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Lung function testing in pre-school children

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The measurement of lung function in preschool children is important in the development of our understanding of the natural history of lung diseases in this age group, often with their origin in prenatal life or early infancy. Many of these conditions will persist throughout childhood and may form the basis of long term illness and chronically impaired lung function even into adult life. They are also useful for making a diagnosis, monitoring disease progress and assessing the effects of treatment.

The measurement of lung function in this age group presents a number of challenges. Many such young children are unable to perform specific respiratory manoeuvres used in older children. They have a short attention span so may need to be otherwise distracted, for example, by videos or encouraged to perform “incentivised” fun based games which are attached to the lung function equipment. Children with underlying disease and impaired lung function, the ones most likely to benefit from such measurements, are even more unlikely to be able to cooperate fully in what is requested of them.

As in all laboratory based measurement systems, equipment specially designed and adapted for use in this age group is required. Factors relevant to this include the relatively small lung volumes to be measured, the need to minimise equipment dead space and the short time in which data must be acquired.¹ It is also important that normative data for this age group are available for boys and girls, appropriate to body size and ideally for different ethnic groups.² A great deal of work is already under way in order to achieve this goal.

Spirometry

As in older age groups spirometry is one of the most useful measurements of lung function.³ The respiratory manoeuvre involved is to measure the time taken to breathe from a maximal inspiration at total lung capacity (TLC) down to residual volume (RV) - the forced vital capacity (FVC). This produces volume-time and flow-volume curves which can be analysed in a number of different ways. One of the most useful values is the forced expiratory volume (FEV) compared to time or to the percentage of vital capacity expired.

In older patients the FEV1 is the most commonly measured parameter. This represents the forced expiratory volume in 1 sec. In the preschool age group volumes expired in 0.5 s or 0.75 s may be used. This is because by 1 sec many such children have already reached their FVC. The maximum expiratory flow (MEF) at a defined percentage of FVC can also be calculated. MEF75 is the flow when 75% of the FVC remains in the lungs and MEF25 is the flow when 25% of the FVC remains.

The performance of such manoeuvres in preschool children requires particular cooperation and understanding to start at full inspiration and then to perform a maximal expiratory manoeuvre in a single non-stop breath. Special techniques have been developed by highly skilled paediatric respiratory measurement staff to facilitate such measurements. Apart from an understanding and empathy with such young children these techniques include computer-based breath activated programmes built into the spirometers which pictorially reward successful attempts at testing. These include blowing out candles, blowing up a balloon or sending a bowling ball to knock over skittles. Several

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successful attempts are necessary in order to produce reliable and reproducible results. Children of this age also appreciate stickers which reward their success in testing. The parents should take part whenever possible as they can encourage their children and can be congratulated if the measurements are successfully completed. It is most important to inspect each volume-time and flow-volume curve in order to ensure that there are no artefacts which can easily be produced by coughing, involuntary glottic closure or insufficient effort to reach maximal lung volume or to complete the manoeuvre down to residual volume.

Reporting of flow-volume results requires careful review of a number of tests in order to show reproducibility and to ensure that the values reported represent the best that the child has been able to achieve on the day of testing. Ideally a variation of less than 10% between loops is desirable. Aurora et al.⁴ have published data on quality control in this age group and several studies of normal values have been reported.⁵⁻⁸

As in older children spirometry is particularly useful in the diagnostic evaluation, measuring response to treatment and long-term monitoring of young children with asthma and other wheezing disorders. It has also been shown to be useful in the detection and assessment of early airway changes in young children with cystic fibrosis.^{9,10}

Given the correct child-orientated laboratory environment, appropriately trained personnel and age adapted equipment for spirometry, these measurements in this age group have now moved from the experimental to the routine for the majority of young children.

Forced Oscillation Technique

One measurement which has been particularly useful in preschool children is the forced oscillation technique (FOT). This is a relatively easily performed measurement which can be used to assess airway obstruction. It consists of the application of a high frequency oscillatory wave into the airway via a facemask which can then be used to assess impedance across the large and small airways. Impedance is the inverse of resistance which can then be calculated by a simple mathematical equation.¹¹ Measurements are best performed in the sitting position with the child wearing a nose-clip and with the cheeks manually supported by the lung function measurement technician. The equipment is portable and measurements can be readily performed in any hospital setting and also in the community.

In the most commonly used method, a loudspeaker generated high frequency oscillatory wave usually in the range of 4–8 up to 20 Hz is applied at the mouth and transmitted to the airway.¹¹ Resulting pressures and volumes are measured by an airway manometer and a pneumotachograph. This combination of measuring devices enables continuous analysis of reactive changes in airway pressure and flow. Three to five measurements over 8–16 seconds are made and the mean results reported.

Standardisation of methodology has been described¹ and normal values have been obtained and reviewed by Marchal et al.¹

FOT measurements have been particularly useful in studying asthma and other wheezing disorders in preschool

children results correlating with reduced FEV1 as measured by spirometry.¹² They can also be useful in studying response to therapy in the emergency department.¹³ In contrast to its use in asthma, FOT has not been found to be useful in the monitoring of changes in lung function in preschool children with cystic fibrosis; this may be due to changes in bronchial wall elastic tissue due to the underlying chronic inflammatory disease process.

Interrupter technique

This technique uses rapid interrupter methodology (Rint) which consists of occlusion of the airway for 100 milliseconds utilising a valve which closes in less than 10 milliseconds. Measurements are made in the sitting position breathing through a mouthpiece with the cheeks supported by the measurement technician and a nose-clip in position. Measurements are acquired at peak expiratory flow.² The technique allows for equilibration of airway pressure from the mouth throughout the lungs unless small airway resistance is extremely high. Cheek support is particularly important in this age group because pressure changes in the compliant upper airways may dampen the pressure equilibration in high resistance lower airways. Successful results can be obtained in the majority of preschool children providing they are given time to become familiar with the equipment and to get used to the noise of the valve closing which suddenly occludes the airway. Repeated measurements are made on ten occasions in order to provide five reliable results. The median and mean of all technically acceptable occlusions should be reported.^{2,14} Full technical details of the methods used for acceptable occlusion should be reported and linear back extrapolation for Rint should be used.¹⁴ Commercially available equipment is available for this procedure and standardised age and sex-related normal values have been obtained for use in clinical practice.^{15,16} As many as 80% or more of children in the preschool age group are able to successfully perform Rint measurements. This makes it an excellent tool for use both in the laboratory but also outside using portable equipment. The variability of Rint results in the same child is between 10–13%.¹⁷ Unfortunately the variability of measurements between individuals and the overlap with the normal population limits its use in large studies of the asthmatic population. It has however been successfully used in assessing the effects of treatment in asthmatic children.¹⁸ Its most useful day to day usage appears to be in the assessment of short-term bronchodilator responsiveness in individual children.¹⁹

Multiple Breath Washout

This technique has been used for many years to measure functional residual capacity (FRC). The classical technique involves the measurement of washout time of an inert gas such as helium or nitrogen.²⁰ More recently the multiple breath washout technique has been updated using other inert gases such as sulphur hexafluoride (SF₆) to measure the efficacy of distribution of ventilation in the lungs as well as the FRC. The methodology requires the subject to breathe through a sealed facemask or mouthpiece. Since it only requires quiet tidal breathing it is well suited for use in

the preschool age group. Recordings of the concentration of SF₆ and respiratory airflow at the airway opening are obtained. This method yields the lung clearance index (LCI) which is the cumulative expired volume required to clear the inert gas from the lungs divided by the FRC. This methodology is applicable throughout life from the neonatal period onwards. It is therefore an excellent technique with which to assess disease progress over long periods of time. It has been shown to be more sensitive than spirometry or measurements of airway resistance in detecting early lung function changes in infants and young children with cystic fibrosis.^{21,22}

Airway Resistance

The measurement of specific airway resistance (sRaw) is another important parameter which can be measured successfully in the majority of preschool children.²³ In this age group it can be measured by whole body plethysmography. Young children may need to sit inside the body box accompanied by an adult for reassurance and to enhance cooperation during the test. They also respond to video cartoons being shown during the period of the test itself. Nowadays computer software can eliminate the effects of simultaneous adult breathing in the box. sRaw is usually reported from at least two sets of five consecutive breathing loops. The within subject coefficient of variation (CV) of sRaw in this age group is reported to be 8–11%.^{24,25} sRaw is independent of age, gender or height so it is a particularly useful measurement for long-term studies throughout life. sRaw is known to be increased in preschool asthmatics and non-asthmatic wheezers and in young children with cystic fibrosis.²⁶ Various studies have also demonstrated the usefulness of sRaw measurements in assessing bronchodilator response in young asthmatics.²⁷ Also the effects of leukotriene antagonists²⁸ and inhaled corticosteroids.²⁹

Bronchial hyper-responsiveness (BHR)

The measurement of BHR in preschool children is another potentially useful tool in the increasing understanding of emerging lung disease in this age group.³⁰ Due to the short concentration span of preschool children a number of adaptations of the techniques used in older children have been made in order to increase the success rate of testing in this population. Bronchoconstriction can potentially be measured by the administration of pharmacological agents such as histamine or methacholine or by physiological challenge such as with cold air. Precise details of the methods used and the standardisation of results reporting have been set out in official statements from the American Thoracic Society and the European Respiratory Society.^{2,30} Bronchodilation can also be assessed using similar methods of measurement of changes in lung function. Several methods have been used to assess such bronchial reactivity. These include spirometry, plethysmographic measurement of sRaw, forced oscillation technique, impulse oscillometry and Rint.

Despite much research in this area the wide variability in repeat measurements in unwell children and the considerable overlap with results in the normal population means

that so far these tests have limited usefulness in the epidemiological assessment of short and long-term changes in bronchial hyper-responsiveness in this age group. Further research will undoubtedly improve the specificity of these techniques.

Cold air challenge (CACH)

This is another technique of bronchial challenge which has been successfully modified from protocols in older children for the preschool age group.³¹ A single-step four minute hyperventilation test has been developed and successfully applied in this age group.³² The test is facilitated by the use of a computer animated on-screen programme in which the child maintains, by controlled hyperventilation, a large balloon at a pre-determined level.^{31,32} The test is performed using a facemask with an inbuilt mouthpiece to reduce the risk of external inspiratory leaks. The test is safe and normal values and its repeatability levels have been established.^{31,32} CACH has been used in a number of studies which have been reviewed by Nielson and Bisgaard, in 2005.³¹ These have demonstrated the usefulness of CACH in assessing the efficacy of short and long-term bronchodilators, leukotriene receptor antagonists and inhaled corticosteroids in preschool asthmatic children. This technique thus has considerable potential in this age group to facilitate our knowledge and understanding of basic disease mechanisms and the evolution of illnesses such as asthma over an extended period of time.

Conclusions

Lung function testing in the preschool child has developed remarkably during the last two decades. The techniques which have been developed, although increasingly sophisticated, have also overcome many of the clinical challenges required in achieving the cooperation of these young children in the performance of such tests. A major further contributory factor is the dedication and child-friendly approach of the staff involved in such studies. The helpfulness of the children's parents is, in this area of research, also hugely appreciated. As a result of this large amount of work, normal values and a high quality of reproducibility of results can now be obtained in the majority of these young children. This holds great promise for further research in this area in the future.

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