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Forced expiratory time—its reliability as a lung function test

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Macdonald, J. B., Cole, T. J., and Seaton, A. (1975). *Thorax*, **30**, 554–559. **Forced expiratory time—its reliability as a lung function test.** Three studies of factors affecting variability of forced expiratory time (FET) have been carried out. In the first, different observers or repeated measurements over a few minutes were shown to make no significant contribution to FET variability. Time of day was also relatively unimportant. In the second study, FET was shown to vary considerably more than peak flow rate, forced expiratory volumes, and mid expiratory flow rates over the course of five days. In the third study, FET was shown to correlate with other measurements of airways obstruction though the correlation coefficients were relatively low. The measurement of FET is thought to be too variable to be of practical use as a screening test for small airways disease, though its clinical value is not questioned.

The time taken for a forced expiration can be measured easily with stopwatch and stethoscope. Over the last 30 years many observers have been attracted by this simplicity and have proposed a number of uses for forced expiratory time (FET) as a lung function test. Recently, McFadden and Linden (1972) and Cochrane *et al.* (1974a) have drawn attention to FET as a possible measurement of obstruction to airways of less than 2 mm internal diameter. Both groups suggest a good correlation between FET and other tests of small airways obstruction. Since smokers appear to develop small airways obstruction before standard spirometry becomes abnormal (McFadden and Linden, 1972), a simple small airways test might show which smokers are most likely to develop chronic airways obstruction (Cochrane *et al.*, 1974b) and be of use in epidemiological surveys. Previous tests of small airways disease—frequency dependence of compliance (Macklem, 1972), closing volume (McCarthy *et al.*, 1972), and maximal expiratory flow at 50% of forced vital capacity (McFadden and Linden, 1972) or at 75% of forced vital capacity (Mead *et al.*, 1967)—all depend on complex equipment and so are limited to specialized laboratories. On the other hand, FET would be very valuable in small airways disease if it proved to be relevant and reliable.

This paper analyses FET reliability in three ways: (1) how FET varies when measured by different observers, at different times of day and after repeated attempts at the test; (2) how FET variability compares with that of other lung function tests measured simultaneously; and (3) how well FET correlates with established tests of airways obstruction.

METHODS

Three studies were performed. In all three, clinical FET was measured using a stethoscope diaphragm placed over the sitting patient's upper trachea in the suprasternal notch. The time taken for a forced expiration was measured with a stopwatch graduated in 0·2 second.

1. FACTORS AFFECTING REPRODUCIBILITY Twenty-one patients aged 18–79 (mean 53) years, 16 males and 5 females, were studied. They represented a wide range of pulmonary disorders and their FETs ranged from 1 to 16·5 (mean 8·2) seconds (Table I). On the day of study, subjects had no therapy (bronchodilator aerosols or radiotherapy) likely to affect FET transiently.

Four observers were used—two doctors experienced in FET measurement and two respiratory

TABLE I

MEAN ± STANDARD DEVIATION FOR PARAMETERS MEASURED IN ALL THREE STUDIES

Study	Clinical FET (sec)	Spirometric FET (sec)	MEF_{50} (l/min)	MEF_{75} (l/min)	PEFR (l/min)	FEV_1 (l.)	FVC (l.)	FEV_1/FVC %
First								
21 patients	8·2±4·7							
Second								
15 patients	8·6±3·2	9·9±4	91±83	24±24	300±144	1·7±0·8	2·5±0·9	65±12
10 normals	3·6±1·7	4·9±2·4	250±78	110±56	540±135	3·3±0·6	4·0±0·7	83± 9
Third[1]								
37 patients	8·6±4·7	9·4±4·6	95±77	31±26				
18 controls	2·8±1·3	4·5±2·5	250±82	110±50				

[1]Includes the 15 patients and 10 normals from second study.

technicians who had not used a stethoscope before.

On the day before the study, each patient had three attempts at FET to accustom him to the technique. The next day, each of the four observers measured the patient's FET in turn, repeated at four set times during the day—9.15 am, 12 noon, 2 pm, and 4.30 pm. The order in which observers measured FET on each occasion was determined by a latin square design. Observers were not permitted to see other observers' results nor their own previous results. The effects on FET of the observer, the time of day, and repeating the test were subjected to analysis of variance. As the variability of the long FETs was substantially greater than that for shorter times, log FET was used in the calculations.

2. COMPARISON OF FET VARIABILITY WITH OTHER MEASUREMENTS OF VENTILATORY FUNCTION Fifteen additional patients aged 39–80 (mean 55) were studied. They also showed a wide spectrum of chest disease, and no patient was on any therapy likely to cause day to day variation in lung function. Ten healthy controls aged 21–57 (mean 34), 6 male and 4 female, were also studied. None had any history or symptoms of respiratory disease and only two were smokers (Table I).

Each subject performed two forced expiratory manoeuvres at a fixed time between 9.30 am and 10.30 am each day for five days. On each forced expiration eight variables were measured simultaneously by timing clinical FET over the trachea while the subject expired into a spirometer. An Ohio 840 differentiating spirometer provided flow and volume signals. Flow-volume curves displayed on a DuMont 401B oscilloscope were recorded by Polaroid photography, giving peak expiratory flow rate (PEFR) and maximum expiratory flow rates at 50% and 75% of vital capacity (MEF_{50} and MEF_{75}). A volume-time curve shown on a direct-recording ultraviolet oscillograph (Southern Instruments Ltd) produced forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), and spirometric FET. Clinical FET was timed by two observers (JBM and a technician), one measuring each of the two manoeuvres on each occasion.

Log (FET) was again used as the FET variable except where noted. The variation for each respiratory measurement in an individual patient was assessed by its coefficient of variation (standard deviation/mean). The coefficient of variation for each measurement, averaged over the 25 subjects, was then used as an index of variability.

As a more fundamental criterion is a test's ability to discriminate between two subjects, the spread of FET between one patient and another (the 'between-subject' variability) was calculated and from it the ratio of 'within-subject' variation to 'between-subject' variation, an index of a test's practical value.

3. CORRELATION BETWEEN FET AND ESTABLISHED TESTS OF AIRWAYS FUNCTION Two methods of assessment were used. In the first, correlation coefficients were calculated between the mean FET and the mean values of MEF_{50}, MEF_{75}, FEV_1, FEV_1/FVC, and PEFR. In this study, we have included the 25 subjects in the variability study and have added 30 subjects (22 patients, 8 normals) whose clinical and spirometric FET and flow-volume curves were measured in the course of routine lung function testing. The correlations are thus based on 55 subjects (37 patients, 18 controls) (Table I). For ease of calculation, FET rather than log (FET) was used.

To aid comprehension of the practical importance of a given correlation coefficient ρ between two variables, we have also calculated the extent

to which fixing one variable will reduce the standard deviation (SD) of estimates of the other variable.[1] Unless this SD reduction is substantial, correlation between the two variables will be unimportant practically.

Finally, correlation coefficients within each subject were calculated, that is, between the small changes in each patient's FET, MEF_{50}, and MEF_{75}, from one expiratory attempt to another, using figures from the 25 subjects in the variability study. For ease of calculation, FET rather than log (FET) was used.

RESULTS

1. FACTORS AFFECTING REPRODUCIBILITY Table II shows the effect on FET of the time in the day at which the test was done, the order of blow from first to fourth each time, and the four different observers. The time of day is seen to have a significant effect on FET variability in three of the 21 subjects while the order of blow was significant in only one subject. FET reproducibility was not significantly affected by different observers making the measurement. FET is therefore relatively unaffected by observer effects or order of blow but shows a small tendency to vary during the day.

TABLE II

ANALYSIS OF VARIANCE OF FET IN 21 SUBJECTS, MEASURED BY FOUR OBSERVERS FOUR TIMES A DAY LEVELS OF SIGNIFICANCE REACHED BY THREE FACTORS LIKELY TO AFFECT REPRODUCIBILITY, WITH NUMBERS OF SUBJECTS AT EACH LEVEL

P[1]	Time of Day	Order of Blow	Observer Error
< 1%	2	—	—
< 5%	1	1	—
< 10%	2	—	2
< 20%	6	2	3
> 20%	10	18	16

[1] % SD reduction = $(1-\sqrt{1-\rho^2}) \times 100$, for large groups

2. COMPARISON OF FET VARIABILITY WITH OTHER MEASUREMENTS OF VENTILATORY FUNCTION The subjects were selected to show a wide range of mean FET (1·2–16·4 seconds). The mean coefficient of variation (standard deviation/mean) for each ventilatory measurement is shown in Table III. On this modest criterion, the simple lung function tests (FEV_1, FVC, FEV%, and PEFR) come out best, that is, with the smallest coefficients of variation. MEF_{50}, MEF_{75}, spirometric FET, and especially clinical FET are shown to be considerably more variable within individuals.

The ratio of 'within-subject' variation to 'between-subject' variation for each parameter is shown for patients and controls combined in Table III. On this assessment FET performs poorly, with a considerably larger 'within to between' variability than any other parameter. FET not only has the largest 'within-subject' variation shown but also a relatively small 'between subject' variation, indicating a substantial overlap in FET scores between one subject and another. These analyses have also been done using log FET, and while this reduces the figures in Table III (last column) slightly, the conclusions are unchanged.

3. CORRELATION BETWEEN FET AND ESTABLISHED TESTS OF AIRWAYS FUNCTION

(a) *'Between-subject' correlation of FET and other measurements* These correlations are shown in Table IV. Although all are statistically significant ($P<0.01$), the actual coefficients are relatively low, except as expected between clinical and spirometric FET (0·94) and between MEF_{50} and MEF_{75} (0·93). The correlations between FET and MEF_{50} and MEF_{75}, PEFR, and FEV_1 respectively were of the order of 0·6, 0·5, and

TABLE III

COMPARISON OF VARIABILITY WITHIN SUBJECTS OF DIFFERENT INDICES OF AIRWAYS OBSTRUCTION: 25 SUBJECTS MEASURED TWICE DAILY FOR FIVE DAYS

Index	Units	Within Subjects				Average Coefficient of Variation within Subjects %	SD within Subjects ÷ SD between Subjects %
		Patients		Controls			
		Mean	SD	Mean	SD		
Clinical FET	sec	8·7	2·4	3·6	1·0	25·8	54
Spirometric FET	sec	9·7	2·2	4·9	1·4	21·4	46
MEF_{50}	l/min	91	14	250	24	14·2	17
MEF_{75}	l/min	30	6·5	70	16	19·7	20
FEV_1	l.	1·66	0·13	3·3	0·11	3·8	11
FVC	l.	2·5	0·19	4·0	0·13	4·2	13
$\frac{FEV_1}{FVC}$%	%	65	4·0	83	2·3	4·2	25
PEFR	l/min	297	40	540	44	4·6	23

TABLE IV

CORRELATIONS BETWEEN TESTS OF AIRWAYS OBSTRUCTION IN 55 SUBJECTS

Indices	Patients (37) and Normals (18)	
	Correlation Coefficient	SD Reduction
FET_C v FET_S	0·94	66%
FET_C v MEF_{50}	−0·59	19%
FET_S v MEF_{50}	−0·55	17%
FET_C v MEF_{75}	−0·57	18%
MEF_{50} v MEF_{75}	0·93	63%
FET_C v PEFR	−0·50	13%
FET_C v FEV_1	−0·39	8%
FET_C v FEV_1/FVC%	−0·58	18%

FET_C = FET measured with stethoscope.
FET_S = FET measured from spirogram.

0·4. The reduction in standard deviation on fixing one variable is small for correlations between flow rates and FET, indicating that these correlations are of little practical importance.

(b) *Correlation of 'within-subject' changes* Table V shows the average of the 'within-subject' correlations between FET, MEF_{50}, and MEF_{75} derived from each subject's 10 attempts. Changes in FET measured clinically and spirometrically are modestly correlated (correlation coefficient 0·55). Changes in clinical FET are surprisingly not correlated with changes in MEF_{50}, but spirometric FET and MEF_{50} changes are slightly correlated. Neither FET technique is correlated with MEF_{75} changes. The substantial correlations (0·60 and 0·77) observed between MEF_{50} and MEF_{75} changes are to be expected, since the two are calculated from a single flow-volume tracing.

DISCUSSION

Forced expiratory time is potentially attractive as a lung function test in that it requires no laboratory equipment whatsoever. Its concept is not new, and its evolution has been gradual. Gross (1943) measured the time taken for expiration and, with Gaensler (1951) and Franklin *et al.* (1955), emphasized the importance of volume-time curves. Both Roy, Chapin, and Favre (1955) and Comroe (1955) associated a long FET with airways obstruction. This idea was developed by Rosenblatt and Stein (1962) and by Lal, Ferguson, and Campbell (1964), who showed that, of simple spirometric tests, FET correlated best with FEV_1/FVC. As the concept of small airways disease developed, both McFadden and Linden (1972) and Cochrane *et al.* (1974a) suggested that FET might be a useful index of small airways obstruction in the patient with normal spirometry.

In the assessment of FET as a test of airways obstruction three aspects should be considered. First, it must be shown to be a reliable test. This means that it must be easy to measure consistently and that it should vary no more than other similar tests. Secondly, it should discriminate between normal and abnormal subjects, as defined by other similar tests. Thirdly, it should correlate with other tests that are used for measurement of airways function.

Consistency was analysed in our first study, which showed that FET reproducibility was very little affected by observer error or by up to four attempts at the test. In only three of 21 patients was time of day significant in increasing FET variability. Observer–patient interactions were also unimportant. FET thus stood up well to the factors most likely to distort its measurement in practice. However, the effect of these factors can only be analysed relative to the measurement's overall variability, so this analysis does not help to decide how variable the test is in itself. For this, we need to compare FET variability with other tests, and here FET comes out less favourably. Its variability within each patient was easily the worst of the eight tests analysed under identical conditions; it also had an exceptionally low power to discriminate between one patient and another. Overall, this excessive variability alone is probably enough to

TABLE V

AVERAGE CORRELATIONS WITHIN SUBJECTS OF VARIOUS TESTS OF AIRWAYS OBSTRUCTION MEASURED ON 10 OCCASIONS IN 25 SUBJECTS

Indices	Patients (15)		Controls (10)	
	Correlation Coefficient	Probability	Correlation Coefficient	Probability
FET_C v FET_S	0·55	<0·1%	0·26	<1%
FET_C v MEF_{50}	−0·11	NS	−0·02	NS
FET_S v MEF_{50}	−0·18	<5%	−0·27	<1%
FET_C v MEF_{75}	−0·14	NS	−0·14	NS
MEF_{50} v MEF_{75}	0·60	<0·1%	0·77	<0·1%

FET_C = FET measured with stethoscope.
FET_S = FET measured from spirogram.

rule out FET as a serious, accurate lung function test.

The development of the concept of small airways disease as a forerunner of chronic airways obstruction in patients with chronic bronchitis has given rise to the hope that it might be possible to detect those subjects most at risk by tests of small airways function. Our main aim has been to show whether FET, undoubtedly a sufficiently simple test to be used in epidemiological studies, is sufficiently reliable for widespread application. Unfortunately, we have shown in this study that the variation in individual patients and normal subjects over a week is considerably greater than that of other commonly used spirometric tests and that this variability within subjects approaches the variability between subjects. Unless, therefore, there is clear evidence that FET correlates better with measurements purely of small airways obstruction than it does with these spirometric tests, it is unlikely to be of use in the detection of small airways disease.

We have not looked specifically at subjects with 'small airways disease', who would be defined as having normal spirometry and pressure-volume curves and yet an abnormality of either dynamic compliance at faster rates of respiration or of closing volume. The closest we have got to this has been to correlate FET with flow rates at 50% and 75% of forced vital capacity, tests thought to relate in part to small airways function. Table IV shows that there is a negative correlation between FET and MEF_{50} and MEF_{75}, rather better for controls than for patients. The best correlation, however, is only $-0{\cdot}59$.

These results may be compared with those of Cochrane *et al.* (1974a), whose data show an FET–MEF_{50} correlation of 0·60 and FET–MEF_{75} correlation of 0·635 on 10 normals. The two series, however, differ in several details. We have used actual MEF_{50} and MEF_{75} rather than the % predicted value. Our series is based on larger numbers (55 subjects rather than 20) with a wider FET range (1·2–26 seconds rather than 2·5–8·4 seconds) and measured clinical as well as spirometric FET. Despite these differences, results of a similar order were obtained.

However, although our calculations are similar to those of Cochrane *et al.* (1974a), we must differ from them in the conclusions we draw. A correlation coefficient of 0·65 may be significant at the 0·1% level between two random variables. However, the variables used here are not random but are derived from a single volume signal plotted against time or flow. Thus assumptions based on random variables are inadequate. In these circumstances, we feel that a correlation coefficient of less than 0·65 giving, at best, only a 24% reduction in standard deviation of FET estimation on removing all variability due to MEF_{50} is very poor evidence for FET as a practical index of small airways disease.

The high correlation between clinical and spirometric FET found in the present series (0·94) agrees well with the figure of 0·89 calculable from the data of Lal *et al.* (1964). Both studies provide good evidence that the clinical method is an acceptably accurate technique for measuring spirometric FET. The closely parallel behaviour of FET_c and FET_s in our other calculations confirms this. To test the possibility that clinical FET measured normally differs from clinical FET measured while blowing into the spirometer, these tests were carried out by eight further patients and four normal subjects. No significant difference was found between the two techniques.

Different studies have shown a normal range for FET between about 1·5 and 4·5 seconds (Table VI). Our clinical practice suggests that it is quite exceptional to find a patient with an FET longer than 5 seconds who does not have respiratory disease. The clinical usefulness of the test is not therefore in doubt. The studies reported here do, however, cast doubt on its potential value as a suitably reproducible test for the detection of subjects with early airways disease in epidemiological surveys. Whether FET will prove of value as a test of small airways obstruction awaits further study, but its variability and its poor correlation with MEF_{50} and MEF_{75} suggest that it will not.

TABLE VI

MEAN AND STANDARD DEVIATION OF NORMAL FET IN PUBLISHED SERIES

FET (sec)	No. of Subjects	Series
2·18±0·63	10	Roy *et al.* (1955)
2·58±0·7	31	Rosenblatt and Stein (1962)
2·82±1·3	16	Present study
3·6 ±0·8	10	Cochrane *et al.* (1974a)
3·7 ±0·8	?	McFadden and Linden (1972)

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