Auscultated Forced Expiratory Time as a Clinical and Epidemiologic Test of Airway Obstruction*

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Objective: Seeking an inexpensive, readily available, clinical, screening, and field surveillance test of airway obstruction, we determined the validity of current dogma that forced expiratory time (FET) is a good clinical test of airway obstruction yet is of no epidemiologic use given excessive intrasubject variability.

Subjects and Methods: Two hundred twenty-nine white male plumbers and pipewrights were evaluated by spirometry, chest roentgenography, and a standardized respiratory questionnaire during a union-sponsored asbestos screening program. Subjects were classified as having large airway obstruction (LAO), small airway obstruction (SAO) alone, or no obstruction, on the basis of standard spirometric prediction equations. Two physicians, blinded to clinical and spirometric data, independently measured FET while auscultating the trachea with a stethoscope. The FET was defined as the time taken for an individual to forcefully exhale through an open mouth from total lung capacity until airflow became inaudible. Five such times were recorded for each subject. The mean of the three times having the narrowest range was deemed the FET for calculating test sensitivity and specificity. Based on previous literature, an FET ≥6 s was considered abnormally prolonged.

Results: Two hundred five subjects completed both spirometry and FET testing; 67 had LAO, 5 SAO, and 133 no obstruction. A total of 85 percent had three FETs reproducible within a range of ≤1 s. The sensitivity and specificity of FET for LAO were 92 and 43 percent, respectively, while for SAO alone, 60 and 44 percent, respectively. Overall, FET misclassified 56 percent of nonobstructed subjects. Adjusting the normal-abnormal cutoff points for both FET and SAO minimally improved the performance of FET.

Conclusion: Although FET is a simple, inexpensive, sensitive, and fairly reproducible clinical test of LAO, it cannot be recommended as a clinical or an epidemiologic tool because of its extremely low specificity.

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LAO = large airway obstruction, defined as present when the FEV1/FVC falls below the 95 percent confidence interval for the predicted value; SAO = small airway obstruction alone, defined as present when the FEF25-75% falls below the 95 percent confidence interval for the predicted value in the absence of both large airway obstruction and restriction

Slowing of forced expiration has long been recognized to be a prominent feature of both asthma and COPD. The time required to complete a forceful expiration, the forced expiratory time (FET), can be easily determined using a stopwatch and a stethoscope. In 1962, Rosenblatt and Stein found the auscultated FET to be accurate in identifying both individuals with clinically relevant obstructive pulmonary disease and those without such disease. Lal and co-workers reached similar conclusions and reported that the auscultated FET correlated well with both spirometric indicators of airway obstruction and spirometrically determined FET. On the basis of this work, the auscultated FET has remained a recommended bedside clinical test for the past 25 years.

In the early 1970s, investigators found that spirometrically determined FET held promise as a screening test to detect small airways disease prior to the development of a clinically relevant obstructive impairment. However, subsequently, MacDonald and his colleagues found the auscultated FET to have excessive intrasubject variability; these workers recommended continued use of the test as a clinical tool but not as a screening or research instrument.

Upon review, we became skeptical as to the claimed accuracy of FET in the clinical setting, yet remained intrigued that it might provide a simple, inexpensive test of airway obstruction. Further, we wondered whether a standardized protocol, incorporating principles of test reproducibility, might sufficiently minimize intrasubject variability to permit the use of FET in screening and epidemiologic investigation. It was extremely attractive to think that FET might be useful in (1) clinically evaluating patients with respiratory symptoms, (2) screening asymptomatic smokers for small airways disease in the hope of facilitating smoking cessation efforts, and (3) conducting cross-workshift surveillance studies of occupational asthma when both spirometers and peak flowmeters were unavailable.

In the present study, then, we investigated the
sensitivity and specificity of auscultated FET for both large airway obstruction (LAO) and small airway obstruction (SAO), as well as the reproducibility of FET, in a group of consecutively evaluated building trades workers participating in a union-sponsored screening program.

METHODS

Subjects

On June 22 to 23, 1985, and January 25 to 26, 1986, a screening examination for asbestos-related disease was offered to all 561 active and retired union plumbers and pipefitters in Rhode Island. The 229 participating white men constituted the study group. Each subject completed a respiratory questionnaire based on the American Thoracic Society (ATS) Epidemiology Standardization Project and was evaluated by physical examination, chest roentgenography, spirometric lung function testing, and auscultated FET at the individual’s union hall.

Spirometry

Three technicians certified by the National Institute for Occupational Safety and Health conducted spirometry, according to ATS criteria, using three Warren-Collins 8-L portable water-filled spirometers attached to microprocessors. Predicted spirometric values based on age, sex, and height were computed using the regression equations of Crapo et al.14

Large airway obstruction was considered present when the ratio of FEV1 to FVC was below the 95 percent confidence interval for the predicted value. Restrictive lung function was considered present when the FVC, but not the FEV1/FVC, was below the 95 percent confidence interval. Small airway obstruction alone was considered present when the forced expiratory flow rate between 25 and 75 percent of FVC (FEF25-75%) was below the 95 percent confidence interval, but there was no LAO or restriction. Subjects having indeterminate spirometric values, that is, a low FEV1, in the face of both a normal FVC and a normal FEV1/FVC, were categorized on the basis of their questionnaire, physical examination, chest roentgenogram, and lung volume measurements without reference to FET measurements.

FET Determination

The FET was defined as the time taken for an individual to complete a forceful exhalation after maximal inspiration. Two physician observers, blinded to clinical and spirometric data, independently measured FET while auscultating the trachea with a stethoscope. The observer placed the bell of the stethoscope over the seated subject’s suprasternal notch and instructed him first to take in as deep a breath as possible and then to blow it out through an open mouth as forcefully as possible. The observer used a stopwatch to measure the time between the first sound of forced expiratory flow and the point at which airflow was no longer audible. Measurements were recorded to the nearest tenth of a second and for no longer than 12 s. Allowing at least 30 s between blows, subjects were asked to repeat the maneuver five times in an effort to obtain three measurements within a 1-s range. For each subject, the three measurements were chosen that minimized the sum of the squares of the deviations around the subject’s mean, analogous to the least squares method of finding the line of best fit in regression analysis.18 The mean of the three chosen values was deemed the subject’s FET for the purpose of analysis. On the basis of previous reports,14–16 an FET ≥ 6 s was considered abnormally prolonged.

Statistical Analyses

Sensitivity was calculated as the probability that the FET was abnormally prolonged when airway obstruction was present (true positives/true positives plus false negatives). Specificity was calculated as the probability that FET was normal when airway obstruction was not present (true negatives/false negatives plus false positives). Accuracy, or efficiency, was defined as the sum of true positives plus true negatives divided by the sum of true positives, true negatives, false positives, and false negatives.

RESULTS

Of the 229 subjects, 24 failed to complete both FET testing and spirometry and were excluded from further analysis. The remaining 205 subjects had a mean age ± 1 standard deviation of 50 ± 15 years. One hundred seventy-one (83 percent) of these subjects reproduced three FET measurements within a 1-s range.

Table 1 shows the frequency of normal and abnormal FETs among the 67 subjects with LAO, five with SAO, eight with restriction, and 125 with normal spirometry. On the basis of these data, the sensitivities and specificities of FET were calculated (Table 2). For LAO, the sensitivity was 92 percent and the specificity was 43 percent; for SAO, the values were 60 and 44 percent, respectively. Overall, 56 percent of subjects without spirometrically defined obstruction had an abnormally prolonged FET.

Table 3 shows that changing the normal-abnormal FET cutoff point from 6 s to 5, 7, 8, or 12 s minimally affected overall test accuracy.

Use of a less restrictive definition of SAO (FEF25-75% less than 75 percent of predicted) yielded 39 subjects with SAO, 99 with no obstruction, and a surprisingly negligible improvement in the FET specificity (Table 4). Results nearly identical to these were obtained when SAO was defined on the basis of the FEF25-75% being more than one standard error below the predicted value: 43 subjects had SAO, 95 had no

### Table 1—Distribution of Subjects with Normal and Abnormal FETs by Category of Airway Obstruction

<table>
<thead>
<tr>
<th>Spirometric Category</th>
<th>LAO* (n = 67)</th>
<th>SAO† (n = 5)</th>
<th>No Obstruction (n = 133)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal (≥ 6 s)</td>
<td>62</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Normal</td>
<td>5</td>
<td>2</td>
<td>58</td>
</tr>
</tbody>
</table>

*FEV1/FVC falling below the 95 percent confidence interval for the predicted value.
†FEF25-75% falling below the 95 percent confidence interval for the predicted value in the presence of a normal FVC and FEV1/FVC.

### Table 2—Sensitivity and Specificity of FET for Airway Obstruction at a Cutoff Point for FET ≥ 6 Seconds

<table>
<thead>
<tr>
<th>Category of Airway Obstruction*</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAO</td>
<td>92</td>
<td>43</td>
</tr>
<tr>
<td>SAO</td>
<td>60</td>
<td>44</td>
</tr>
</tbody>
</table>

*See Table 1 for definitions.
obstruction, and sensitivities and specificities differed by no more than 1 percent from the corresponding values shown in Table 4.

**DISCUSSION**

In Rosenblatt and Stein's original investigation, 31 normal subjects and 79 patients with varying degrees of COPD were studied. No normal subject had an FET >4 s, whereas this value was exceeded by most subjects with COPD. Unfortunately, no information was provided on the severity of airway obstruction in those with COPD and the selection criteria and smoking status of the normal control subjects. Consequently, it cannot be determined whether the impressive results of the study are testimonial only to the ability of the test to discriminate nonsmokers with supernormal pulmonary function from patients with marked airway obstruction. The limited spectrum of both diseased and normal subjects recruited for investigations of diagnostic tests has been held responsible for the frequent failure of such tests during their subsequent widespread use. 9,10

Lal and his colleagues 3 measured both spirometric lung function and FET in 96 clinic patients and hospital staff. Of the 42 subjects having an FEV1/FVC ≥65 percent, none had an FET >5 s. Of the 53 subjects with FEV1/FVC <65 percent, 46 had an FET >5 s. A cutoff point of 5 s, then, yielded a specificity of 100 percent and sensitivity of 87 percent. Again, there was little information provided on the selection of subjects, the protocol for measuring FET, and the extent to which subjects and investigators were blinded. Although the authors' choice of a diagnostic
gold standard (FEV1/FVC <65 percent) was far superior to that of Rosenblatt and Stein, it was still arbitrary and disregarded the influence of age and height on FEV1/FVC; an FEV1/FVC of 65 percent is just barely normal for a tall octogenarian while grossly abnormal for a short young man.

In the current study, LAO was defined as being present when a subject's FEV1/FVC was more than 1.73 standard errors below the age-, height-, sex-, and race-predicted value. 14 A number of our subjects characterized as having LAO would have been considered nonobstructed according to the spirometric gold standard criterion used by Lal et al. 3 It follows, then, that application of the gold standard used by Lal et al 3 to the current study population would have increased both the proportion of subjects categorized as nonobstructed and, in turn, the opportunity for false-positive FETs. This reflects the mathematical truism that as the normal-abnormal cutoff point of a diagnostic gold standard (here, FEV1/FVC defining LAO) is adjusted to provide greater specificity, the diagnostic test (here, FET) supported by the standard becomes less specific. Therefore, in any setting, use of our definition of LAO as opposed to that of Lal et al 3 would have served only to increase the specificity of FET. In a similar vein, a 6-s, rather than a 4- or 5-s, normal-abnormal FET cutoff time, was chosen to increase the likelihood that previous claims of exceptional test specificity would be confirmed. Nevertheless, the present investigation found that in the detection of LAO, FET had an unacceptable specificity that could not be rectified through manipulation of the normal-abnormal FET cutoff point.

MacDonald et al 16 rejected FET as a screening test for SAO on the grounds that its intrasubject variability exceeded that of the spirometrically determined FEF25-75%. The present investigation was partially motivated by the belief that for FET to be useful, it did not necessarily have to be less variable that FEF25-75%. Furthermore, it was hoped that the intrasubject variability of FET could be reduced through use of a standardized protocol. In fact, the protocol did provide fairly good test reproducibility. It was all the more unfortunate, then, to find that in the detection of SAO, FET had extremely low specificity. Once again, adjustment of the normal-abnormal FET cutoff point did not remedy the problem.

In light of the mathematical truism noted above, the choice of a diagnostic gold standard for SAO was a likely contributor to the low specificity of FET. This choice of gold standard also led only five subjects to be classified as having SAO, thereby ensuring an unstable estimate of the sensitivity of FET to detect SAO. Why there were so few subjects assigned to this category can be ascribed to the large inter-individual variation in FEF25-75% and the resulting

| Table 3—Sensitivity, Specificity, and Accuracy of FET at Different Cutoff Points |
|---------------------------------|-----------------|-----|-----|-----|-----|
| Category of Airway Obstruction* | Test Characteristic | FET Cutoff Point, s |
| LAO                            | Sensitivity, %   | 96  | 92  | 90  | 82  | 55  |
|                                | Specificity, %   | 30  | 43  | 51  | 61  | 92  |
|                                | Accuracy, %      | 53  | 60  | 64  | 68  | 73  |
| SAO                            | Sensitivity, %   | 80  | 60  | 60  | 40  | 20  |
|                                | Specificity, %   | 31  | 44  | 52  | 61  | 92  |
|                                | Accuracy, %      | 33  | 44  | 52  | 60  | 80  |

*See Table 1 for definitions.

| Table 4—Test Characteristics of FET for Less Restrictively Defined SAO* |
|---------------------------------|-----------------|-----|-----|-----|-----|
| Category of Airway Obstruction | Test Characteristic | FET Cutoff Point, s |
| SAO                            | Sensitivity, %   | 85  | 69  | 64  | 59  | 26  |
|                                | Specificity, %   | 36  | 48  | 58  | 69  | 85  |
|                                | Accuracy, %      | 50  | 54  | 59  | 66  | 68  |

*FEF25-75% <75% of the predicted value in the presence of a normal FVC and FEV1/FVC.
wide range of normal values. In fact, when previous investigators\textsuperscript{17,18} have defined an abnormal FEF\textsubscript{25-75%} on the basis of 95 percent confidence intervals, very few subjects have been identified whose FEV\textsubscript{1} or FEV\textsubscript{1}/FVC was not also abnormal. In the present study, when the criterion for SAO was relaxed, there was, unfortunately, little improvement in the ability of FET to discriminate among study subjects. The only consolation was a more reliable estimate of the sensitivity of FET in detecting SAO.

The necessary conclusion, then, is that although the auscultated FET is a simple, inexpensive, sensitive, and fairly reproducible test of LAO, it cannot be recommended as a clinical or epidemiologic test because of its extremely low specificity.

REFERENCES