



## Official American Thoracic Society Technical Standards: Spirometry in the Occupational Setting

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**Purpose:** This document addresses aspects of the performance and interpretation of spirometry that are particularly important in the workplace, where inhalation exposures can affect lung function and cause or exacerbate lung diseases, such as asthma, chronic obstructive pulmonary disease, or fibrosis.

**Methods:** Issues that previous American Thoracic Society spirometry statements did not adequately address with respect to the workplace were identified for systematic review. Medline 1950–2012 and Embase 1980–2012 were searched for evidence related to the following: training for spirometry technicians; testing posture; appropriate reference values to use for Asians in North America; and interpretative strategies for analyzing longitudinal change in lung function. The evidence was reviewed and technical recommendations were developed.

**Results:** Spirometry performed in the work setting should be part of a comprehensive workplace respiratory health program. Effective technician training and feedback can improve the quality of spirometry testing. Posture-related changes in FEV<sub>1</sub> and FVC,

although small, may impact interpretation, so testing posture should be kept consistent and documented on repeat testing. Until North American Asian-specific equations are developed, applying a correction factor of 0.88 to white reference values is considered reasonable when testing Asian American individuals in North America. Current spirometry should be compared with previous tests. Excessive loss in FEV<sub>1</sub> over time should be evaluated using either a percentage decline (15% plus loss expected due to aging) or one of the other approaches discussed, taking into consideration testing variability, worker exposures, symptoms, and other clinical information.

**Conclusions:** Important aspects of workplace spirometry are discussed and recommendations are provided for the performance and interpretation of workplace spirometry.

**Keywords:** spirometry; occupational; FEV<sub>1</sub>; longitudinal spirometry; medical surveillance

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### Overview

The purpose of this document is to address spirometry performed as part of a workplace respiratory health program. Performance of spirometry for this purpose should meet criteria in prior American Thoracic Society (ATS)/European Respiratory Society (ERS) Statements on Spirometry. Selected aspects relevant to the quality and interpretation of spirometry as part of a workplace program that have not been adequately addressed by previous statements were evaluated.

This article has an online supplement, which is accessible from this issue's table of contents at [www.atsjournals.org](http://www.atsjournals.org)

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Key conclusions and recommendations are:

- The key components of a workplace spirometry program should be clarified before performing spirometry, including the purpose for testing, lines of communication and responsibility, and interpretation of the results.
- To optimize the quality of spirometry, technicians should undergo practical training and refresher courses. They should also receive on-going feedback about the quality of tests that they perform, and how to correct problems in test performance.
- Standing or sitting test posture can be used for testing, but the same posture should be used when possible on repeat testing, and should be documented. The rationale is that posture-related changes in FEV<sub>1</sub> and FVC, although small, may significantly impact evaluation.
- Racial or ethnic differences in lung function exist. Specific reference equations (such as National Health and Nutrition Examination Survey [NHANES] III) that have been developed from studies of certain populations are preferable when available. When such reference equations are not available, however, the use of correction factors is an appropriate interim solution. As an example, a correction factor of 0.88 may be applied to white subject reference values for FEV<sub>1</sub> and FVC when evaluating Asian populations within North America.
- Spirometry measurements should be evaluated relative to workers' baseline or prior tests, in addition to comparing to normal ranges. This is particularly important when baseline measurements exceed predicted values. FEV<sub>1</sub> decline over time should be evaluated using one of the approaches described and interpreted in the context of worker exposures, symptoms, and other clinical information.
- Overall guidance for the performance and evaluation of workplace spirometry, including individual results and group (employer/company) spirometry data is provided.

**Introduction**

The purpose of this document is to address selected aspects of spirometry performed as

part of a workplace respiratory health program. The most recent ATS/ERS standards address spirometry performance and interpretation (1–3), but do not focus on issues specifically related to the work setting. Other organizations and governmental agencies have published documents that address certain aspects related to spirometry in the work setting, such as the American College of Occupational and Environmental Medicine (ACOEM) (4–6), the Occupational Safety and Health Administration (OSHA) (7), and the National Institute for Occupational Safety and Health (NIOSH) (8). However, an ATS document that uses systematic literature reviews to provide additional guidance for the work setting is needed.

Spirometry that is performed as part of a workplace spirometry program differs from clinical diagnostic spirometry in several key respects, including its purpose, patient–healthcare provider–employer relationships, and its role in individual and workplace decision making, as detailed in Table 1. Four issues thought to be inadequately addressed in previous ATS spirometry statements were selected for evidence-based review and recommendations: (1) technician training; (2) spirometry test posture; (3) reference values for Asians in North America and Europe; and (4) evaluation of spirometry over time. Other important areas, such as quality control considerations and test interpretation, are discussed in detail in other recent documents (2, 3, 6–8). The intended

audience is occupational health, primary care and pulmonary clinicians, occupational and public health professionals, and other personnel involved in worker health and safety.

**Methods**

The project co-chairs were selected by the leadership of the Environmental and Occupational Health Assembly on the basis of their experience in group leadership and occupational medicine. Committee members were selected based upon their expertise in pulmonary medicine, occupational health, and/or spirometry. Potential conflicts of interest among the chairs and committee members were disclosed, vetted, and managed according to the policies and procedures of the ATS.

Issues identified for detailed evidence-based review of the literature were: (1) optimal training for technicians performing spirometry; (2) spirometry test posture; (3) reference values for Asian workers in North America and Europe; and (4) how to evaluate decline in lung function over time. A systematic review of the literature was conducted. A professional medical librarian searched Medline for articles from 1950–2012 and Embase for articles from 1980–2012. Details of search terms used, criteria for inclusion/exclusion, and methods for review of the papers are given in the online supplement. Because there were limited numbers of papers identified

**Table 1: Components of Workplace Spirometry Programs**

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Define purpose of the spirometry testing, such as:
a) Medical surveillance (to detect effects of inhalational exposures/occupational lung diseases)
b) Appropriate job placement (after hire, before job placement)
c) Component of medical evaluation for respirator usage
d) Component of an impairment or disability evaluation
Define parameters for the spirometry program, including:
a) Inhalational exposures and lung diseases of concern
b) Regulatory and workplace-mandated requirements
c) Frequency of testing.
d) Workers to be tested (based on potential hazards or other concerns)
Clarify responsibility for evaluation of:
a) The individual worker
b) Aggregate analysis of the spirometry and other data collected on the group of workers
Clarify lines of communication of relevant information between the patient, employer, and medical provider
Ensure that spirometers and technician training meet or exceed ATS recommendations
Establish and maintain an effective quality assurance program
Define appropriate spirometry reference values and interpretative strategies
Establish triggers for further evaluation and initial action plan

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*Definition of abbreviation:* ATS = American Thoracic Society.

in the systematic reviews that were based on work populations, the committee also considered indirect evidence from studies conducted in alternative settings or with nonoccupational populations. Additional relevant papers identified by committee members were included.

The full committee discussed the results in a series of meetings. Committee members were then divided into groups and assigned to write a portion of the document. The co-chairs collated and edited the contributions from each group into a single document, which was then reviewed by the full committee. After several cycles of review, comments, and revisions, the document was approved by all members of the committee for submission.

## Technician Training

The importance of technician training and feedback in assuring high-quality spirometry testing is widely recognized. In the United States, OSHA requires that technicians performing spirometry for certain occupational indications complete a training course (9–11). European countries are also implementing standards for training and qualification of technicians (12). ATS/ERS and ACOEM note the importance of training and recommend training similar to a NIOSH-approved spirometry course (3, 4, 6), and refresher training at 3–5 years and 5-year intervals, respectively (3, 4, 6). However, the specific components and timing of a training program that are most effective are not clear. A systematic review of the literature was performed to identify evidence related to the impact of technician training on spirometry quality in the workplace. The review identified 22 relevant papers: 2 studies of workers exposed to the World Trade Center disaster and 20 nonoccupational studies, summarized in Table E1 in the online supplement (13–34).

The largest body of literature supporting technician training and feedback consists of observational reports from large spirometry programs, where the combination of initial training, refresher training, electronic feedback from spirometers, and on-going test quality review and feedback have been used together to achieve high levels of acceptable spirometry tests and technician performance. Examples include spirometry programs for general

populations (18, 21, 22), the elderly (13), and World Trade Center surveillance (19, 20).

More limited evidence supports the effectiveness of individual components of training and feedback (27). Several studies support the usefulness of refresher training and providing technicians with feedback (18). Assigning spirometry test quality grades may also be helpful in providing feedback (20). However, the optimal frequency for refresher training remains unclear.

Recommendations for specific content of training courses have been based on professional judgment. ATS/ERS and ACOEM both recommend training similar to the NIOSH-approved spirometry training, 2- and 3-day courses that include didactic training in the fundamentals of spirometry and hands-on training (3, 4, 6). Approaches to optimizing spirometry quality, including equipment considerations, technician training, and testing technique are summarized in Table 2 and addressed in greater detail in several recent documents (1, 2, 4, 6, 12).

## Recommendation

Technicians should undergo initial practical training and refresher courses to maintain their skills. Technicians should also receive on-going feedback about the quality of tests that they perform, and how to correct problems in test performance.

## Posture during Spirometry

The 2005 ATS/ERS guideline (3) recommends performing spirometry in the standing or sitting test posture, whereas ACOEM (4) recommends that testing be conducted standing, unless workers have experienced problems with fainting. To clarify whether standing versus sitting impacts spirometry results in the workplace, a systematic review of the medical literature was performed. The search identified seven relevant studies (see Table E2) (35–41), although none were performed in an occupational setting. Two studies found significant postural effects. Standing values of the FEV<sub>1</sub> and/or FVC exceeded sitting values by 0.04–0.07 L (37, 41). Studies comparing these postures

**Table 2:** Approaches to Assure High-Quality Spirometry in the Work Setting

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- I. Equipment considerations:
    - a) Use equipment meeting ATS/ERS and ACOEM performance standards.
    - b) Perform calibration checks and save results. Investigate anomalous test results.
    - c) Supplement calibration checks by using standard subjects as biological controls.
    - d) Use spirometers that can save and export all data and all flow–volume and volume–time curves and can display them on real-time graphical displays large enough for inspection of quality by technicians as tests are performed.
    - e) Whenever possible, use the same type of spirometer for serial testing, and document the spirometer used.
  - II. Testing technique:
    - a) Testing should be performed consistent with existing ATS/ERS guidelines.
    - b) Consider postponing testing if the subject has had recent respiratory infection, abdominal or thoracic surgery, or recent use of a bronchodilator. If test is performed anyway, document these or other factors (e.g., inhaled steroids) that might affect results.
    - c) Document test acceptability and repeatability, recognizing that variable results may be due to flawed technique, faulty equipment, and/or underlying disease, and may not preclude interpretation of the results.
    - d) The test subject can be sitting or standing, recognizing that standing may yield slightly increased values. Whenever possible, use the same test posture for serial testing of an individual, and document the test subject's posture.
  - III. Technician training and feedback:
    - a) Use a combination of interventions to optimize technician performance.
    - b) Provide technicians with initial training and periodic refresher courses, which should include hands-on practical experience.
    - c) Use spirometers that can assess quality of tests and provide automated real-time feedback to technicians.
    - d) Conduct ongoing review of the quality of spirometry tests that are performed and provide technicians timely, ongoing feedback about the quality of their tests and how to correct problems that are identified.
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*Definition of abbreviations:* ATS = American Thoracic Society; ACOEM = American College of Occupational and Environmental Medicine; ERS = European Respiratory Society.

have also reported no significant differences in FEV<sub>1</sub> and/or FVC (35, 37, 40). Although small, changes in FEV<sub>1</sub> and FVC related to posture may be significant when evaluating spirometry longitudinally. No published studies were identified that reported safety concerns with standing versus sitting.

### Recommendation

Standing or sitting test posture can be used, but the same posture should be used when possible on repeat testing, and this should be documented. The rationale is that posture-related changes in FEV<sub>1</sub> and FVC, although small, may significantly impact spirometry interpretation.

## Reference Values

### Identifying Individuals with Abnormal Spirometry, Lower Limit of Normal

Determining what constitutes an abnormal versus a normal spirometry result is particularly important when spirometry is performed related to the workplace. In addition to prompting further evaluation of a worker and workplace exposures, an “abnormal” spirometry result can also impact a worker’s job (e.g., determining job placement). The ATS/ERS and ACOEM recommend using the fifth percentile lower limit of normal (LLN) to differentiate normality from abnormality, rather than a fixed value, such as 80% of predicted, for the FEV<sub>1</sub> and FVC, or 0.70 for the observed ratio of FEV<sub>1</sub>/FVC (3, 6). Because the FEV<sub>1</sub>/FVC ratio declines with age, using a fixed value, such as 0.70, to determine an obstructive defect will result in false-negative results for younger workers (age 25–45 yr), and false-positive results in older workers (men >45 yr, women >55 yr) (42). Spirometry values that are below the fifth percentile LLN are considered abnormal, and may reflect a pulmonary problem. However, by definition, 5% of a healthy population will also fall below the fifth percentile LLN.

### Reference Values for Asian Americans

ATS/ERS, ACOEM, and OSHA (1, 2, 4, 6, 7) recommend using the reference values from NHANES III, which provided reference values for whites, African Americans, and Hispanics (predominantly Mexican Americans), but not Asian Americans (43, 44). The ATS/ERS

Statement recommended an adjustment factor of 0.94 for Asian Americans (3), but the 2011 ACOEM statement suggested that a factor of 0.88 (applied to white subject reference values for FEV<sub>1</sub> and FVC) may be more appropriate (6). We conducted an evidence-based systematic review of the literature to determine an appropriate adjustment factor to use for persons of Asian ethnicity in the North American workplace. The review identified seven studies that met inclusion criteria, although they did not specify an occupational setting (see Table E3) (45–51).

FEV<sub>1</sub> and FVC values were, on average, 7–20% lower for Asian Americans compared with reference values for whites in these studies (45–51). These findings are consistent with studies performed in Asia-Pacific countries showing generally smaller lung volumes in these populations compared with whites (52, 53). Analysis of spirometry from 1,068 participants in the Multi-Ethnic Study of Atherosclerosis provides the best current data to approximate a correction factor for Asian-Americans (46). The authors concluded that a correction factor for Asian-Americans of 0.88 was more appropriate than the previous recommendation of 0.94. The other studies identified were very limited in size (47, 48, 50), and/or were limited to a specific population (45, 49, 51). Thus, although normative data on persons of Asian ancestry living in North America and Europe remains limited, a correction factor of 0.88 is considered more appropriate than 0.94.

The reviewed articles also demonstrate the considerable variability within the same racial/ethnic group (e.g., Asians, Hispanics), the limited data on many ethnic groups (e.g., in India, Pakistan), the complexity of identifying appropriate reference values (52–54), and the complexities in assigning racial/ethnic groups (55). Assigning specific correction factors for racial/ethnic groups will become even more complicated in the future as racial/ethnic diversity increases.

### Recommendation

Racial or ethnic differences in lung function exist. It is preferable to use specific reference equations (such as NHANES III) that have been developed from studies of certain populations when they are available (3). When such reference equations are not available, however, the use of correction factors is an appropriate interim solution.

As an example, a correction factor of 0.88 may be applied to white subject reference values for FEV<sub>1</sub> and FVC when evaluating Asian populations within North America.

## Evaluation of Spirometry over Time

Workers can undergo periodic, often annual, spirometry tests in mandated or recommended medical surveillance programs. It is important to evaluate such measurements not only relative to normal ranges, but also relative to the workers’ baselines, particularly when lung function values are within the normal range (56). Many workers have FVC and FEV<sub>1</sub> that exceed their predicted values. Such individuals must lose a significant portion of their lung function before their spirometry results fall below the LLN, and they are identified as abnormal. Longitudinal evaluations of periodic spirometry testing may detect excessive lung function loss due to an exposure or underlying condition earlier than using a single spirometry test.

How to evaluate loss of lung function over years has not been directly addressed by the ATS or ERS (3). We performed an evidence-based systematic literature review to identify evidence relevant to the question of how to evaluate excessive decline in lung function in a North American or European working population (see the online supplement). Of the 97 papers selected for full review, 7 met the inclusion criteria, which included longitudinal spirometry (at least three spirometry tests over 5 yr) that was performed in an occupational cohort (with either normal control subjects or a low-exposure group), and incorporated an assessment of variability in FEV<sub>1</sub> decline (see Table E4) (57–63). Additional papers relevant to assessing longitudinal change in lung function were also considered (see Table E5) (64–68).

Lung function normally increases during childhood, before reaching a maximum, and then starting to decline, around the age of the mid-20s to mid-30s (43, 65, 66, 69). A systematic review of the literature identified the typical rate of decline in FEV<sub>1</sub> in nonsmokers as 29 ml/yr (70). The rate of decline can be affected by occupational exposures, cigarette smoking,

weight gain, general lack of fitness, and sex (51, 66, 69, 71–73), and may accelerate in older individuals (62, 65, 66). More rapid lung function decline, typically about 50–90 ml/yr, has been associated with increased morbidity and mortality from chronic obstructive pulmonary disease and cardiovascular disease, and with increased all-cause mortality (74–78).

Assessment of decline in lung function is affected by several factors, including: spirometry technical quality and test variability; testing frequency and duration of follow up; and definition of excessive decline. The primary measurement used to assess longitudinal change should be the FEV<sub>1</sub>, as it is less affected by technical factors than the FVC (3, 6).

### Spirometry Testing Quality and Test Variability

As noted previously here, comprehensive spirometry programs should be established so that valid measurements are recorded over time. Even with good programs, spirometer inaccuracy and imprecision and survey biases (unexplained technical changes) may limit the size of the detectable change or contribute extraneous variability to longitudinal measurements (79). Changes in weight over time should be recorded, since weight gain can contribute to decline in lung function (71, 72, 80, 81).

Maintaining calibration check records and tracking spirometry results for groups of workers over time (e.g., mean FEV<sub>1</sub>, within-person variation, proportions of high or low values) can help identify ongoing health hazards and also anomalous results possibly resulting from technical issues (60, 78, 82).

### Frequency and Duration of Testing

As length of follow up increases, real decline in pulmonary function becomes easier to distinguish from background measurement variability. The precision of the estimated rate of FEV<sub>1</sub> decline improves with increasing frequency of measurement and duration of follow-up (58, 60, 83). Because chronic occupational respiratory diseases (such as chronic obstructive pulmonary disease and pneumoconioses) typically develop over many years, spirometry performed less frequently than annually (e.g., every 2–3 yr) should be sufficient to monitor for the development of such diseases (63, 82). However, for diseases that can develop more rapidly (such as flavoring-related

**Table 3:** Approaches to Detect Excessive Decline FEV<sub>1</sub> in Individuals Undergoing Medical Surveillance

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- I. A 15% decline from baseline FEV<sub>1</sub> (plus expected age-related loss)
- A) Percent predicted method:  
*Calculation of threshold:* Baseline (initial) FEV<sub>1</sub>% predicted minus current FEV<sub>1</sub>% predicted  
*Interpretation:* If  $\geq 15\%$ , then observed decline in FEV<sub>1</sub> may be excessive.
- B) Volume method:  
*Calculation of threshold:* Baseline (initial) predicted FEV<sub>1</sub> minus current predicted FEV<sub>1</sub> plus  $(0.15 \times \text{baseline FEV}_1)$   
*Interpretation:* If observed change in FEV<sub>1</sub> (FEV<sub>1</sub> baseline minus FEV<sub>1</sub> follow up) is greater than threshold, then decline in FEV<sub>1</sub> may be excessive
- Notes:  
 1) These methods are very similar; the percent predicted method is easiest to calculate for most practitioners.  
 2) Use the same set of FEV<sub>1</sub> prediction equations for baseline and current predicted values. Verify that demographic data has been appropriately entered for all visits.  
 3) With increasing years of follow-up these methods detect smaller annual % declines in FEV<sub>1</sub> as abnormal, for example 15% decline in Year 1 of follow up to 4% annual decline with 5 years of follow up.
- II. Limit of LLD:  
*Calculation of threshold:* Calculate LLD using available software\*, based on spirometry quality and variability.  
*Interpretation:* If current FEV<sub>1</sub> falls below LLD threshold, then observed decline in FEV<sub>1</sub> may be excessive
- Notes:  
 1) To calculate data precision for determining LLD, multiple results must be accessible to the computer program.  
 2) This method can be used for individuals and groups of workers. It allows programs with quality spirometry (e.g., 3–5% variability) to establish lower thresholds for excessive decline without losing specificity in predicting subsequent excessive FEV<sub>1</sub> decline. LLD-based thresholds for programs with more variability (about 6%) are quantitatively similar to the 15% approach above. Spirometry programs with more variability should evaluate if it is due to technical issues or increased prevalence of disease, and should use the 15% approach above to evaluate individual results.  
 3) This method can be used for up to 5–8 years of follow up, although small short-term longitudinal changes (<5 yr) may be difficult to interpret because of the relatively large inherent FEV<sub>1</sub> technical variability in spirometry testing.
- III. Linear regression  
*Calculation of threshold:* Use available linear regression software\* to calculate FEV<sub>1</sub> slope (ml/yr) using all available acceptable spirometry results over time.  
*Interpretation:* Compare observed rate of FEV<sub>1</sub> decline with rates of decline associated with adverse health outcomes (>60–90 ml/yr).
- Notes:  
 1) This method requires a minimum of 5 years of follow up for reliable estimates of FEV<sub>1</sub> slope.  
 2) FEV<sub>1</sub> decline is not always linear, so data should be visually inspected.  
 3) Those with lower FEV<sub>1</sub> at baseline will be affected sooner by a given rate (ml/yr) of FEV<sub>1</sub> loss.
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*Definition of abbreviation:* LLD = limit of longitudinal decline.

\*<http://www.cdc.gov/niosh/topics/spirometry/spirola-quick-calculation.html>, <http://www.cdc.gov/niosh/topics/spirometry/spirola.html>, or alternate spirometry analysis software.

lung disease or occupational asthma), more frequent follow up at intervals of 6 months to 1 year may be appropriate (84–86).

### Determination of Excessive Decline in FEV<sub>1</sub>

Great care is required in determining what constitutes an “excessive” FEV<sub>1</sub> decline when evaluating periodic testing in worker populations. It is important to avoid the consequences of either false-positive or -negative findings. The purpose of such

periodic testing is to detect progressive lung disease at an earlier stage, which might otherwise be missed, especially when lung function values are above LLN. All available longitudinal FEV<sub>1</sub> values should be reviewed in the context of worker exposures and other clinical information, especially respiratory symptoms. Display of all longitudinal measurements in relation to reference values may facilitate decision making from the observed data.

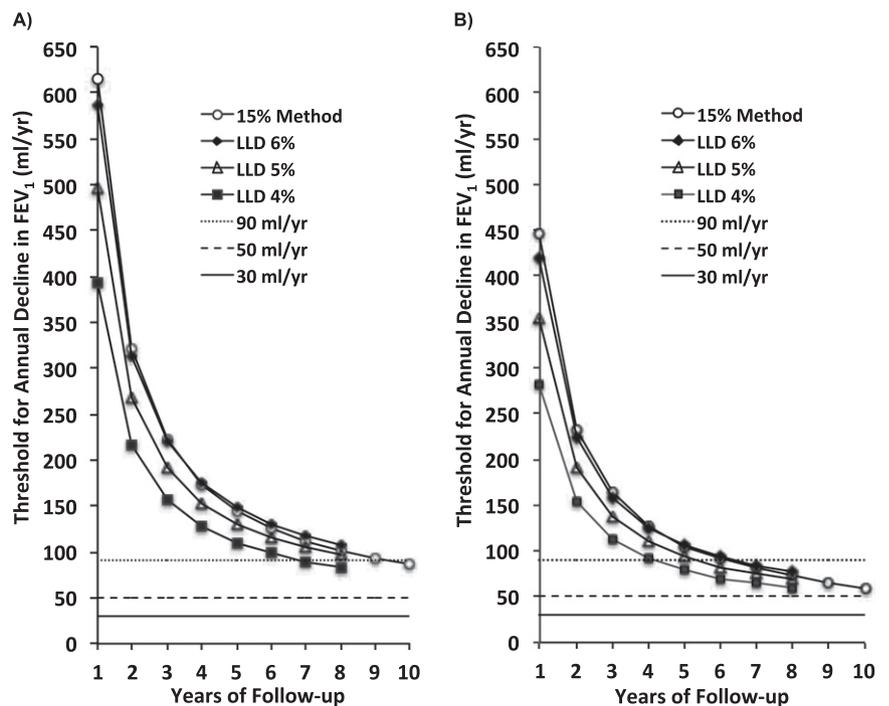
Change in FEV<sub>1</sub> over time in workers can be evaluated using several approaches, summarized in Table 3. These methods are most effective for evaluating declines in FEV<sub>1</sub> over relatively long time periods (≥5 yr). Excessive shorter-term (<5 yr) longitudinal FEV<sub>1</sub> declines have been shown to presage long-term losses (60, 87), but can be difficult to interpret in any individual worker because of the relatively large technical variability often encountered in spirometry testing. Despite this variability, to protect lung health among workers with diseases that develop rapidly, clinicians may need to identify individuals who may have experienced declines in FEV<sub>1</sub> over shorter time periods (months to a few years) (87, 88).

The most practical thresholds for clinicians to use in comparing longitudinal FEV<sub>1</sub> measurements are based on a 15% loss from baseline, taking into account expected age-related loss. ATS recommends that a decline of 15% or more over a year in otherwise healthy individuals be called “significant,” beyond what would be expected from typical variability (3). A threshold of 15% decline in FEV<sub>1</sub> from baseline to follow up for longer periods of time, beyond the expected loss due to aging during the follow-up period, has been recommended by NIOSH to monitor coal miners (89), and by ACOEM (5, 6). Some caution in interpretation of early changes in coal miners has been advised, because initial rapid decline in FEV<sub>1</sub>, primarily in the first year of work, may be transient, possibly due to inflammatory changes (90–92).

Table 3 shows two methods to calculate a 15% decline in FEV<sub>1</sub> beyond expected aging: a percent predicted method and a volume method. Although not identical, they provide very similar thresholds for excessive decline in FEV<sub>1</sub>. This 15% approach detects smaller annual percent declines in FEV<sub>1</sub> as excessive with more years of follow up (e.g., from 15% decline with 1 yr of follow up to 4% annual decline with 5 yr of follow up) (82). These thresholds are similar to the threshold FEV<sub>1</sub> decline determined by more complicated computerized approaches (described below) when within-person testing variability is about 6%) (Figure 1). For diseases that develop rapidly, declines in FEV<sub>1</sub> of less than 15% over shorter time periods may be clinically important (87, 93).

Computerized approaches using linear regression or calculating lower limit of longitudinal decline (LLD) have also been used to evaluate longitudinal spirometry data in individuals and groups of workers (program data) (Table 3 and Figure 1) (60, 82, 94). Computer approaches can evaluate individual and group within-person variation (program data precision), and calculate a threshold FEV<sub>1</sub> LLD based upon the actual data precision (82). Studies using LLD have shown that the approach provides high clinical utility (specificity) in recognizing excessive FEV<sub>1</sub> decline in several working populations, (e.g., firefighters, pulp paper mill workers,

and construction workers) (60). When this method is used, it is most useful during the initial years (up to 5–8 yr) of follow up, when testing variability limits the interpretation of smaller changes in FEV<sub>1</sub> (60, 82). As noted, the 15% (plus expected aging) threshold for FEV<sub>1</sub> assumes a within-person variation of about 6% (82). Higher quality spirometry programs can have less variability (e.g., 3–5%), and may be more reliable in identifying smaller declines in FEV<sub>1</sub> (e.g., 8–10%) as being excessive during the initial years of follow up (Figure 1) (20, 60, 82). Thus, high-quality spirometry programs with better data precision can enhance the clinician’s



**Figure 1.** Threshold rates of FEV<sub>1</sub> loss that can be considered excessive based on different approaches to identify excessive FEV<sub>1</sub> volume loss. Examples based on (A) a 50-year-old white man (70 inches tall with a baseline FEV<sub>1</sub> of 3.93 L) and (B) a 50-year-old white woman (64 inches tall with baseline FEV<sub>1</sub> of 2.81 L). The rates of decline in FEV<sub>1</sub> (ml/yr) that can be considered excessive based on using several methods described in Table 3 to identify excessive threshold values of FEV<sub>1</sub> decline are shown for each example. The method based on a 15% threshold FEV<sub>1</sub> loss (plus aging-related FEV<sub>1</sub> decline) is as described in Table 3. The limit of longitudinal decline (LLD), recommended for use over the first 8 years of follow up, is shown at three different levels of spirometry program quality, estimated by within-person variation in FEV<sub>1</sub> (6%, less precision; 5%, better precision; 4%, even better precision). For all methods, the rate of FEV<sub>1</sub> decline that can be identified as excessive decreases as the years of follow up increase. Similar thresholds for FEV<sub>1</sub> decline are obtained using the 15% method as the computerized LLD approach when testing variability is about 6%. With better-quality spirometry (4 and 5% variation), the LLD method identifies lower rates of FEV<sub>1</sub> decline as excessive. Rate of decline determined using linear regression (by calculating the individual’s observed rate of FEV<sub>1</sub> decline [ml/yr] using all available acceptable spirometry results) is not shown. Also shown are three rates of annual decline discussed in the text: 30 ml/yr (typical average annual decline), and two higher rates associated with increased morbidity and mortality in long-term epidemiology studies (50 and 90 ml/yr).

ability to identify individuals who are experiencing excessive declines.

After follow-ups of more than 5–8 years, the rate of lung function decline can be reliably estimated by linear regression, using all of the person’s observed FEV<sub>1</sub> data over time (82). Because FEV<sub>1</sub> decline is not always linear, data should be inspected to assure that a linear model is appropriate. Although a specific action level for rate of decline has not been established and is difficult to apply to an individual, the typical rate of decline in FEV<sub>1</sub> in nonsmokers is about 29 ml/yr. Accelerated rates of decline (>60–90 ml/yr on average) have been associated with increased morbidity and mortality, as noted previously here.

Some computer approaches can also identify excessive variability and other measures of program quality in groups under surveillance, which may reflect either correctable technical issues in performing spirometry or increased burden of disease, potentially related to work exposures (20, 82, 95).

**Recommendation**

Spirometry measurements should be evaluated relative to workers’ baseline or prior tests, in addition to comparing to population normal ranges. This is particularly important when baseline measurements exceed predicted values. FEV<sub>1</sub> decline over time should be evaluated using one or more of the approaches described, and interpreted in the context of worker exposures, symptoms, and other clinical information.

**Action Plan for Spirometry in the Work Setting**

The key components of a workplace spirometry program should be supervised by the clinician responsible for performing spirometry testing (Table 1). Groups eligible for spirometry monitoring should be defined based upon the potential respiratory hazards. The specific reason(s) spirometry is being performed should be clear, including the exposures of concern, which may dictate the frequency and/or timing of testing. Spirometry can be part of the medical evaluation for respirator use, in which case the employer should have a complete written respiratory protection program (96, 97). The “action levels” that will be

**Table 4: Evaluation of Spirometry Performed in the Work Setting**

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<p><b>Individual worker</b>                  Assess technical quality of testing and accuracy of demographic information. Consider repeat spirometry if poor-quality test or not reproducible, which may also indicate disease.                  Ensure that appropriate reference values are selected, considering ethnicity, height, sex, and age.                  Compare current FEV<sub>1</sub>, FVC, and FEV<sub>1</sub>/FVC values to predicted values and LLN.                  Compare spirometry tests to previous results. Determine if decline in FEV<sub>1</sub> from baseline may be excessive by:                  a) &gt;15% decline in FEV<sub>1</sub> after correcting for aging or                  b) Use computer software to determine a LLD or linear regression of FEV<sub>1</sub> slope                  Consider other relevant clinical information (symptoms, exposures, weight change, smoking history, lung disease)                  Based on above, identify and notify workers in need of further evaluation, and provide appropriate referral if needed (e.g. occupational pulmonary specialist).                  Review results of further evaluation (e.g. full PFTs, CT scan).                  Consider preventive interventions.                  Protect worker confidentiality. Providers must not disclose individual workers’ personal health information to employers without their consent.</p> <p><b>Group of workers</b>                  De-identify data.                  Determine distribution of spirometry abnormalities by job, location, and/or tasks.                  Determine group changes in FEV<sub>1</sub> to detect spirometry quality or exposure problems.                  Evaluate aggregate group FEV<sub>1</sub> values (e.g., % predicted, FEV<sub>1</sub> decline/yr) by exposure groups; assess relationships of FEV<sub>1</sub> with exposure and other variables.                  Consider preventive interventions for the workforce and workplace.</p>	of relevant information, and also maintain confidentiality of medical information. The results of spirometry performed in the work setting require careful interpretation (Table 4). Clinicians involved should be familiar with the performance and interpretation of spirometry, and should have knowledge of the work exposures of concern. To protect worker
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*Definition of abbreviations:* CT = computerized tomography; LLD = limit of longitudinal decline; LLN = lower limit of normal; PFTs = pulmonary function tests.

considered abnormal and trigger further evaluation need to be established, as well as a plan for when action levels are exceeded. Responsibilities for evaluation of both the individual and group spirometry and other health and workplace data should be clarified. Lines of communication should be established between the provider, worker, and employer that enable communication

**Table 5: Workers Referred for Further Evaluation**

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<p>Assess technical quality of spirometry and repeat testing if indicated based on spirometry quality, and other relevant information below                  Obtain comprehensive medical and occupational history and physical exam including:                  Work and exposure history                  Smoking history                  Respiratory symptoms, timing in relationship to work                  Physical exam, including lung exam and chest wall deformities                  MSDSs, results of workplace measurements, if available                  Review pre-employment, follow-up questionnaires and spirometry, if available                  Possible additional diagnostic testing:                  If airflow obstruction, spirometry with bronchodilator response                  If restrictive pattern, full pulmonary function tests (lung volumes, diffusing capacity)                  Chest imaging (chest x-ray, CT scan)                  If asthma, consider peak flow recordings at and away from work.                  If interstitial lung disease, consider high resolution chest CT scan                  If non-reversible airflow obstruction, consider occupational etiologies, even in smokers (e.g., occupational COPD, bronchiolitis obliterans).                  If a possible work-related problem is identified, consider other at-risk workers</p>	of relevant information, and also maintain confidentiality of medical information. The results of spirometry performed in the work setting require careful interpretation (Table 4). Clinicians involved should be familiar with the performance and interpretation of spirometry, and should have knowledge of the work exposures of concern. To protect worker
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*Definition of abbreviations:* COPD = chronic obstructive pulmonary disease; CT = computerized tomography; MSDSs = material safety data sheets.

confidentiality, providers must not disclose individual workers' personal health information to employers without employee consent.

The technical quality of spirometry testing and accuracy of demographic information should always be reviewed. Consider repeat testing if tests are invalid; lack of repeatability, in particular, may indicate disease. The measured values from spirometry should be compared with predicted reference values, and levels below LLN identified. Current spirometry results should be compared with available prior testing, even if above the LLN. Excessive decline in FEV<sub>1</sub> should be determined using one of the approaches discussed here (Table 3). Workers with values below the LLN and/or an excessive decline in FEV<sub>1</sub> should be further evaluated for potential causes and preventable risk factors. Factors such as work exposures, respiratory symptoms, and medical information (e.g., diagnoses, medications) should always also be considered, as spirometry values or rates of decline can remain "normal" when other factors may indicate that further evaluation is needed.

The specific steps to be taken will depend on several considerations, including the exposures of concern, the magnitude of the lung function abnormality and/or decline over time, and the clinical context (Table 5). A careful occupational history, including workplace exposures and work-related symptoms, should be obtained, and baseline/follow-up questionnaires should be reviewed. Further workup may include more complete pulmonary function testing (e.g., lung volumes, diffusing capacity) and chest imaging (radiographs, computerized tomography scan). Detailed algorithms and guidelines exist for specific work-related pulmonary diseases, and are beyond the scope of this article (98–100). Appropriate interventions could include improved administrative or engineering controls to reduce exposures, termination of implicated occupational exposures, smoking cessation, and/or treatment of medical conditions, such as asthma.

In addition to management of the individual worker, the analysis of aggregate worker data (from the same workplace, company, job, or industry), both cross-sectional and longitudinal, can

offer significant benefit. Spirometry, questionnaire, other health data, and exposure and job information can be linked for further evaluation while also being de-identified to protect individual worker privacy. Associations can be identified between work factors (exposures, job tasks, work locations) and lung function, which can easily be missed when reviewing workers individually, helping to target preventive efforts, such as reduction of potentially hazardous exposures. Such analysis can also help employers assess the effectiveness of current workplace preventive measures and better focus further preventive efforts. The distribution of individuals with spirometry abnormalities by job category, location, and/or task should be evaluated. Although additional expertise and support from the employer is needed for more complex aggregate analysis of spirometry and other available data, such analysis is strongly encouraged, as it may permit identification and control of exposure-related health problems. The computerization of medical and workplace data should greatly facilitate such aggregate data analysis. ■

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