Editorial

PEDIATRIC PULMONARY FUNCTION TESTING

The diagnosis and management of patients with pulmonary disease have improved with the recent introduction of pulmonary function tests. Pulmonary function tests provide objective evidence of the nature and severity of lung disease, occasionally make a specific diagnosis, are useful in monitoring progress and assist in perception of the severity of the disease by the patient and the physician. Pulmonary function testing in a child differs from that in the adult largely because of the volume changes that occur from birth through the period of growth to adulthood. These differences influence technique, methodology and interpretation(1,2). The reliability of pulmonary function tests especially in younger age groups are suspect, because these measurements are fraught with poor patient cooperation and difficulty in obtaining reproducible results(3).

Children younger than 6 years are generally unable to inspire to total lung capacity (TLC) and exhale to residual volume (RV)(4). Implicit in normal pulmonary function data in childhood is the broad distribution of values around the mean for each test(2,3). However, two simple tests of pulmonary function, the volume time (VT) curve and the flow volume (FV) curve, provide enough information to diagnose, and manage most pediatric patients with pulmonary disease(5,6).

Special Considerations

In order to achieve reasonable success in obtaining pulmonary function tests in children, factors that are usually not important in testing the adult patient must be considered. These include the technicians/staff nurse, the pulmonary function equipment and the laboratory facilities. The other two relevant considerations are, level of cooperation by the child and size adjustment for growth and development of child's lungs(1-6).

Children are fearful of unknown and can be frustratingly uncooperative, have limited attention spans and are easily distracted(5). They require informative reassuring and an honest introduction to the laboratory and equipment. A common mistake is to test children in an adult oriented laboratory where distractions are frequent and personnel are not accustomed to study children(2,3).

Indications

The major clinical indications(2-6) are: (*i*) Diagnosis/characterization of lung disease; (*ii*) Assessment of severity of lung disease; (*iii*) Monitoring the course of lung function impairment; (*iv*) Evaluation of therapy; (*v*) Preoperative evaluation; and (*vi*) Definition of the cause of limitation of physical exertion. For research purposes, pulmonary functions can be studied in children to record the changes with age and also, long term effects of acute and chronic factors on lung growth(3).

Spectrum of Pulmonary Functions

Unless a specific physiologic abnormality has been already documented by previous pulmonary function testing or suggested by clinical examination, the child is studied to characterize one of the following components of the respiratory system: (*i*) Lung mechanics; (*ii*) Lung volumes; (*iii*) Distribution of ventilation; (*iv*) Gas exchange; (*v*) Exercise response; (*vi*) Respiratory muscle function; (*vii*) Ventilatory control to PO_2 and PCO_2; and (*viii*) Respiration during sleep. The response to aerosols (bronchodilators or provocative agents) may also be studied, whenever required(2,3).

Spirometry

Standard water-seal and non-water sealed spirometer can be used in children, but it must conform to the ATS standards and specifications(7,9). The procedure is performed as in adults, but after four to five minutes of practice and those less than 6 years old may require longer practice. It is preferred to have polygraph or any other graphic recording simultaneously in children, as they may not be able to produce computerized acceptable and adequate performance(8). Spirometers must have adequate stability, linearity and response time without hysteresis. In such situations graphic record of forced expiratory maneuvre is extremely helpful in interpretation(9). The best of 3 efforts are taken, but in children less than 10-12 years old, more than three trials may be required to obtain the child's best possible effort. Both slow and forced VC maneuvres should be performed. Since, expired volumes are calculated at ATPS it needs to be corrected to BTPS (body temperature, saturated with water vapor).

Air Flows

In childhood, the mid maximal expiratory flow rate (MMFR) is the most reliable and reproducible index of airway function(5). While a young child (<7 years) may not be able to inspire fully to TLC or exhale to RV, valuable and reproducible information concerning airway function in this age group can be obtained by partial flow volume curve, measuring maximal expiratory flow at FRC(11) and with this study it is possible to study children as young as 4 years old and as small as 96 cm in height. At least three trials are required with each maximal expiratory or inspiratory flow maneuvre to increase the potential of obtaining an accurate estimate of airway function. Because the level of lung volume at which the maximal expiratory flow is initiated will affect the test result, it is helpful to determine, whether the patient is at TLC, when the maximal expiratory flow rate is initiated(8). Analysis of contour of MEFV curve, as in adults provides important qualitative information concerning the level of airways responsible for expiratory flow limitation.

Comparison of flow-volume curves obtained during breathing air or helium in 20% oxygen (He/O_2) are useful to diagnose large and small airway obstruction.

Airways Resistance

Body plethysmograph is used to determine airways resistance (RAW) as RAW = alveolar pressure/airflow. It is dependent upon lung volume and therefore SRAW (RAW/lung volume = specific airway resistance, *i.e.*, SRAW) is calculated. Reverse of airway resistance is called airway conductance (GAW) and specific airway conductance (SGAW). Relationship between lung volume and airway conductance is linear and hence more helpful. Although it is technically an easy test for a child to perform, it is a less sensitive test for determination of limitation of expiratory flow(9,12). Tables showing the relationship between specific airway resistance versus length/height for newborns, younger children are available(13).

Lung Volumes

Although determination of lung volumes requires cooperation of the patient, often it is not feasible in children less than 6 years of age. However, there are methods that permit the measurement of lung volumes in even newborns, *e.g.,* body plethysmography(14), nasal pneumotachography (because infants less than 6 months old are obligate nasal breathers)(15) or respiratory induction plethysmography(16). These methods are impractical for use in routine pulmonary function laboratory due to cost, bioengineering and need for pediatric support personnel.

Functional residual capacity (FRC) can be measured by helium-dilution (single breath or steady state), nitrogen washout or body plethysmography(2). However, body plethysmography is the method of choice for both procedural and technical reasons. A young child has a short attention span and when breathing through a mouth piece, may have a rapid respiratory rate while tending to have change in FRC breath by breath. Thus, with gas dilution method it is difficult to catch the patient at end tidal respiratory point for FRC. With rapid, electrically activated, mouth shulter used in plethysmography, it is possible to obtain the measurement of thoracic gas volume (TGV) at FRC. It is also possible to repeat the measurement until a consistent minimal value for the patient is determined.

Lung volume measurement provides a useful guideline for planning postoperative care. In a child who will undergo a major surgery, *e.g.,* scoliosis, pectus excavatum repair, major upper abdomen or chest surgery, inspiratory capacity (IC) may fall as much as 50-70% in the postoperative period. A patient with postoperative IC of 15 ml/kg will probably not require assisted ventilation and hence, a preoperative IC of 30 ml/kg is required for safe surgery(17).

Diffusion Test

Although diffusion capacity (DLCO) was developed to assess pulmonary membrane gas transport, in practice it is a test of pulmonary capillary blood volume(18). The DLCO single breath (SB) requires patient cooperation. The exhaled gas volume size required for gas analysis by some DLCO systems may preclude measurement of this parameter in the young child(18). The DLCO steady state (SS) is less informative than DLCO (SB) and is not useful, unless the other test is not possible due to technical reasons. The DLCO is normalized for patients' lung volume (DLCO/VA). In contradiction to adults, the DLCO (SB) is relatively insensitive in children, and some pediatric pulmonary function laboratories do not perform this test(17).

Blood Gas Analysis

This provides the most sensitive index of lung function in infants and children. It is the test which is most likely to be abnormal in patients with apparently minimal lung disease. The right radial and temporal arteries are the most accessible superficial arteries in newborn infants while radial artery is most accessible in children(19). Allen's test must be performed before radial artery puncture. Precautions of size of syringe, volume of anticoagulant and volume of blood drawn are more important as compared to adults.

Arterialized capillary blood accurately reflects arterial pH and PCO_2 under good conditions, *e.g.,* (*i*) adequately prewarmed skin (42°C for 10 minutes)(20); (*ii*) normal blood flow to the area, and (*iii*) proper technique used for blood collection. However, arterialized PO_2 does not approximate to arterial PO_2. Recent advances in technology permit transcutaneous measurements of PO_2 ($tcPO_2$) and PCO_2 ($tcPCO_2$)(21,22). Their approximation to arterial values is dependent upon, cutaneous blood flow, skin thickness and color, and technical factors.

Bronchoprovocation

Non-allergic provocation tests are performed in children with respiratory symptoms to determine whether asthma is the underlying cause. The types of provocation generally used in children include (*i*) Bronchodilators; (*ii*) Exercise; (*iii*) Histamine/methacholine; and (*iv*) Others–cold air, hyper- and hypo-osmolar aersols. The selection of test depends upon patient's age, facilities available, and ability to cooperate.

(*i*) *Bronchodilator Response*

When airways obstruction is detected on routine pulmonary function tests, response to bronchodilator aerosol is measured routinely. Almost 15% improvement in maximal expiratory flow rate (MEFR) or reduction in RV is seen in asthmatic children. As in adults, to label a response, 15% change in pulmonary function parameter is required. However, specifically in children response in maximum flow at 80% of TLC (V_{max} 80%), at 70% of TLC (V_{max} 75%) and at 60% of TLC (V_{max} 60%) are especially useful because the changes in lung volume are reflected in the measurement(23). If routine pulmonary functions are normal, no response may be seen even in asthma.

(*ii*) *Exercise Challenge*

Virtually all asthmatics will exhibit exercise-induced bronchospasm (EIB) if subjected to strenuous exercise(24). Exercise provocation should be done in a child with history of asthma but normal physical examination and routine pulmonary functions. Free running and uphill treadmill running are most asthmogenic while bicycling and swimming are less likely to provoke asthma. Exercise is required for 6-8 minutes which achieves maximum heart rate of 170-180 beats per minute(24). However, it is infrequent to find adequate cooperation from children less than 10 years old, for exercise and hence, these studies are most useful in adolescents. Fall in PEFR (of 12.5%), FEV_1 (of 10%) and/or in MMEF (of 26%) is diagnostic of exercise induced asthma (EIA)(25).

(*iii*) *Histamine/Methacholine Challenge*

Virtually all asthmatic children will develop broncho-constriction in response to inhaled histamine or methacholine. Sensitivity of these stimuli are measures of the increased bronchial reactivity characteristic of asthma, but also seen in few children with severe obstructive lung disease (OLD) other than asthma due to airway injury(26). Hence, normal baseline pulmonary functions are required to properly interpret the data. More than 20% fall in FEV_1 compared to baseline, indicates a positive response.

A comparative study of exercise and histamine provocation in asthmatic children revealed that histamine is more informative, sensitive, safe and comfortable and all children with EIA were detected by histamine challenge(27). Whereas, over 90% of asthmatic children between the ages of 6 and 16 years show a positive response to inhaled histamine, upto 30% of control children will also show positive response when the standard criteria of Chai *et al*. are used (28). Bronchospasm induced by histamine can be easily reversed with beta-2-aerosol.

Exercise Testing

This is done primarily to provoke EIA, to unconver lung disease, to define heart versus lung etiology of exercise intolerance, to monitor the course of disease or effectiveness of therapy(29). Few children will exercise maximally, especially young ones and hence a given result must be assessed in circumspect.

Pulmonary limitation may be accompanied by decreased maximal O_2 uptake ($VO_{2\ max}$), fall in $tcPO_2$, increased VD/VT (dead space/tidal volume) ratio, increased ventilatory equivalent for O_2 uptake(30).

Pediatric Pneumogram

Quantification of ventilatory pattern during sleep is useful in diagnosis of respiratory control disorders, especially in infants with apnea(31). In this age group, all apneas longer than 15 seconds are abnormal. Heart rates below 80 upto 3 months, below 70 from 3-6 months of age and below 60 over 6 months of age, are abnormal if sustained for 10 seconds. Any apnea with bradycardia or cyanosis is abnormal. Periodic breathing should not exceed 4% of total sleep time (TST), except in preterm infants.

D.D.S. Kulpati,
Director-Professor of Medicine,
D. Talwar,
Department of Medicine,
Maulana Azad Medical College and
Associated Lok Nayak Jai Prakash
Narain Hospital, New Delhi 110 002.

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