airway conductance and lung volumes. *Respir Med*. 2009;103(1): 136-143.

9. Crim C, Celli B, Edwards LD, et al; ECLIPSE investigators. Respiratory system impedance with impulse oscillometry in healthy and COPD subjects: ECLIPSE baseline results. *Respir Med*. 2011;105(7): 1069-1078.
10. Faria AC, Costa AA, Lopes AJ, Jansen JM, Melo PL. Forced oscillation technique in the detection of smoking-induced respiratory alterations: diagnostic accuracy and comparison with spirometry. *Clinics (Sao Paulo)*. 2010;65(12):1295-1304.
11. Qaseem A, Wilt TJ, Weinberger SE, et al; American College of Physicians; American College of Chest Physicians; American Thoracic Society; European Respiratory Society. Diagnosis and management of stable chronic obstructive pulmonary disease: a clinical practice guideline update from the American College of Physicians, American College of Chest Physicians, American Thoracic Society, and European Respiratory Society. *Ann Intern Med*. 2011;155(3):179-191.
12. Pisi R, Tzani P, Aiello M, et al. Small airway dysfunction by impulse oscillometry in asthmatic patients with normal forced expiratory volume in the 1st second values. *Allergy Asthma Proc*. 2013;34(1): e14-e20.
13. Mahut B, Caumont-Prim A, Plantier L, et al. Relationships between respiratory and airway resistances and activity-related dyspnea in patients with chronic obstructive pulmonary disease. *Int J Chron Obstruct Pulmon Dis*. 2012;7:165-171.
14. Oostveen E, Boda K, van der Grinten CP, et al. Respiratory impedance in healthy subjects: baseline values and bronchodilator response. *Eur Respir J*. 2013;42(6):1513-1523.
15. Berger KI, Reibman J, Oppenheimer BW, Vlahos I, Harrison D, Goldring RM. Lessons from the World Trade Center disaster: airway disease presenting as restrictive dysfunction. *Chest*. 2013; 144(1):249-257.
16. Hellinckx J, Cauberghs M, De Boeck K, Demedts M. Evaluation of impulse oscillation system: comparison with forced oscillation technique and body plethysmography. *Eur Respir J*. 2001;18(3): 564-570.
17. Bikov A, Pride NB, Goldman MD, et al. Glottal aperture and buccal airflow leaks critically affect forced oscillometry measurements. *Chest*. 2015;148(3):731-738.
18. Oostveen E, MacLeod D, Lorino H, et al; ERS Task Force on Respiratory Impedance Measurements. The forced oscillation technique in clinical practice: methodology, recommendations and future developments. *Eur Respir J*. 2003;22(6):1026-1041.
19. Robinson PD, Turner M, Brown NJ, et al. Procedures to improve the repeatability of forced oscillation measurements in school-aged children. *Respir Physiol Neurobiol*. 2011;177(2):199-206.

Rebuttal From Dr Berger et al

Kenneth I. Berger, MD; Roberta M. Goldring, MD; Beno W. Oppenheimer, MD; New York, NY

We agree that the holy grail of pulmonary physiologists is a test that detects early chronic airway disease. Although Dr Enright[1] remains "cautiously optimistic" that forced oscillation technique (FOT) can serve this purpose, there are sufficient data to mitigate his caution.

Diagnosis of Early Airway Disease

Accumulating literature provides evidence for enhanced diagnostic capabilities of FOT vs spirometry (reviews cited in our point editorial[2]). Despite normal spirometry, FOT abnormalities in those studies indicate small airway dysfunction based on bronchodilator responsiveness and correlation with symptom severity, quality of life, and response to treatment. Moreover, isolated improvement in FOT metrics during treatment occurs with simultaneous improvement in airway and alveolar inflammation as well as with bronchial hyperreactivity (methacholine).

Populations exposed to dust from the World Trade Center collapse provide a unique opportunity to address the role of FOT in detecting small airway disease because histologic evaluation demonstrated distal penetration of inhaled particles with small airway injury.[3] Our group's large case-control study reaffirms the role of FOT in detection of small airway disease in subjects with normal spirometry.[4] The magnitude of dust exposure was only associated with FOT abnormalities in subjects with new-onset persistent respiratory symptoms.[4] Furthermore, we demonstrated an association between FOT abnormalities and systemic inflammation in other exposed subjects.

FOT in Subjects With Established COPD

The Evaluation of COPD Longitudinally to Identify Predictive Surrogate Endpoints (ECLIPSE) study suggested that a proportion of patients with COPD and abnormal spirometric findings may have FOT measures in the normal range.[5] This conclusion was based on prediction equations derived from the control group. However, the equations had poor correlation, dictating wide CIs. In fact, the normative range used was at or above the upper end of previously published values. A more recent large normative dataset has demonstrated values significantly lower than those of the ECLIPSE control group.[6]

Lack of correlation in the ECLIPSE study between FOT and CT imaging airway metrics is expected because smaller airways (<2 mm) are not visible radiographically. Moreover, lack of correlation between FOT and focal emphysema is not unexpected because FOT parameters do not directly assess parenchymal destruction.[5]

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CONFLICT OF INTEREST: None declared.

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Normative Data

Despite the difficulty discussed by Dr Enright[1] for the most recent published normative dataset, data were successfully pooled from all institutions for parameters that reflect distal airway function.[5] Moreover, for all FOT parameters (whether derived from four or five sites), the derived predictive equations have narrow CIs.

Additional Considerations

FOT resistance can be referenced to the functional residual capacity (FRC) as specific airway conductance.[7,8] Post-bronchodilator changes in FRC can be determined in the absence of plethysmography by assessment of inspiratory capacity.[7] For subjects with low FRC (eg, those who are obese), voluntary inflation to predicted FRC may remove confounding effects of altered lung volume.[7] If FOT is valid for pediatric and elderly populations, then it must also be valid for populations that perform spirometry without difficulty. Finally, even spirometry technicians require specific training and supervision.[9]

In conclusion, we also applaud the memory of Joe Rodarte, MD, and the role he played in the development of the field of pulmonary physiology. Although no test is perfect, data clearly demonstrate the enhanced diagnostic capability of FOT, particularly in detecting disease localized to the small airways.

References

1. Enright PL. Counterpoint: should oscillometry be used to screen for airway disease? No. *Chest*. 2015;148(5):1135-1137.
2. Berger KI, Goldring RM, Oppenheimer BW. Point: should oscillometry be used to screen for airway disease? Yes. *Chest*. 2015;148(5): 1131-1135.
3. Caplan-Shaw CE, Yee H, Rogers L, et al. Lung pathologic findings in a local residential and working community exposed to World Trade Center dust, gas, and fumes. *J Occup Environ Med*. 2011;53(9): 981-991.
4. Friedman SM, Maslow CB, Reibman J, et al. Case-control study of lung function in World Trade Center Health Registry area residents and workers. *Am J Respir Crit Care Med*. 2011;184(5):582-589.
5. Crim C, Celli B, Edwards LD, et al; ECLIPSE Investigators. Respiratory system impedance with impulse oscillometry in healthy and COPD subjects: ECLIPSE baseline results. *Respir Med*. 2011;105(7): 1069-1078.
6. Oostveen E, Boda K, van der Grinten CP, et al. Respiratory impedance in healthy subjects: baseline values and bronchodilator response. *Eur Respir J*. 2013;42(6):1513-1523.
7. Oppenheimer BW, Berger KI, Segal LN, et al. Airway dysfunction in obesity: response to voluntary restoration of end expiratory lung volume. *PLoS One*. 2014;9(2):e88015.
8. Brown NJ, Salome CM, Berend N, Thorpe CW, King GG. Airway distensibility in adults with asthma and healthy adults, measured by forced oscillation technique. *Am J Respir Crit Care Med*. 2007; 176(2):129-137.
9. Enright PL, Johnson LR, Connett JE, Voelker H, Buist AS. Spirometry in the Lung Health Study. 1. Methods and quality control. *Am Rev Respir Dis*. 1991;143(6):1215-1223.

Rebuttal From Dr Enright

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Several years ago while working with Drs Berger, Goldring, and Oppenheimer evaluating people who were exposed to World Trade Center (WTC) dust and fumes, I found them to be excellent pulmonary physiologists, and I appreciate the high quality of their research using pulmonary function tests, such as forced oscillometry technique (FOT). Studies showing that an FOT index is abnormal more often than spirometry in smokers or people exposed to respiratory hazards in the workplace may merely mean that the false positive rate for oscillometry is higher than that for spirometry. An up-to-date review referenced by Dr Berger and colleagues[1] regarding the diagnostic value of FOT concluded that "it is unclear whether any of these measures of airway resistance contribute clinically important information to the traditional measures derived from spirometry (FEV_1, FVC, and FEV_1/FVC)."[2]

Obesity is very common (eg, one-half of WTC responders were obese at their initial examination), and obesity often causes dyspnea on exertion. A study of 100 obese patients (37% of whom reported dyspnea) noted that oscillometric abnormalities "were evident in essentially all subjects, thus confounding the ability of oscillometry to detect associated respiratory dysfunction independent of the effects of mass loading."[3] Spirometry and specific airway conductance (measured by body plethysmography) were normal. Thus, although it is easy to identify obesity in a patient, an abnormal FOT result in overweight patients may be falsely attributed to small airways disease causing their dyspnea. Note that in the pie charts Dr Berger and colleagues[1] present, 50% of the symptomatic cases had abnormal oscillometry (but normal spirometry), but so did 22% of the control subjects. This suggests that about one-half of the abnormal oscillometry interpretations were false positive findings.

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CONFLICT OF INTEREST: P. L. E. has been reimbursed for travel expenses by professional societies during the past 3 years for giving talks at international meetings about pulmonary function testing. These societies were often given funding for these talks by ndd Medical Technologies, Inc, which does not make a forced oscillation technique instrument.

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