viable results, as they are easily distracted.

Despite these challenges, a wide range of PFTs has been successfully performed in preschool children in suitable measurement conditions. These include: incentive spirometry, specific airway resistance (sR_{aw}) measured in a plethysmograph, interrupter resistance (R_{int}), forced oscillation technique (FOT), functional residual capacity (FRC) using gas dilution techniques, and measurements of gas-mixing indices by multiple breath washout. In recognition of these attempts, an American Thoracic Society (ATS)/European Respiratory Society (ERS) statement on pulmonary function testing in preschool children has recently been published [1].

An overview of some of the techniques currently used to measure pulmonary function in the preschool child is presented here.

Spirometry

Spirometry is the most frequently used method for measuring lung function. There is increasing evidence that preschool children are able to perform technically acceptable spirometry. However, these children have difficulty meeting some of the quality-control criteria outlined in the ATS/ERS guidelines for older children and adults. To perform spirometry, the older child or adult must inspire to total lung capacity (TLC), exhale forcefully to residual volume (RV), and repeat the manoeuvre several times until reproducible flow–volume curves are evident. Young preschool children have small absolute lung volumes and large airway size relative to lung volume compared with older children and adults. Forced expiration is therefore completed in a short time, certainly more quickly than the 6 s recommended for adults, but sometimes more quickly even than 1 s. Therefore, the forced expiratory volume in one second (FEV_1) may not be an accurate index of bronchial obstruction in this age group. Recent studies have explored the utility of forced expiratory volumes in 0.5 s ($FEV_{0.5}$) or 0.75 s ($FEV_{0.75}$) as outcome measures in this age group. ▶

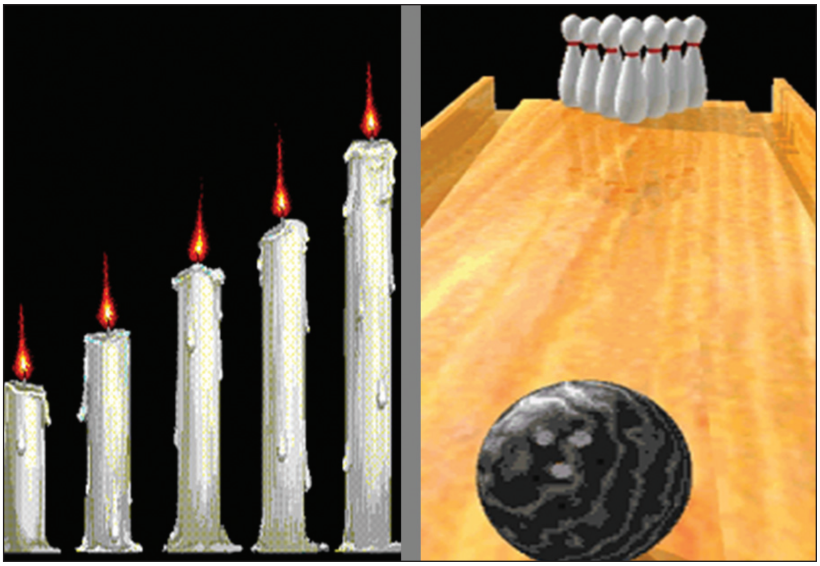

Figure 1. Two examples of breath-activated computer animation programs.

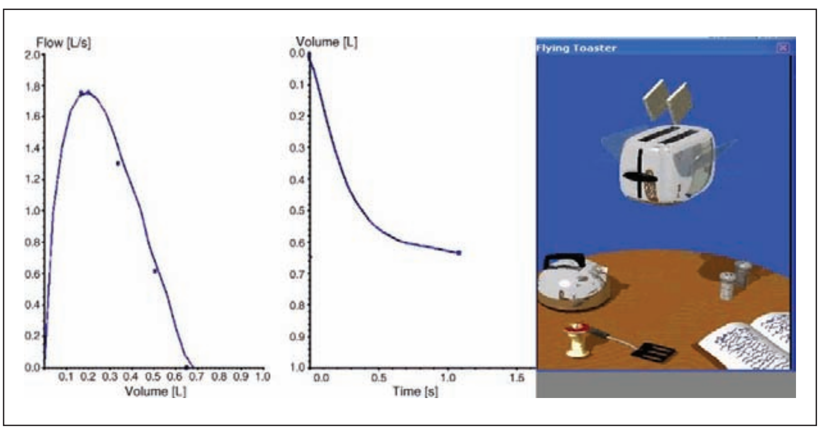

Figure 2. Technically acceptable flow volume loop with incentive spirometry.

Figure 3. Plethysmographic measurement of specific airway resistance.

Success in achieving maximal forced expiration in preschool children may be increased by use of incentive spirometry computer programs (fig. 1). These programs display interactive cartoon games in which the object of the game is achieved if the subject produces a complete forced expiration. However, it is not essential to use incentives as investigators have achieved acceptable preschool data using only verbal training and encouragement. Visual inspection of the flow–volume and volume–time curves is essential for quality control. Preschool subjects are more likely to produce technically inadequate expirations than older subjects, and are also likely to become bored or tired if the test session is prolonged unnecessarily. It is therefore advantageous if the operator is able to visualise these curves on screen, or at least before the next effort (fig. 2).

Plethysmographic measurement of specific airway resistance

Plethysmographic measurement of s*R*aw may serve to assess lung function in children from 2 yrs of age. Measurements are obtained during normal tidal breathing without requiring reproducible forced manoeuvres as in spirometry; the technique requires only the passive cooperation of the conscious preschool child. Assessment of s*R*aw in preschool children is fundamentally based on a method introduced by DuBois in 1956 [2]. In DuBois' original method, airway resistance (*R*aw) was calculated by Boyle's law. However this method requires measurement of FRC during a shutter occlusion and some preschool children find this difficult. Most preschool labs therefore use the modified calculation described by Dab and Alexander [3] in 1976, where s*R*aw is measured directly. s*R*aw reflects the overall dimensions of the airways, including the influence of lung volume on airway calibre. As s*R*aw is the product of *R*aw and FRC, it does not discriminate if improvements or deteriorations are caused by either component. Any change in *R*aw or FRC or both results in abnormal s*R*aw. s*R*aw is therefore more sensitive than *R*aw, as demonstrated in asthmatics and healthy children. s*R*aw measurements have been successfully adapted and approved for use in preschool children in a number of studies in asthma and cystic fibrosis. Measurements employ a constant-volume whole-body plethysmograph, which in principle is a sealed cabin built for use with adults (fig. 3). s*R*aw measurements performed with commercially available electronic body temperature and pressure, saturated (BTPS) compensation exhibit positive frequency dependency. When electronic BTPS compensation is used, measurements should be made at breathing frequencies of ▶

30–45 breaths·min^{-1}, which will also reduce the risk of disturbance caused by irregular breathing. Most children aged 2–3 yrs usually breathe at the required frequency spontaneously, but coaching of children aged >3 yrs may be required. An increase in breathing frequency and flow results in an unacceptable increase in s*R*aw (fig. 4). s*R*aw is calculated as the median value of five technically satisfactory specific resistance loops. Despite being an important assessment of pulmonary function, the body plethysmograph is bulky and expensive, a factor that restricts the availability of such tests to specialised centres.

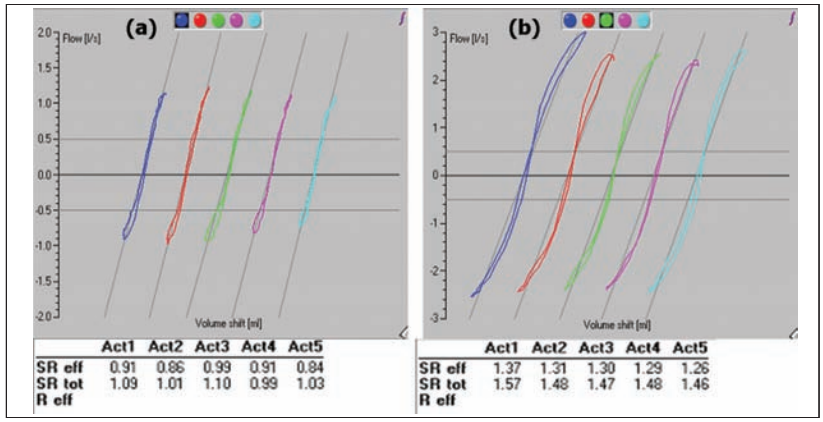

Figure 4. a) Acceptable specific airway resistance (sRaw) loops. b) Unacceptable changes due to increase in breathing frequency (50% increase in sRaw with increased respiratory rate).

Interrupter technique

The measurement of airway resistance using the interrupter technique (*R*int) is currently in routine use in several laboratories for the evaluation of lung function in preschool children, both as a research and as a clinical tool. It is particularly useful in preschool children as it is effort-independent and noninvasive, requires minimal cooperation and is able to detect changes in airway calibre. *R*int measurements may be obtained using plethysmography or portable equipment such as the Micro*R*int machine using a flowmeter, a pressure measurement device, and a flow interruption system. The principle of the interrupter technique is that, during a sudden airflow interruption at the mouth, alveolar pressure and mouth pressure (*P*mo) will rapidly equilibrate. *R*int is defined as this pressure divided by the airflow measured immediately before interruption. The clinical interpretation of the interrupter resistance in preschool children has recently been made easier by the availability of reference values for this age group. *R*int measurements appear to be most useful in the assessment of bronchodilator responsiveness, where it is found to be as sensitive as spirometry. Several studies have shown the usefulness of the interrupter technique in evaluating airway response to methacholine in asthmatic preschool children, although its sensitivity has been reported to be lower than that of body plethysmography.

Forced oscillation technique

The FOT, or impulse oscillometry, requires minimal cooperation as it is performed during tidal breathing and is therefore useful to measure airway function in preschool children. A number of studies have demonstrated that the FOT is able to identify airway obstruction and responses to bronchodilators and bronchoconstrictors. It measures respiratory impedance (*Z*rs) and respiratory reactance (*X*rs), thereby differentiating between resistive and elastic elements during tidal breathing. Measurements of respiratory impedance have a potential role in the measurement of changes in lung mechanics in young children. The technique involves applying positive and negative pressure oscillations and flow impulses generated by a loudspeaker to the respiratory system (lungs and chest wall) during tidal breathing. The resultant peaks in maximal impulse pressure and flow signals are measured and used to calculate resistance, reactance and impedance. The pressure oscillations may be applied at single or multiple ranges of frequencies and the response of the lungs depends on the frequency of the applied pressure oscillation. The lower frequencies (1–2 Hz) primarily reflect the behaviour of the parenchyma while the higher frequencies (>5 Hz) reflect the mechanical properties of the conducting airways. For clinical applications of FOT, it is usual to apply a medium frequency range, 4–20 Hz. FOT is a growing technique and has the potential to improve the diagnosis of airway obstruction, including reversibility and hyperactivity, and thus, monitoring disease progression.

The multiple-breath inert gas washout technique

The multiple-breath inert gas washout (MBW) method estimates distribution of ventilation in the lungs and lung volume during washout of an inhaled mixture of inert gases. Inert gases are harmless and are not absorbed into the body in significant amounts. Several inert marker gases with low solubility in blood and tissues can be used for MBW. The most well known is nitrogen, which can be washed out from the lungs by letting the patient breathe pure oxygen. ▶

Other gases, such as argon, helium, or sulphur hexafluoride (SF_6), may also be used, but measuring these gases may require expensive equipment, such as a mass spectrometer. A number of parameters can be derived from this technique. The two reported from our laboratory are: the lung clearance index (LCI), which is calculated as the cumulative expired gas volume required to lower the end-tidal tracer gas concentration to 2.5% of its starting concentration, divided by the resting lung volume/FRC; and the mixing ratio (MR), which is calculated from the ratio between the ideal and actual number of breaths needed to lower the end-tidal tracer gas concentration to a specified level. Other centres also report moment ratios. This technique has been successfully adapted for use in infants and young children, who are simply required to breathe through a mask or mouthpiece for 2–3 min. No special manoeuvres are required and measurements can be repeated after 5–10 min. The child is asked to breathe the gas through a face mask (fig. 5) until the lungs are equilibrated with this mixture – the wash-in phase (fig. 6). The gas supply is then removed, and the child breathes air. Any inert gas in the child's lungs at the end of the wash-in period will therefore be cleared over a number of breaths when the gas supply is removed. The change in concentration of inert gas through this washout period is monitored. The washout continues until the concentration of expired inert gas has fallen to 2.5% of the

Figure 5. A 4-yr-old girl performing the multiple-breath inert gas washout technique. The photograph is taken during the wash-in phase when a tracer gas mixture containing 4% SF_6 is inspired via (a), a bias flow from large bore anaesthesia tubing. (b) is a Fleisch pneumotachometer, connected to (c) a transparent face mask which is sealed with therapeutic putty ensuring an airtight seal. (d) is a sampling capillary from the respiratory mass spectrometer.

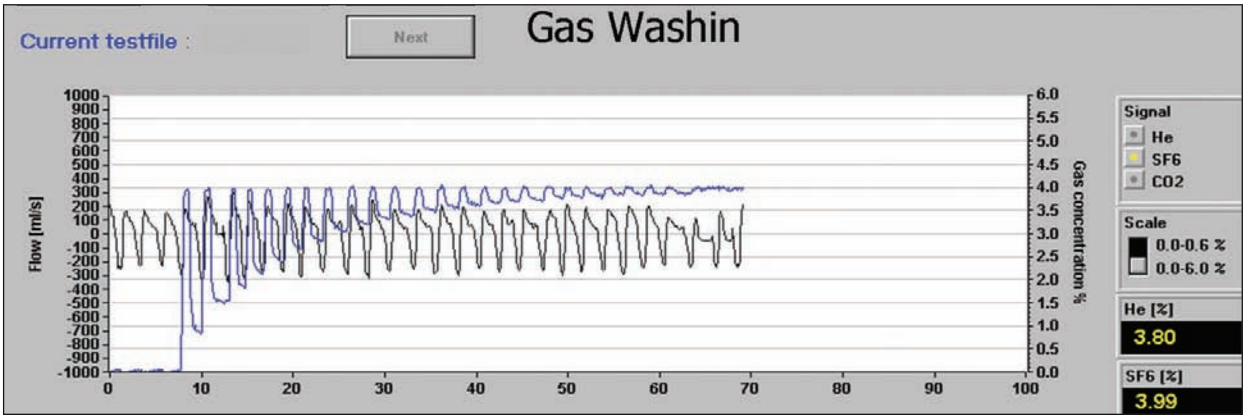

Figure 6. Wash-in curve. The black trace represents flow and the blue trace represents SF_6 concentration. The SF_6 concentration on inspiration increases with each breath, as the resident gas of the lung progressively reaches equilibrium with the inspired gas.

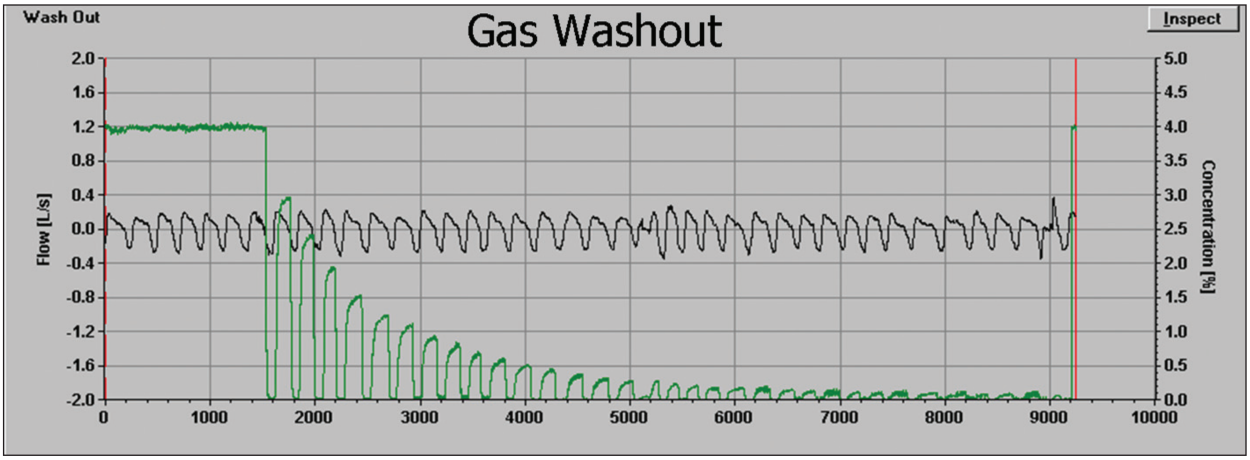

Figure 7. Washout curve. The black trace represents flow and the green trace represents SF6 concentration. The SF6 concentration on expiration falls with each breath, as the resident gas of the lung is progressively diluted by the inspired air.

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original value (fig. 7). Analysis of the change in SnIII slope through the washout can give information as to the location of airways disease and the contributions from conductive (S_{cond}) and acinar (S_{acin}) zones to total inhomogeneity can be estimated. The MBW method appears to be particularly useful as a tool to evaluate lung function in preschool children because it requires only passive cooperation and tidal breathing. Currently, MBW is performed routinely in preschool children in only a limited number of laboratories, presumably because suitable equipment is not commercially available.

Clinical implications

It is increasingly recognised that even young preschool children can perform various PFTs. Little doubt exists about the value of these tests in clinical and epidemiological research. However the influence of these tests on the clinical management in an individual child is still debatable as it is a growing field and most of these tests are not yet standardised for use in this age group.

Conclusions

Measurement of lung function in preschool children is now feasible. It is difficult to answer the question "Which test is best in the preschool age group?" As with the other age groups, one test will not answer all questions. Systematic studies using a range of tests are needed before a place for each can be ascertained. ■

FURTHER READING

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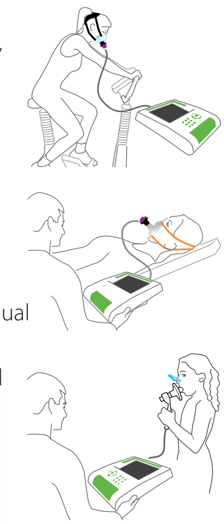

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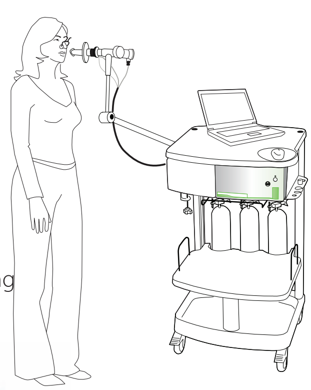

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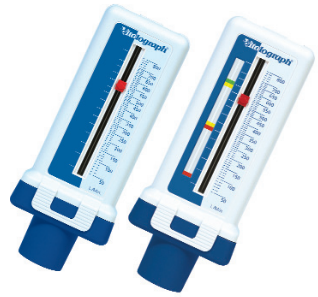

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