Utility of forced expiratory time as a screening tool for identifying airway obstruction and systematic review of English literature

Ashutosh Nath Aggarwal, Sharmishtha Das, Ritesh Agarwal, Navneet Singh
Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India

ABSTRACT

Setting: This study was conducted at a pulmonary function laboratory of a tertiary care hospital in North India.

Objective: The objective was to study the diagnostic characteristics and clinically useful threshold of forced expiratory time (FET, measured by auscultation over trachea) as a screening tool for identifying airway obstruction and to substantiate the diagnostic utility of FET through a systematic review of English literature.

Methods: FET was compared in seventy patients with airway obstruction (Group A) and seventy controls with normal spirometry (Group B). Within-subject reproducibility of FET, and its correlation with spirometric parameters, was assessed. Diagnostic accuracy of FET in detecting airway obstruction was evaluated at various time thresholds. A systematic review of English literature on FET was also carried out.

Results: Median FET was significantly longer in Group A (7.04 s [interquartile range (IQR) 6.67–7.70 s] vs. 4.14 s [IQR 3.60–4.68 s], \( P < 0.001 \)). At a threshold of 5 s, FET had high sensitivity (0.943) and reasonable specificity (0.814) in detecting airway obstruction. FET measurements were reproducible and correlated negatively with forced expiratory volume in first second (FEV1), FEV1/forced vital capacity, and peak expiratory flow. The systematic review yielded 13 publications. At a widely used threshold of 6 s to describe airway obstruction, pooled sensitivity and specificity from five datasets were 0.802 (95% confidence interval [CI] 0.668–0.890) and 0.837 (95% CI 0.570–0.952), respectively.

Conclusion: FET of 5 s or more, rather than the commonly recommended threshold of 6 s, should be regarded as abnormal.

KEY WORDS: Forced expiratory time, obstructive lung diseases, sensitivity and specificity, spirometry, systematic review

INTRODUCTION

Airway obstruction is currently defined as a disproportionate reduction of forced expiratory volume in the first second (FEV1) in relation to the forced vital capacity (FVC) during a spirometric evaluation.[1] Spirometry is, therefore, considered essential for evaluation of persons suspected to have airflow limitation due to common disorders such as bronchial asthma or chronic obstructive pulmonary disease (COPD). This is especially important as patient history and clinical examination is often subjective, and symptoms and signs often have poor accuracy in identifying or excluding airflow limitation. Although spirometry can objectively document the presence of an obstructive ventilatory defect, it is an expensive investigation, requires technical expertise in test performance and equipment calibration and maintenance, and is not widely available, especially in resource-constrained settings. This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

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therefore, a need for simpler, yet objective, parameters which can detect airway obstruction.

Historically, several tests such as whistling, blowing out candles, and blowing out matches have been employed as a surrogate for spirometry to screen for airway obstruction. However, these, and other physical signs of airway obstruction, were inadequately standardized and suffered from a high degree of variability and were therefore poor markers for this condition.[2] Auscultation of tracheal sounds to generate an objective measure – the forced expiratory time (FET) – was proposed more than 50 years ago. The test is simple to perform, requires no additional infrastructure, can be easily added to routine patient examination without consuming much time, and provides results comparable to the time calculated on spirometry.[3,4] It has good reproducibility and correlates well with other measures of airflow limitation.[5-7] Several investigators have found variable diagnostic accuracy at different threshold timings and reported correlation with clinical outcomes.[4,6,15] A threshold of 6 s is widely used based on early description of the test characteristics.[4] However, there is no clarity on the exact utility of this threshold in a clinical scenario. We believe that measurement of FET can be a useful screening tool to identify individuals with higher probability of airway obstruction, who merit more detailed evaluation. FET thresholds therefore need to be optimized to fulfill this target, and an ideal threshold should provide a high sensitivity and an acceptable specificity in identifying airway obstruction. We conducted this study to study the diagnostic characteristics and clinically useful threshold of FET, measured by auscultation over trachea, as a screening tool for identifying airway obstruction, and to substantiate the diagnostic utility of FET through a systematic review of English literature.

METHODS

Participants were prospectively enrolled in this cross-sectional study from among patients referred for spirometry to our pulmonary function laboratory. FET estimation may be useful as a screening test and should demonstrate high sensitivity in identifying airway obstruction. Sample size was therefore estimated to fulfill this target, and an ideal threshold should provide a high sensitivity and an acceptable specificity in identifying airway obstruction. We conducted this study to study the diagnostic characteristics and clinically useful threshold of FET, measured by auscultation over trachea, as a screening tool for identifying airway obstruction, and to substantiate the diagnostic utility of FET through a systematic review of English literature. The systematic review was conducted as per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[16] An electronic database search was conducted through PubMed and Embase platforms, using the search terms forced expiratory time, forced expiratory noise, forced expiratory sound, forced expiratory tracheal time, forced expiratory tracheal noise, and forced expiratory tracheal sound. This was supplemented by additional citations obtained from bibliographic review of key publications, as well as articles from our personal records. Titles and abstracts of publications identified through this search were screened for articles meriting detailed evaluation. Publications in foreign languages, animal studies, and articles not primarily related to FET were excluded. Full text of the remaining articles was evaluated in detail independently by two investigators (ANA and RA) to identify publications suitable for data synthesis. Any disagreements were resolved through consensus. We included all original articles describing methodology, diagnostic performance, and/or clinical utility of FET in identifying airway obstruction or describing clinical features or outcomes. Review articles, case reports, editorials, commentaries, letters to editor not

FET was measured by a single investigator (SD) who had no knowledge about the spirometry report. Participants were made to sit comfortably, and a forced expiratory maneuver was demonstrated to them. They were then asked to inhale deeply, followed by a forced exhalation with mouth open, as quickly and as completely as possible. A stethoscope bell was positioned over the upper trachea in the suprasternal notch for auscultation during exhalation. The total duration of audible expiration was timed to the nearest 0.1 s using a stop watch. The test was considered acceptable if the participant did not pause or cough in between. This exercise was considered as a practice maneuver and its result was not considered further. Next, three more maneuvers were similarly repeated, with at least 30 s interval between successive blows. The largest time from among these was recorded as that participant’s FET.

Observed FET timings were summarized as medians and corresponding interquartile range (IQR) and compared between patient groups using the nonparametric Mann–Whitney U-test. Diagnostic accuracy of FET in identifying airway obstruction at various thresholds was studied by computing sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), and positive and negative predictive value, and summarized using a receiver operating characteristic (ROC) curve. Intrasubject reliability of repeated measurements was explored through coefficient of variance and intraclass correlation coefficient. FET was also correlated with other measured spirometric variables through Spearman’s correlation coefficient. Statistical significance was assessed at P < 0.05.
RESULTS

Both groups had 37 men and 33 women. Participants in Group A and Group B had similar age (mean, 46.5 ± 13.8 years vs. 45.7 ± 14.0 years, \( P = 0.738 \)) and height (mean, 158.9 ± 9.1 cm vs. 161.1 ± 8.9 cm, \( P = 0.134 \)). Significantly more participants in Group A (21 of 70, 30.0%) had smoked tobacco as compared to those in Group B (11 of 70, 15.7%, \( P = 0.044 \)). In Group A, 61 (87.1%), 50 (71.4%), and 49 (70.0%) patients, respectively, reported having dyspnea, wheeze, and cough. Of these, 34 patients had asthma, 33 had COPD, and the rest had other diagnoses.

FET could be easily recorded for all the included participants. FET measurements within the same session were quite reproducible, with median coefficient of variation of 3.04% (IQR, 1.61%–5.22%) and intraclass correlation coefficient of 0.977. Median FET was 7.04 s (IQR, 6.67–7.70 s) for Group A participants and 4.14 s (IQR, 3.60–4.68 s) for Group B participants. This difference was statistically significant (\( P < 0.001 \) on Mann–Whitney U-test). FET was negatively and significantly correlated with FEV1 (% predicted), FVC (% of predicted), FEV1/FVC, and PEF (Spearman’s correlation coefficients –0.717, –0.506, –0.761, and –0.539, respectively, \( P < 0.001 \) for all) [Figure 1].

Diagnostic accuracy estimates for various FET thresholds are summarized in Table 1. Area under the ROC curve was 0.933 (95% confidence interval [CI] 0.890–0.976), suggesting FET to be a good discriminator in identifying airway obstruction [Figure 2]. Using the ROC curve, the best tradeoff between sensitivity and specificity was noted around FET of 5 s. At a threshold of ≥5 s, FET had a high sensitivity and a reasonable specificity to retain its utility as a screening test for airway obstruction [Table 1].

Our literature search yielded 392 citations, of which only 13 were finally considered for data synthesis [Figure 3].\[1-15\] Auscultation for measuring FET was conducted over posterior chest wall, or over sternum, in one study each.\[3,14\] All other studies used suprasternal notch for auscultation [Table 2]. Five studies reported some form of training to participants prior to actual testing.\[4,9,11,12\] Both simple wrist watch with seconds hand and a stop watch were used for recording time [Table 2]. Up to five FET maneuvers were performed in each session, and either the longest or the average time was generally reported for data analysis [Table 2]. Five studies provided data on diagnostic accuracy of FET through sensitivity and specificity calculations [Table 3].\[4,8,9,11,15\] Two of these reported data on multiple diagnostic thresholds and higher thresholds were associated with better sensitivity but with poor specificity.\[8,11\] At a widely used threshold of 6 s to describe airway obstruction, sensitivity ranged from 0.61 to 0.92 and specificity from 0.43 to 1.00, in four studies [Table 3]. Pooled sensitivity and specificity from these four reports, plus the present study, were 0.802 (95% CI, 0.668–0.890) and 0.837 (95% CI, 0.570–0.952), respectively [Figure 4]. Corresponding pooled PLR and NLR were 4.932 (95% CI, 1.574–15.451) and 0.237 (95% CI, 0.131–0.429), respectively. Four studies summarized diagnostic performance using likelihood ratio or area under ROC curve.\[10-12,14\] Area under ROC curve was 0.61 and 0.72 in two of these studies.\[10,11\] Five studies reported negative correlations with spirometric volumes and flows, FEV1/FVC, or specific airway conductance [Table 3].\[3,4,6,7,15\] In one study on preoperative assessment before nonthoracic surgery, 22.4% of patients had obstructive airway disease and higher FET was significantly associated with postoperative complications.\[13\]

DISCUSSION

There is no doubt that spirometry is the best modality to diagnose airway obstruction by demonstrating a reduction in FEV1/FVC ratio. However, the investigation is not universally available, and clinicians in resource-limited settings often rely on soft clinical pointers to assess probability of airflow limitation so that only those with higher probability of airway obstruction get referred for pulmonary function testing. Unfortunately, most of these clinical signs are rather subjective and poor at screening for airway obstruction. FET has been proposed as an easy
Table 1: Diagnostic performance of forced expiratory time in assessing spirometrically determined airway obstruction

| FET threshold | Sensitivity  | Specificity | PLR       | NLR       | Positive predictive value | Negative predictive value |
|---------------|--------------|-------------|-----------|-----------|---------------------------|---------------------------|
| ≥3 s          | 0.986 (0.923-1.000) | 0.114 (0.051-0.213) | 1.113 (1.018-1.216) | 0.125 (0.016-0.973) | 0.527 (0.438-0.614) | 0.889 (0.517-0.997) |
| ≥4 s          | 0.986 (0.923-1.000) | 0.429 (0.311-0.552) | 1.725 (1.406-2.117) | 0.033 (0.005-0.238) | 0.633 (0.535-0.723) | 0.968 (0.833-0.999) |
| ≥5 s          | 0.943 (0.860-0.984) | 0.814 (0.703-0.897) | 5.077 (3.098-8.320) | 0.070 (0.027-0.183) | 0.835 (0.735-0.909) | 0.934 (0.840-0.982) |
| ≥6 s          | 0.829 (0.720-0.908) | 0.886 (0.787-0.949) | 7.250 (3.744-14.04) | 0.194 (0.115-0.326) | 0.879 (0.775-0.946) | 0.838 (0.734-0.913) |
| ≥7 s          | 0.529 (0.405-0.649) | 0.986 (0.923-1.000) | 37.00 (5.220-262.3) | 0.478 (0.373-0.614) | 0.974 (0.862-0.999) | 0.676 (0.577-0.766) |
| ≥8 s          | 0.100 (0.041-0.195) | 1.000 (0.949-1.000) | Cannot be estimated | 0.900 (0.832-0.973) | 1.000 (0.590-1.000) | 0.526 (0.438-0.613) |

Figures in parenthesis are 95% confidence limits. PLR: Positive likelihood ratio, NLR: Negative likelihood ratio, FET: Forced expiratory time.

Table 2: Study characteristics of publications identified for data synthesis

| Study                      | Study population                                                                 | Area of auscultation | Training of participants | Measurement | Number of attempts | FET reporting |
|----------------------------|----------------------------------------------------------------------------------|----------------------|--------------------------|-------------|--------------------|---------------|
| Rosenblatt and Stein, 1962 | 31 healthy controls and 96 patients with various respiratory disorders; 79 had airway obstruction | Posterior chest wall | NS                       | Stop watch  | Two                | Longest       |
| Lal et al., 1964           | 95 participants, both healthy controls and patients; 52 with obstruction (FEV₁/FVC < 0.65) | Suprastrernal notch  | Yes                      | Wrist watch or stopwatch (least count 0.5 s) | Three               | Longest       |
| Godfrey et al., 1969       | 11 patients (9 with OAD) in initial study, another 21 patients (all OAD) after physician training | Suprastrernal notch  | NS                       | NS          | NS                 | NS            |
| Godfrey et al., 1970       | 24 patients, all with airway obstruction                                           | Suprastrernal notch  | NS                       | NS          | NS                 | NS            |
| Macdonald et al., 1975     | 21 patients with a variety of disorders; another 15 patients and 10 healthy persons | Suprastrernal notch  | Yes                      | Stopwatch   | Up to four          | NS            |
| Kernand Patel, 1991        | 205 plumbers, 67 with airway obstruction                                           | Suprastrernal notch  | NS                       | Stopwatch   | Five               | Average       |
| Badgett et al., 1993       | 92 participants, smokers or self-reported OAD; 32 had COPD and 35 had asthma       | Suprastrernal notch  | Yes                      | Watch with seconds hand | Two                | Average       |
| Holleman et al., 1993      | 164 patients at preoperative assessment clinic, 44% had OAD                        | Suprastrernal notch  | NS                       | Multiple    | Multiple            | Longest, least, and average |
| Schapira et al., 1993      | 384 participants undergoing lung function testing, 55% had OAD                     | Suprastrernal notch  | Yes                      | Stopwatch   | Two                | Longest       |
| Straus et al., 2002        | 161 patients, 66 with known COPD                                                  | Suprastrernal notch  | Yes                      | Watch with seconds hand | Two                | Longest       |
| McAlister et al., 2003     | 272 preoperative patients, 61 had OAD                                              | Suprastrernal notch  | NS                       | NS          | NS                 | NS            |
| Mattos et al., 2009        | 200 inpatients or outpatients referred for lung function testing, 98 had COPD      | Suprastrernal notch  | NS                       | NS          | NS                 | NS            |
| Wali, 2011                 | 201 participants undergoing lung function testing, 98 had obstructive pattern      | Suprastrernal notch  | NS                       | Stopwatch   | Three               | Average       |

COPD: Chronic obstructive pulmonary disease, FET: Forced expiratory time, FEV₁: Forced expiratory volume in 1s, FVC: Forced vital capacity, NS: Not specified, OAD: Obstructive airway disease

Figure 2: Receiver operating characteristic curve to assess the diagnostic performance of forced expiratory time

We reported the highest FET measurement from among three maneuvers in the same test session. Previous investigators have generally used either the mean or the maximum FET from multiple attempts [Table 2], and there is no consensus on the issue. At least one previous study has suggested that the choice of least, average, or maximum FET does not significantly influence the predictive ability of the test.¹⁰ We tried to establish a threshold for FET that would provide a high sensitivity and a reasonable and a more objective marker, but there is no consensus regarding its utility. Very few studies have evaluated FET in clinical practice, as is evident from the results of our systematic review [Tables 2 and 3]. Previous studies have reported on diagnostic accuracy of FET, but not on its performance as a screening test. This study was undertaken to fill some of these knowledge gaps.
specificity, features expected from a good screening test. Earlier studies had focused more on optimizing diagnostic accuracy, and a threshold of 6 s is widely used. At this threshold, both sensitivity and specificity are moderately high. Unfortunately, neither is sufficiently high to enable the test to have clinical utility as either a screening (high sensitivity) or a diagnostic (high specificity) tool. We found that a slightly lower FET threshold of 5 s provided high sensitivity (0.943) and an acceptable specificity (0.814), indicating that this cutoff can be used to screen patients for airway obstruction. We also calculated the PLR and NLR at this threshold. Likelihood ratios may be a better way of expressing diagnostic performance, by providing a measure of how much the odds of disease change based on a negative, or a positive, test result. In general, PLRs above 10 or NLRs <0.1 reflect the test’s ability to confirm or exclude disease, respectively.\(^\text{[20]}\)

Specifically, a NLR of 0.070 at the 5 s threshold in our study suggests that there are only seven false negatives for every 100 true negatives, implying that this threshold can be used to exclude airway obstruction [Table 1]. However, the PLR of 5.077 at this threshold suggests that there are ten false positives for every 51 true positives; hence, this threshold is less useful to confirm airway obstruction. In fact, FET can be a good confirmatory test only at a threshold of 7 s, but a low sensitivity and high NLR at this threshold severely limit its clinical utility [Table 1]. On the other hand, pooled PLR and NLR from five studies (including our study) providing information on the commonly used FET threshold of 6 s were 4.932 and 0.237, respectively. At this threshold, FET is unlikely to be useful in either confirming or excluding airway obstruction.

Our data also support excellent within-subject reproducibility of FET measurements in a single test session. A single previous study had reported mean within-subject coefficient of variation of 25.8% and concluded that such variability precluded the use of FET as a screening test in clinical practice.\(^\text{[7]}\) However, three other studies have shown good test repeatability.\(^\text{[5,10,11]}\) Previous studies have also shown good interrater reliability of the test, although this was not examined in our study.\(^\text{[7,14]}\) We have also shown good negative correlation between FET and spirometrically determined lung volumes and PEF, implying that FET gets prolonged with worsening airway obstruction. This is largely similar to previous studies.\(^\text{[3,7,15]}\)

Our study has certain limitations. We have looked at the diagnostic accuracy of FET as the sole test in diagnosing airway obstruction. However, other clinical parameters can also be indicative of the same, and this information is routinely available to the clinician while figuring a probability of airway obstruction. In one study, self-reported history of COPD and presence of wheezing improved the likelihood of diagnosing COPD.\(^\text{[12]}\) Our study population consisted of patients referred for spirometry at a tertiary care center, and many had severe airflow limitation. Hence, our findings may not be truly reflective of the utility of FET in other settings (for instance, screening for COPD in the general population). Moreover, the general population may also include patients with restrictive ventilatory disorders. We did not include such patients in our study since low lung volumes are associated with early completion of
In summary, we have documented diagnostic accuracy and clinical utility of FET in identifying airway obstruction. The frequently used FET threshold of 6 s is a poor discriminator, both for screening and confirming airway obstruction. We propose that FET of 5 s or more should be regarded as abnormal during patient screening, and these patients should undergo spirometry for confirmation of diagnosis. Our suggestions need to be replicated in other studies in more diverse settings.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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### Table 3: Important observations from studies included in the systematic review

| Study                  | Threshold | Sensitivity | Specificity | Likelihood ratio | Area under curve | Correlation with other lung function parameters | Others                                                                 |
|------------------------|-----------|-------------|-------------|------------------|------------------|------------------------------------------------|----------------------------------------------------------------------|
| Rosenblatt et al., 1962 |              |             |             |                  |                  | Negative correlation with FEV₁, MEF, MBC          | <4 s in all normal participants <6 s in 66% patients with mild obstruction ≥7 s in most patients with moderate-to-severe obstruction |
| Lal et al., 1964       | >=6 s     | 0.86        | 1.00        |                  |                  | Underestimates spirometric FET FEV₁/FVC -0.84    | Nonlinear and poor correlation with PEF                               |
| Godfrey et al., 1969   |           |             |             |                  |                  | Experience agreement index of 80%, improving to 92% after training |                                                                     |
| Godfrey et al., 1970   |           |             |             |                  |                  | SGaw regression coefficient - 0.0452             |                                                                     |
| Macdonald et al., 1975 |           |             |             |                  |                  | Average within-subject coefficient of variation 25.8%, good interrater agreement |                                                                     |
| Kern and Patel, 1991   | ≥5 s      | 0.98        | 0.30        |                  |                  |                                                  |                                                                     |
|                        | ≥6 s      | 0.92        | 0.43        |                  |                  |                                                  |                                                                     |
|                        | ≥7 s      | 0.90        | 0.51        |                  |                  |                                                  |                                                                     |
|                        | ≥8 s      | 0.82        | 0.61        |                  |                  |                                                  |                                                                     |
|                        | ≥12 s     | 0.55        | 0.82        |                  |                  |                                                  |                                                                     |
| Badgett et al., 1993   | ≥11 s     | 0.12        | 0.99        |                  | 0.72             |                                                  |                                                                     |
| Holleman et al., 1993  |           |             |             |                  |                  |                                                  |                                                                     |
| Schapira et al., 1993  | ≥3 s      | 0.92        | 0.38        |                  |                  | 0.36 (at <2 s) to 2.32 (at ≥8 s) for <60 years age; 0.15 (at <2 s) to 4.08 (at ≥8 s) for ≥60 years |                                                  |
|                        | ≥6 s      | 0.74        | 0.75        |                  |                  |                                                  |                                                                     |
|                        | ≥12 s     | 0.28        | 0.94        |                  | 0.61             |                                                  |                                                                     |
| Strauss et al., 2002   | ≥9 s      |             |             |                  | 6.7              |                                                  |                                                                     |
|                        | 6-9 s     |             |             |                  | 1.8              |                                                  |                                                                     |
|                        | <6 s      |             |             |                  | 0.6              |                                                  |                                                                     |
| McAlister et al., 2003 | ≥9 s      |             |             |                  |                  |                                                  | 42/72 had prolonged FET, odds ratio 5.7 for postoperative complications |
| Mattos et al., 2009    | ≥4 s      |             |             |                  | 3.44             |                                                  |                                                                     |
| Wali, 2011             | ≥6 s      | 0.61        | 0.79        |                  |                  | FEV₁ -0.36                                      |                                                                     |

FET: Forced expiratory time, FEV₁: Forced expiratory volume in 1st s, FVC: Forced vital capacity, MBC: Maximal breathing capacity, MEF: Midexpiratory flow, PEF: Peak expiratory flow, SGaw: Specific airway conductance

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forced expiration, and hence a low FET. Our systematic review identified only articles published in English, and we may have missed some important publications in other languages.

In summary, we have documented diagnostic accuracy and clinical utility of FET in identifying airway obstruction. The frequently used FET threshold of 6 s is a poor discriminator, both for screening and confirming airway obstruction. We propose that FET of 5 s or more should be regarded as abnormal during patient screening, and these patients should undergo spirometry for confirmation of diagnosis. Our suggestions need to be replicated in other studies in more diverse settings.
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