The Role of Pulmonary Function Testing in Infants

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Tests of pulmonary function are used routinely in school-age and older children to augment or confirm clinical findings obtained by a careful history and physical examination. Spirometry allows both detection of airway obstruction even before wheezing can be heard and objective assessment of medical interventions. Measurement of lung volumes separates those processes that cause restriction from those that do not affect lung size or those that cause air trapping. Serial measurements have yielded important insights into the normal growth and aging of the lung as well as showing how various diseases affect lung and airway growth and repair.

Barriers to Testing

Although techniques to measure lung function in infants and toddlers have been available for more than 40 years, they have not been used clinically to the same degree that pulmonary function testing has been used in older children and adults. Possible reasons for infant pulmonary function testing not to be performed routinely relate both to the testing conditions and to the information gained. Chief among the former is the need to sedate all but the youngest infants to perform many of these studies. Both parents (1) and physicians (2) express concern over the need to sedate sick infants, even though the sedation typically is tolerated well. Some tests, such as respiratory inductive plethysmography or the forced oscillation technique, do not require sedation of the infant.

Other procedural barriers include what must be done to the infant to obtain the necessary information. For example, measurements of dynamic pulmonary compliance and resistance require placement of an esophageal balloon or catheter and, therefore, are considered invasive. Forced expiratory flows by the rapid thoracic compression (“squeeze”) technique may appear uncomfortable for the infant, although infants do not demonstrate any physiologic signs of distress or discomfort during the testing. Some parents have expressed negative feelings after seeing their child undergo the raised volume rapid compression technique, in which the infant’s lungs initially are inflated through a face mask before the chest and abdomen are squeezed, citing recollections of their child’s past days of mechanical ventilation and critical illness in the neonatal period.

Finally, infant lung function testing is expensive, both in terms of the equipment and the personnel required. Often, two or three people must be present to complete a study, depending on its complexity. Also, the duration of the study can vary from 30 minutes to 3 hours, again depending on its complexity. The equipment is specialized and often created on site at centers interested in performing such measurements. Commercially available systems have been accessible for only the last several years. Lack of standardization of equipment and techniques has led to difficulty in comparing results across some studies. For these reasons, the American Thoracic Society and the European Respiratory Society convened a joint task force to address issues of standardization and techniques for measuring pulmonary functions in infants. Their efforts have resulted in several publications, workshops, and a book to help make the testing of lung function in infants more consistent. (3)(4)(5)

Until recently, information obtained through infant pulmonary function testing, consisting largely of measurements of tidal pulmonary mechanics, could not be compared directly with spirometry data obtained in older children. In the last 15 to 20 years, however, the ability to obtain measures of forced expiratory flow in infants, first over the tidal range of breathing and later over almost the entire vital capacity, has allowed for comparison of similar functions using partial or maximal expiratory flow maneuvers in older children.

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Use of Pulmonary Function Testing

Where, then, do measurements of lung function fit in the care of neonates? Their use has contributed not only to our understanding of normal chest wall, airway, and lung growth and development, but also to the effects of diseases on these processes. They also add a critical functional dimension to anatomic observations. For example, Gerhardt and associates (6) measured pulmonary compliance and conductance (the reciprocal of resistance) in 40 children from the newborn period through the first 5 years of life. They found that compliance, normalized for lung volume (specific compliance), remained constant with age. In contrast, conductance, normalized for lung volume (specific conductance), was high in preterm infants, but fell rapidly until infants reached about 10 kg, after which it remained constant with age. Together, these findings support the concept that airways are well developed in late gestation and that postnatal lung growth is dysynaptic; that is, rapid alveolar multiplication in the postnatal period causes the volume of lung parenchyma to increase more quickly than does airway size.

Pulmonary function testing also has provided important insight into normal airway smooth muscle function in infants. Even within the last 2 decades, controversy surrounded the role of bronchospasm in wheezing infants. Earlier anatomic studies suggested that airways of infants younger than about 2 years of age did not contain sufficient smooth muscle to cause significant airway narrowing. Using the rapid thoracic compression technique, Tepper (7) demonstrated that healthy infants younger than 15 months of age not only had adequate smooth muscle to cause airway obstruction, but that cholinergic and adrenergic receptors were present and functional and accounted for the observed airway reactivity. More recently, Goldstein and colleagues (8) demonstrated that healthy infants have the same overall basal level of airway smooth muscle tone as do older children and adults, but infants younger than 1 year of age and those exposed to environmental tobacco smoke had the greatest response to an inhaled bronchodilator.

Among infants who have disease, pulmonary function testing has elucidated both the natural history of the disorder and response to various therapies. Several studies of serial lung function measurements, such as those typified by Iles and Edmunds (9) and Mallory and associates, (10) demonstrate that forced expiratory flows in infants and toddlers who have a history of bronchopulmonary dysplasia are lower than normal and do not increase to normal values over the first few years of life. These data suggest that the airways of infants who have bronchopulmonary dysplasia are damaged in the neonatal period and do not demonstrate catch-up growth thereafter.

Various tests of lung function have been used to assess the effects of therapies such as surfactant replacement in preterm neonates; bronchodilator use in infants who have bronchopulmonary dysplasia, recurrent wheezing, or viral bronchiolitis; and diuretic therapy in infants who have bronchopulmonary dysplasia. Godfrey and colleagues (2) noted that based on recent publications, these tests are overwhelmingly used as research, not clinical tools.

Neonates, however, represent a population for whom clinical use of lung function testing is probably under-realized. Perhaps nowhere is the potential clinical use of pulmonary function testing greater than in the ventilator-dependent infant. Adjustments in ventilator support are reflected rapidly by changes in mechanics. Some data suggest that using regular bedside pulmonary function tests to help guide ventilator management can improve outcomes in preterm infants who have respiratory failure. (11) Pulmonary function tests also can be used to help determine the best level of distending pressure necessary for infants who have chronic respiratory failure.

Conclusion

In this issue of NeoReviews, we highlight several tests of pulmonary function used in neonates, infants, and toddlers. Palmer, Allen, and Mayer discuss measurements of tidal breathing patterns using either direct measurements of flow with a pneumotachograph or indirect measurements by respiratory inductive plethysmography. Airen and Panitch review other measurements made during tidal breathing, including dynamic and passive respiratory mechanics. Perez and Weiner present newer tests that enhance our ability to assess airway function by reproducing forced expiratory maneuvers. Finally, Traeger and Panitch discuss an often-ignored aspect of pulmonary function in neonates: tests of respiratory muscle strength and endurance. In each review, the basic physiology underlying the tests as well as their methods and examples of clinical and research uses are presented. The list is by no means exhaustive; rather, it represents some procedures that can be used in a variety of patients from critically ill, intubated preterm infants to healthy toddlers.

The indications for pulmonary function testing in infants continue to evolve. Godfrey and coworkers (2) suggested three clinical indications for the use of pulmonary function testing in infants who have lung disease:
1. The infant who has unexplained pulmonary symptoms and in whom results from the history, physical examination, and evaluation with less difficult tests have not provided a diagnosis.
2. The infant who has severe chronic obstructive lung disease of unknown cause who does not respond to a clinical trial of bronchodilators and inhaled corticosteroids.
3. The infant who has known chronic lung disease to ascertain the severity and guide various treatment decisions.

Both clinical and research indications for infant lung function testing will continue to expand. As basic mechanisms of disease are discovered and new treatments based on this knowledge are created, objective tests will be necessary to test their effectiveness. Infant pulmonary function tests provide such a critical tool for assessing pulmonary outcomes in translational studies. A basic understanding of the types of tests and their limitations will help both the clinician and investigator enhance their care of neonates who have lung disease.

References