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FEV_6 as a surrogate for FVC in detecting airways obstruction and restriction in the workplace

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ABSTRACT: Compared with measurements of forced vital capacity (FVC), using the forced expiratory volume in six seconds (FEV_6) reduces test time and frustration. It was hypothesised that using FEV_6 in the workplace setting would result in an acceptably low misclassification rate for detecting airways obstruction and spirometry-defined restriction when compared with using the traditional FVC.

Experienced technicians from the National Institute for Occupational Safety and Health performed spirometry using dry rolling-seal spirometers as per American Thoracic Society guidelines in four workplace investigations. Airways obstruction was defined as an FEV_1/FVC % below the lower limit of normal (LLN) using National Health and Nutrition Examination Survey III reference equations. Restriction was defined as an FVC below the LLN with a normal FEV_1/FVC %. These "gold standard" definitions were compared with definitions based on FEV_6 (obstruction: FEV_1/FEV_6 below the LLN; restriction: FEV_6 below the LLN with a normal FEV_1/FEV_6).

The median (range) age of the 1,139 workers was 37 yrs (18–71 yrs) and 51.4% were male. A significantly high overall agreement was obtained between the two definitions.

In conclusion, the current results confirm that forced expiratory volume in six seconds can be used as a surrogate for forced vital capacity in detecting airways obstruction and restriction in workers, although with some misclassification when compared to obtaining American Thoracic Society-acceptable manoeuvres of longer duration.

KEYWORDS: Forced expiratory volume in six seconds, pulmonary function test, spirometry

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The most widely used pulmonary function test is spirometry. However, spirometry is an effort-dependent test that requires careful instruction and the full cooperation of the test subject. The inability to perform acceptable and repeatable manoeuvres may be due to poor subject motivation, poor coaching techniques or failure to understand instructions [1]. A prolonged exhalation effort is often needed to obtain a volume–time plateau to meet acceptable end-of-test (EOT) criteria. In subjects with airways obstruction, an acceptable EOT plateau may not occur even after 20 s of exhalation [2, 3]. This can be physically exhausting and frustrating for both the subject and the technician, and occasionally results in subject syncope.

The results of spirometry tests are critically important in the occupational setting when used for screening and surveillance programmes [4]. Poor quality tests increase the misclassification rates for restriction and airways obstruction. The use of forced expiratory volume in six seconds (FEV_6) as a surrogate for the forced vital capacity (FVC) has recently been found to be acceptable in clinical settings [5, 6]. Spirometry results from four recently performed investigations were used to evaluate the possibility that use of FEV_6 would also be acceptable in workplace investigations.

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METHODS

Study population

Spirometry results were collected from 1,143 workers from four different workplace investigations during 2000–2003. All workers signed consent forms approved by the National Institute for Occupational Safety and Health (NIOSH) Human Studies Review Board (Morgantown, WV, USA).

Spirometry

Spirometry was performed with automated Ohio 827 dry rolling-seal spirometers (Ohio Medical

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Products, Madison, WI, USA) with software that checks for unacceptable manoeuvres [7]. Four highly experienced NIOSH technicians followed American Thoracic Society (ATS) spirometry recommendations [1]. The test results were compared to the lower limit of normal (LLN) values from the National Health and Examination Survey (NHANES) III reference values [8] to identify workers with two abnormal spirometry patterns: obstruction and low vital capacity [9]. Airways obstruction was defined as FEV1/FVC % below the LLN. Spirometry-defined ''restriction'' was a FVC below the LLN with a normal FEV1/FVC %. The ''traditional'' definitions were compared with definitions based on FEV6 (obstruction: FEV1/FEV6 below the LLN based on FEV6 from NHANES III; restriction: FEV6 below the LLN and normal FEV1/FEV6).

Statistical analyses

The current authors calculated the sensitivity, specificity, and positive and negative predictive values of using the FEV6 for the determination of overall abnormal spirometry, airways obstruction and restriction. The agreement between test result classification based on FVC and FEV6 was also calculated using the Kappa test.

Those individuals classified differently by two techniques were evaluated separately. Their age, height and pack-yrs data were compared with rest of the group by paired t-test. Ever- and never-smoking status and test reproducibility were tested using Chi-squared tests.

RESULTS

Only four out of the 1,143 workers had invalid spirometry results (test sessions where less than three acceptable manoeuvres were obtained), so their results were excluded from this analysis. The median (range) age of the remaining 1,139 workers was 37 yrs (18–71 yrs) and 51.4% were male (table 1). Among them, 42.0% were current smokers, 15.4% were former smokers and 42.6% were never-smokers.

Interpretations based on the FEV6 had a high agreement rate with those based on the FVC (Kappa=0.90; $p<0.001$; table 2). When the values of FEV1/FEV6 % were used, the sensitivity for detecting airways obstruction was 92% and specificity 98%. For detecting restriction, the sensitivity was 89% and specificity was 99%. For abnormal spirometry, the sensitivity was 94% and specificity was 98%. Positive and negative predictive values for abnormal spirometry were 92% and 98%, respectively.

TABLE 1 Demographic characteristics of workers at the four plants studied

	Workers n	Caucasian %	Male %	Ever-smoking %	Age yrs
Workplace A	160	80.6	58	53.8	43.5±11.6
Workplace B	215	95.4	68	72.6	35.8±9.4
Workplace C	236	74.2	39	37.0	46.4±8.3
Workplace D	528	83.3	48	61.4	32.8±11.6

Data are presented as mean±SD, unless otherwise stated.

TABLE 2 Comparisons of spirometry classifications using the two techniques

	Based on FVC			Total
	Normal	Obstruction	Restriction	
Based on FEV6				
Normal	862	8	8	878
Obstruction	14	152	2	168
Restriction	6	5	82	93
Total	882	165	92	1139

Data are presented as n. FVC: forced vital capacity; FEV6: forced expiratory volume in six seconds.

The spirometry test results for 43 workers (3.8%) were classified differently by the two techniques, and all of them had observed values close to the LLNs. These inconsistently classified cases are found in the upper left and lower right quadrants of figure 1. Among these 43 workers, pack-yrs of cigarette use were significantly higher ($p=0.009$) than in rest of the group. Age, sex, race, test reproducibility, heights and ever-smoking did not differ between these two groups.

DISCUSSION

Clinical practice guidelines state that airways obstruction is defined as a low FEV1/FVC [1, 9]. Errors in the measurement of either the FEV1 or the FVC will cause errors in the measurement of this ratio, which may cause misclassification of the results during the interpretation process, especially if the results are near the LLN range. Workers participating in a workplace screening or surveillance programme are generally healthy, but some are at risk for developing lung disease from their workplace exposures, so the median spirometry values are often closer to the LLN than in groups of patients with respiratory symptoms being referred to a pulmonary function laboratory for testing.

In order to avoid errors in the measurement of the FVC, the 1994 ATS recommendation stated that, to be considered acceptable, each manoeuvre should last until a plateau is achieved on the volume–time graph [1]. This EOT criterion is defined as a <20-mL change in volume during the final 2 s of the manoeuvre. Patients with airways obstruction frequently fail to meet this EOT criterion [3], but, when coached to perform a ''relaxed expiration'', they are somewhat more successful [10]. However, spirometry reference equations were obtained from studies where the subjects were coached to perform with maximal exhalation efforts, so relaxed expirations cannot be recommended as a solution to this problem [11].

The current authors understand that a normal FVC rules out restriction [12], and that a low FVC poorly predicts a low total lung capacity (TLC; true restriction), requiring confirmation by static lung volume tests, which include the TLC, the residual volume and the functional residual capacity [9]; however, static lung volume tests are rarely performed in occupational settings. Failure to obtain FVC manoeuvres with acceptable EOT plateaus is relatively common in the occupational and primary care settings, in some cases due to time constraints,

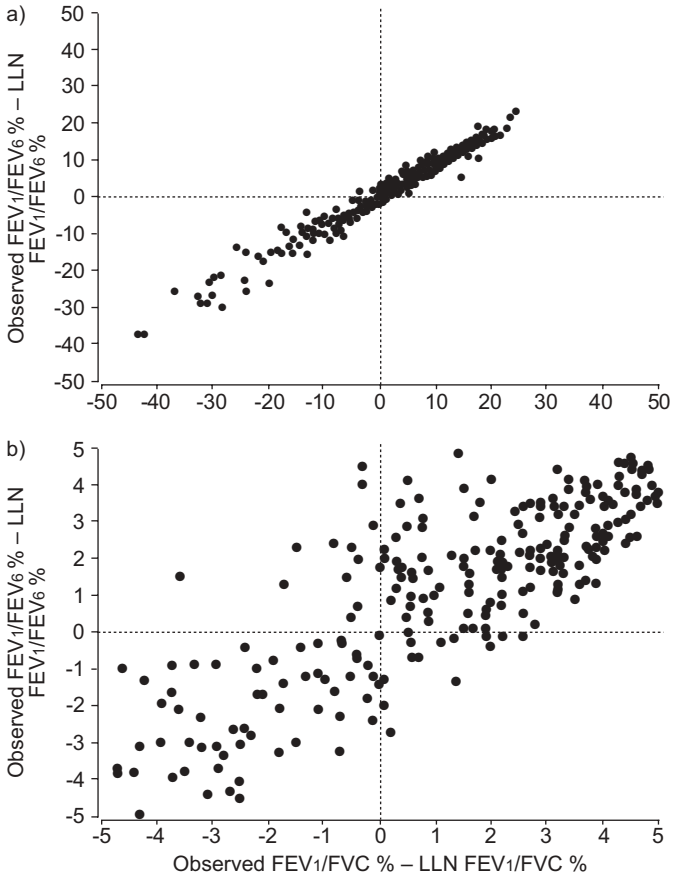

FIGURE 1. a) Overall plot of difference between observed measures and the lower limit of normal (LLN) for both airways obstruction definitions. b) Detailed view of a) in the region of ±5% difference. Quadrant I (upper left): classified as not obstructive by forced expiratory volume in one second (FEV_1)/FEV_6 and obstruction by FEV_1/forced vital capacity (FVC) (1.1%); quadrant II (upper right): classified as not obstructive by FEV_1/FEV_6 and not obstructive by FEV_1/FVC (84.1%); quadrant III (lower left): classified as obstructive by FEV_1/FEV_6 and obstruction by FEV_1/FVC (13.4%); quadrant IV (lower right): classified as obstruction by FEV_1/FEV_6 and not obstructive by FEV_1/FVC (1.4%).

lack of adequate technician training or dedication (leading to poor coaching), poor motivation of the subjects to keep blowing out, a high prevalence of subjects with severe airway obstruction, or a faulty spirometer that prematurely terminates data collection. These short FVC manoeuvres cause underestimations of the true FVC, making a healthy subject's FVC more likely to fall below the LLN, a falsely positive result mimicking 'restriction.' At the same time, the FEV_1/FVC ratio is falsely increased, so that subjects with mild airways obstruction are more likely to have a falsely negative result. These short exhalation times should be detected either by the quality control software of modern spirometers or by the physician interpreting the results. Performance of slow vital capacity (SVC) manoeuvres may demonstrate a vital capacity in the normal range, thereby ruling out restriction, but SVC manoeuvres are rarely performed outside of hospital-based pulmonary function laboratories.

Unfortunately, many spirometers that are currently in use either lack manoeuvre quality-control checks and messages, or they are turned off or ignored. Physicians interpreting the spirometry tests may miss the short exhalation times, the lack of EOT plateaus, or may view only the numeric results. Both types of misclassification of spirometry interpretations have negative consequences in the workplace setting. A potential method for reducing this misclassification rate in the ''real-world'' (nonresearch) setting, where short manoeuvres are common, is to utilise reference equations based on 6-s manoeuvres.

GLINDMEYER *et al*. [13] noted that short FVC manoeuvres result in underestimates of the FVC, and considered recommending shorter spirometry manoeuvres (allowing subjects to stop after 5, 6 or 7 s). However, the ability to use shorter manoeuvres without high misclassification rates awaited the publication of reference equations for these variables from shorter manoeuvres. More than a decade later, the NHANES III study finally provided reference equations for the FEV_6 and FEV_1/FEV_6 [8]. The National Lung Health Education Program quickly recommended that 6-s spirometry manoeuvres and the NHANES III reference equations should be used for detecting airways obstruction in adult cigarette smokers being seen by general practitioners who provide primary care [14]. Some new models of office spirometers provide NHANES III reference equations for the FEV_6 and FEV_1/FEV_6, and base their automated interpretations on these values.

SWANNEY *et al*. [6] showed that using the FEV_1/FEV_6 to detect airways obstruction in 337 patients referred to a hospital-based pulmonary function laboratory in New Zealand resulted in a low misclassification rate when compared with the traditional FEV_1/FVC. ENRIGHT *et al*. [5] then showed that the FEV_1/FEV_6 predicted the subsequent 5-yr decline in FEV_1, as well as the FEV_1/FVC in 5,887 adult smokers.

There is currently some minor confusion regarding the nomenclature for measurements of the vital capacity from 6-s spirometry manoeuvres. The 1999 NHANES III study defined the FEV_6 as the volume in the spirometer at exactly 6 s after the manoeuvre had begun (using the standard back-extrapolation technique to define the start of the exhalation manoeuvre). The air collected inside volume spirometers, such as the ones used by the NHANES III study, cools throughout the FVC manoeuvre (especially when the ambient temperature is relatively low); therefore, in some healthy young subjects who rapidly exhale almost all of their air within 6 s, the cooling and contraction of exhaled air in the spirometer causes the volume–time graph to ''droop'' before the 6-s mark. Such slight downward slopes of the volume–time tracing mimic the effect caused by a leak in the spirometer, and make the FEV_6 slightly lower than the largest volume obtained at any time during the first 6 s (recently defined as the FVC_6). Fast-responding temperature sensors inside the volume spirometer (with real-time body temperature, ambient pressure, saturated with water vapour corrections) can eliminate this artefact, but this degree of sophistication is not currently available in any commercial volume spirometers (and is not used in NIOSH field studies). A re-analysis of the raw data from the NHANES III study recently provided reference equations for the newly defined FVC_6 and FEV_1/FVC_6 [15]. However, the mean differences in the FEV_6 and FVC_6 are very small (<0.05 L) and do not occur when flow-sensing spirometers are utilised.

A recent study from Spain provides an alternate set of FEV_6 and FEV_1/FEV_6 reference equations for older adults [16].

The current results confirm that the forced expiratory volume in six seconds can be used as a surrogate for forced vital capacity in detecting airways obstruction and restriction in workers, although with some misclassification when compared with obtaining American Thoracic Society-acceptable manoeuvres of longer duration. Additional studies are recommended to determine if the current results are generalisable for those using flow-sensing spirometers in occupational settings.

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