

## Original Article

# Spirometry and Impulse Oscillometry in Preschool Children: Acceptability and Relationship to Maternal Smoking in Pregnancy

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**What is already known about this topic?** Measuring pulmonary function in preschool children is challenging. Impulse oscillometry (IOS) does not require active exhalation so it is believed to be easier for children to perform than spirometry.

**What does this article add to our knowledge?** This direct comparison of performance of spirometry and IOS indicates that more preschool children can perform acceptable spirometry tests than acceptable IOS tests and provides longitudinal data in an African American and Hispanic population.

**How does this study impact current management guidelines?** This study challenges the assumption that IOS is easier for preschool children to perform than spirometry but the ability of IOS to detect the effects of cigarette smoke exposure on lung function may be better.

**BACKGROUND:** Comparisons of the technical acceptability of spirometry and impulse oscillometry (IOS) and clinical correlations of the measurements have not been well studied in young children. There are no large studies focused on African American and Hispanic children.

**OBJECTIVES:** We sought to (1) compare the acceptability of spirometry and IOS in 3- to 5-year-old children and (2) examine the relationship of maternal smoking during pregnancy to later lung function.

**METHODS:** Spirometry and IOS were attempted at 4 sites from the Urban Environmental and Childhood Asthma Study birth cohort at ages 3, 4, and 5 years (472, 471, and 479 children,

respectively). We measured forced expiratory flow in 0.5 s (forced expiratory volume in 0.5 seconds [FEV<sub>0.5</sub>]) with spirometry and area of reactance ( $A_X$ ), resistance and reactance at 5 Hz ( $R_5$  and  $X_5$ , respectively) using IOS.

**RESULTS:** Children were more likely to achieve acceptable maneuvers with spirometry than with IOS at age 3 (60% vs 46%,  $P < .001$ ) and 5 years (89% vs 84%,  $P = .02$ ).

Performance was consistent among the 4 study sites. In children without recurrent wheeze, there were strong trends for higher FEV<sub>0.5</sub> and lower  $R_5$  and  $A_X$  over time. Maternal smoking during pregnancy was associated with higher  $A_X$  at ages 4 and 5 years ( $P < .01$  for both years). There was no significant

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Genentech/Novartis, Cephalon, Teva, and Boehringer Ingelheim; has received personal fees from Merck, DBV Technologies, AstraZeneca, WebMD/Medscape, Sanofi, and Vectura. G. T. O'Connor has consultant arrangements with AstraZeneca. W. Morgan reports grants from the Cystic Fibrosis Foundation; and personal fees from Genentech, Cystic Fibrosis Foundation, American College of Chest Physicians, and American Thoracic Society. R. A. Wood has consultant arrangements with Stallergenes and Sanofi; and receives royalties from UpToDate. R. Burton has consultancy arrangements with eResearch Technologies (ERT). J. E. Gern has consultancy arrangements with Janssen, Regeneron, GlaxoSmithKline, Genentech, Amgen, and Novartis; and has stock interest in 3V BioSciences. The rest of the authors declare that they have no relevant conflicts of interest.

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**Abbreviations used**

ATS- American Thoracic Society  
 A<sub>x</sub>- Area of reactance  
 ERS- European Respiratory Society  
 FEV- Forced expiratory volume  
 FOT- Forced oscillation technique  
 IOS- Impulse oscillometry  
 R<sub>5</sub>- Resistance at 5 Hz  
 R<sub>10</sub>- Resistance at 10 Hz  
 R<sub>rs</sub>- Respiratory system resistance  
 URECA- Urban Environmental and Childhood Asthma Study  
 X<sub>5</sub>- Reactance at 5 Hz  
 X<sub>rs</sub>- Respiratory system reactance  
 Z<sub>rs</sub>- Impedance of the respiratory system

**difference in FEV<sub>0.5</sub> between children with and without *in utero* exposure to smoking.**

**CONCLUSION: There is a higher rate of acceptable maneuvers with spirometry compared with IOS, but IOS may be a better indicator of peripheral airway function in preschool children. © 2018 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2018;■:■-■)**

**Key words:** *Forced oscillation technique; Pediatric pulmonary function testing; Wheezing; Epidemiology; African American; Hispanic*

Assessment of lung function is an essential component for understanding lung development and disease progression in early childhood and can serve as an outcome in clinical trials. Measurement of pulmonary function in preschool children is challenging. Spirometry is used in older children and adults and requires a maximal forced expiratory maneuver. Studies from single sites indicate that more than half of children between the ages of 3 and 5 years can perform spirometry successfully.<sup>1-6</sup> The forced oscillation technique (FOT) has been used increasingly to assess respiratory mechanics. Impulse oscillometry (IOS) is a widely used application of FOT. IOS superimposes external pressure oscillations on the respiratory system during spontaneous breathing. One potential advantage of this technique is that it requires only tidal breathing and no forced expiratory maneuvers. Being less effort dependent, IOS may be more suitable for measuring lung function in younger children. IOS measures the impedance of the respiratory system ( $Z_{rs}$ ) that is not directly measured with spirometry. The components of  $Z_{rs}$  are respiratory system resistance ( $R_{rs}$ ) and reactance ( $X_{rs}$ ).  $R_{rs}$  is the part of  $Z_{rs}$  associated with frictional losses in the airways and lung parenchyma and  $X_{rs}$  is determined jointly by the elastic properties dominant at low oscillation frequencies and the inertive properties at higher oscillation frequencies. The majority of studies with IOS involve older children. There are fewer studies in children between 3 and 5 years of age.<sup>7-12</sup> Most studies with spirometry and IOS have a limited number of subjects at the lower end of this age range and include predominantly non-Hispanic white children.

Direct comparisons of the rate of acceptable tests for spirometry and IOS in young children are lacking. We sought to compare the acceptability of the 2 procedures in a large sample of preschool children of predominantly African American and

Hispanic heritage enrolled in the Urban Environmental and Childhood Asthma Study (URECA).<sup>13</sup> The second aim of this study was to determine the ability of the 2 tests to detect abnormalities of lung function. The results of studies using IOS and spirometry in preschool children to detect abnormalities or changes in lung function have been inconsistent.<sup>14</sup> Pulmonary function measurements are known to be decreased in infants of mothers who smoked during pregnancy as measured by thoracoabdominal compression techniques, passive respiratory system compliance, and IOS.<sup>15-17</sup> There has been no assessment of the effect of this exposure on pulmonary function in preschool children. Therefore, we examined the relationship of maternal smoking during pregnancy to lung function in the preschool years as assessed by spirometry and IOS.

**METHODS****Study design**

URECA is a longitudinal multicenter (Baltimore, Boston, New York, St. Louis) birth cohort designed to study the development of asthma and allergies in an inner-city population. Women in their third trimester were recruited between February 2005 and March 2007. Inclusion criteria included a child's gestational age of at least 34 weeks and residence in an area where at least 20% of the population had an annual income below the poverty line. Maternal human immunodeficiency virus, significant congenital anomalies or infections, intubation, or  $\geq 4$  hours of supplemental oxygen or continuous positive airway pressure for 4 or more days excluded the infant from the study. Overall, 2,090 families were screened, 846 were eligible and consented, and 609 were enrolled; 560 newborns at increased risk for the development of asthma because of the parental history of asthma or allergic disease and a smaller group of 49 babies whose parents had no history of these diseases were enrolled. Written informed consent was obtained from the women enrolled, and, after birth, from the parent or legal guardian of the child. The detailed study design has been published previously.<sup>13</sup>

**Study assessments**

After a practice session at age 33 months, spirometry and IOS were performed at ages 3, 4, and 5 years using the Jaeger Master-Screen IOS system (CareFusion, Germany; JLab version 4.65) at all 4 centers. Volume and flow calibrations were completed each day of use, and cleaning was done at scheduled intervals. Operators at each site were trained and certified for measurements of spirometry and IOS according to standardized procedures.<sup>18</sup> All measurements were over-read centrally to ensure quality and consistency.

Both spirometry and IOS maneuvers were performed in the sitting position. IOS was done first followed by spirometry. Participants were asked to hold use of bronchodilator medications (including short-acting  $\beta$  agonists [4 hours], and anticholinergics, leukotriene modifiers, and long-acting  $\beta$  agonists [24 hours]) before the spirometry and IOS measurement sessions. For IOS, children were instructed to support their cheeks with their hands, and to breathe normally while maintaining a good lip seal on the mouthpiece with the tongue placed under the mouthpiece and with nose clips in place. The goal for the IOS session was to obtain 3 acceptable tests in a maximum of 8 attempts. An acceptable test had a segment of at least 15 seconds of normal tidal breathing, containing at least 4 breaths, within a 30-second test period. The acceptable tests had a concordance of resistance at 10 Hz ( $R_{10}$ )  $\geq 0.80$  (coherence), and were clustered within 20% of the highest  $R_{10}$ . The primary IOS variables used for analyses were

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