ACOEM Position Statement

Spirometry in the Occupational Setting

Lead Author:
Mary C. Townsend, DrPH

Improved quality and standardization of spirometry testing and interpretation of results are critically important in the occupational setting. This position statement is meant to contribute to that goal by increasing the occupational medical community’s awareness of the importance and complexities of spirometry testing. The position statement reviews: basic principles of spirometry and indications for spirometry in occupational medicine; essential criteria for ensuring validity of spirometric results; and proper interpretation of results, including selection and race-adjustment of predicted values, comparison with predicted values, assessment of loss of function over time, response to a bronchodilator, and acute changes associated with workplace exposures. The American College of Occupational and Environmental Medicine (ACOEM) makes detailed recommendations in each of these areas, and key points are summarized in tables throughout this position statement.

Spirometry in the Occupational Setting

This position statement provides the occupational physician with guidelines for using spirometry testing in workplace medical programs. The focus is primarily on conducting and interpreting spirometry tests in individual workers, although spirometry data are also analyzed for groups of workers in respiratory surveillance programs and epidemiologic research studies. The topics reviewed by this position statement are presented in Table 1. A glossary of pulmonary function terms and abbreviations is provided in the Appendix.

Principles of Spirometry

Spirometry is the most basic and frequently performed test of pulmonary function, measuring the ventilatory function of the respiratory system, ie, the ability to move air into and out of the lungs. Using a forced expiratory maneuver, which is a maximal expiration from total lung capacity to residual volume, spirometry measures volumes and flow rates. The expired air is measured by a spirometer, and the graphic recording of the expiration is called a spirogram. For the past 50 years, volume–time spiromgrams have displayed expired volume as a function of expiratory time (Fig. 1). Since the mid-1970s, flow–volume spiromgrams have also become common, showing expiratory flow rate as a function of expired volume (Fig. 2). As described below, both displays are critical in assessing the technical quality of a test. Because spirometry is based on a maximal, forced expiratory maneuver, the accuracy of its results are effort-dependent, requiring a subject’s full understanding, cooperation, and effort.

Three clinically useful measurements are obtained from a properly performed spirometry test. The forced vital capacity (FVC) measures the total volume of air exhaled during the maneuver. Speed of the expiratory airflow is quantified by the forced expiratory volume in one second (FEV₁), and by the relationship of the FEV₁ to the FVC, expressed as the FEV₁/FVC ratio. These measurements are usually compared with average values “predicted” for a subject on the basis of sex, age, height, and race. An FEV₁/FVC that is below the lower limit of a subject’s normal range for this ratio indicates probable airways obstruction. The severity of obstructive impairment is determined by the degree of FEV₁ reduction relative to its normal range. In the absence of airways obstruction, an FVC that is below the lower limit of a subject’s normal range suggests restriction of lung volume; the severity of restrictive impairment is reflected by the degree of FVC reduction. In addition, changes in FVC and FEV₁ can be measured over time to determine whether loss of function is excessive. However, the criteria for evaluating longitudinal changes in individuals are less standardized.

An additional measurement, the forced expiratory volume in six seconds (FEV₆), is currently under consideration as a surrogate for the FVC, particularly in the screening setting. However, at the present time, few sets of predicted values include the FEV₆, limiting its usefulness. As predicted values are published for the FEV₆, it may become an easily standardized substitute for the FVC in assessing impaired pulmonary function. It is important to note that the FEV₆ must be compared with a predicted FEV₆, not a predicted FVC.

Indications for Spirometry in Occupational Medicine

When used appropriately, spirometry can play an important role in the primary, secondary, and tertiary pre-
TABLE 1
Spirometry in the Occupational Setting: ACOEM Position Statement

- Principles of Spirometry
- Indications for Spirometry in Occupational Medicine
- Essential Components of Valid Spirometry
  Equipment Performance
  Testing Technique
  Measurement of Results
  Technician Training
- Interpretation of Results
  Selection of Reference Values
  Race-Adjustment of Predicted Values
  Cross-Sectional Evaluation: Normal, Obstructed, Restricted
  Changes Over Time
  Pre- to Post-Bronchodilator Changes in Pulmonary Function
  Acute Work-Related Changes in Pulmonary Function
- Summary

vent of respiratory disease in the workplace. In the primary prevention of respiratory disease, spirometry can be used in pre-placement and fitness-for-duty examinations of individuals when: (1) the physical demands of a job require a certain level of cardio-pulmonary fitness, eg, heavy manual labor or firefighting; or (2) the characteristics of respirator use can impose a significant burden on the cardiopulmonary systems, eg, use of a self-contained breathing apparatus, or prolonged use of certain negative-pressure masks under conditions of heavy physical exertion and/or heat stress. Although not required routinely under the Occupational Safety and Health Administration (OSHA) Respiratory Protection Standard, 29 CFR 1910.134, spirometry may be used in the evaluation of respirator users in some situations.

In addition to pre-placement screening of individuals, primary prevention of occupational respiratory disease also includes research and monitoring of health status in groups of workers. Potential health effects are assessed in occupational groups by comparing workers exposed to an agent or process with those not exposed and/or those with varying levels of exposure. This aspect of primary prevention is particularly important in occupational medicine to detect previously unrecognized health consequences of occupational exposures to specific agents.

In the secondary prevention of respiratory disease, repeated spirometric evaluations can be used in medical surveillance programs when workplace exposures put workers at risk of developing occupationally related respiratory disorders. Surveillance is needed to detect the slowly developing or delayed losses of function that characterize many work-related respiratory disorders. In this case, many healthy individuals are tested to detect early excessive declines in the pulmonary function of a subgroup of sensitive workers, even though the spirometry test results of these workers may still remain in the normal range.

Respiratory surveillance programs require that a baseline be established and that workers be re-tested periodically. These periodic spirometry tests may be mandated by OSHA regulations (eg, for employees exposed to asbestos, cadmium, coke oven emissions, or cotton dust and for respirator-wearers exposed to benzene, formaldehyde, or methylene chloride) or recommended by OSHA Special Emphasis Programs (eg, Silicosis). The contents of the OSHA-mandated physical examinations are summarized in a 1998 publication from the US Department of Defense Occupational Medical Surveillance Manual. The National Institute for Occupational Safety and Health (NIOSH) also recommends respiratory surveillance for more than 25 additional exposures that do not have OSHA-mandated surveillance programs. Periodic spirometry tests may also be part of industry- or company-mandated medical surveillance programs or a component of workplace health promotion programs. As will be discussed later in this position statement, the limitations of spirometry must be borne in mind when interpreting periodic spirometry test results in individuals. Although spirometry can detect large changes over a short time or smaller changes cumulated over a longer observation period, it is not sensitive to small, short-term changes in an individual’s pulmonary function.

In the tertiary prevention of respiratory disease, spirometry is used in the clinical evaluation of symptomatic individuals, because many pulmonary diseases manifest themselves as restrictive, obstructive, or combined ventilatory defects. Spirometry allows some quantification of the severity of lung function loss and is one of the pulmonary function tests used in assessing respiratory impairment. Spirometry may be a required component in the evaluation of workers for disability under the Social Security Administration, the Federal Coal Mine Health and Safety Act, and in the workers’ compensation setting. Although mild spirometric abnormalities are “usually not correlated with diminished ability to perform most jobs,” “progressively
lower levels of lung function are correlated with diminishing ability to meet the physical demands of many jobs. Additional measures of functional impairment, such as determination of diffusing capacity for carbon monoxide, measurement of lung volumes, exercise tolerance testing, or methacholine challenge testing, are beyond the scope of this position statement.

Essential Components of Valid Spirometry

Spirometry is simple but fraught with technical pitfalls that can invalidate the pulmonary function measurements. Failure to obtain full understanding, cooperation, and effort from a subject during any part of the test usually results in an underestimation of the true pulmonary function. Poorly maintained spirometers also affect the accuracy of observed spirometric values. Such erroneous measurements may cause a normal, healthy subject to be mislabeled as “impaired” or lead to incorrect assessments of impaired subjects. When evaluating changes over time, small decrements in pulmonary function may be lost in the noise of the measurements if testing equipment and/or technique are not as accurate, precise, rigorous, and standardized as possible. For analysis of group data, small differences between groups, which may be scientifically important, can be obscured by poor quality data caused by inadequate testing technique.

In occupational medicine, the consequences of such misinterpretations can go beyond simply making an inaccurate diagnosis; decisions regarding fitness for duty, workplace accommodation, and compensation for work-related illness may also be affected. Furthermore, because occupational spirometry tests are often conducted in the regulatory and medical–legal arenas, the validity of the spirometry test is likely to be scrutinized. Therefore, it is critical for both clinical and administrative purposes that occupational medicine physicians understand the need for standardization and quality control in spirometry.

Although timed forced expirations have been measured since the 1950s, it has only been in the past 2 decades that spirometry standardization and quality control have been emphasized. The American Thoracic Society (ATS) has been at the forefront of these efforts, with spirometry standardization statements and updates issued in 1979, 1987, and 1995, as well as interpretation guidelines issued in 1991. Recommendations for infection control and hygiene during spirometry testing are included in the most recent ATS Spirometry Update, and current research supports the continued validity of these recommendations.

As listed in Table 1, validity of spirometry tests is affected by four elements: (1) equipment performance, (2) testing technique, (3) measurement of results, and (4) technician training. Although the details of each of these topics are extensively discussed in the 1994 ATS Update, and in applicable regulations, some key aspects that are often not appreciated by the occupational health community are highlighted below.

Equipment Performance

As summarized in Table 2, spirometers can be classified into one of two types, depending on their mechanical characteristics: volumetric spirometers accumulate and directly measure exhaled air volume as a function of time; flow-type spirometers indirectly measure airflow during exhalation and integrate the flows to obtain expired volume. Although volume and flow-type spirometers are distinguished by their mechanical characteristics, it should be noted that both types of spirometers can produce both volume–time and flow–volume spirometry if the spirometry software is programmed appropriately.
TABLE 3
Equipment Performance Recommendations

1. For volumetric and flow-type spirometers, ATS recommends:
- Minimal performance criteria for range of volumes and flow rates, accuracy, precision, size of graphical display
- Validation by laboratory testing with known waveforms to determine whether specific spirometer models meet ATS performance criteria
- Frequent quality control (calibration) checks to ensure that spirometers remain accurate during use

2. An occupational spirometry testing system should meet as many of the following criteria as possible:
- Have the highest degree of accuracy and precision, exceeding ATS recommendations, particularly when serial spirometry measurements will be evaluated for small changes over time
- Provide real-time volume-time and flow-volume curves to technician for recognizing testing errors
- Provide extensive computer-derived technical quality indicators
- Save all test results and test quality indicators from a test session
- Save adequate data points to reconstruct tracings electronically at a future time

3. ACOEM recommends that users:
- Request written verification from the manufacturer that a particular spirometer has successfully passed its validation checks using the 1994 ATS Update protocol
- Save electronic copies or hard copies of whole spirograms so that technical quality of past tests can be examined when necessary
- Be able to examine volume-time curves to check end of test and flow-volume curves to check start of exhalation to determine whether test results are probably valid or reflect obvious testing artifacts
- Save calibration tracings and records to support validity of spirometry tests
- Maintain a log of problems found/solved and changes made in protocol, computer software, or equipment

4. Many NLHEP testing procedures and "office spirometers" are not acceptable for diagnostic spirometry or for occupational screening, surveillance, and impairment evaluations.

must be able to accumulate 8 L of expired air.

Flow-type spirometers, on the other hand, are lightweight and portable because their components are small, but their mechanical operating characteristics are complex because the measurement of expired volumes is indirect and the range of flows to be measured during a forced expiration is large. Different flow-type spirometers measure: (1) pressure differentials created as expired air passes through an orifice or across a resistance element, eg, composed of parallel capillary tubes or a mesh screen (pneumotachometer); (2) rotation speeds of a turbine as expired air flows across it (turbine); or (3) electrical current required to maintain the temperature of a heated wire as expired air flows across it (hot wire anemometer). The relationship between the measured index (ie, pressure, turbine speed, or electrical current) and flow rate is not always linear, and many flow sensors perform better at high flow rates, which are encountered early in the forced expiration, than they do at low flow rates, which are seen at the end of the maneuver, particularly in subjects with airways obstruction. In general, flow-type spirometers exhibit more variability (less precision) than volumetric spirometers, which can adversely affect interpretation of the serial spirometry measurements of medical surveillance programs.

Because a flow-type spirometer sensor is designed to detect pressure, turbine speed, or electrical current, and the transducer is calibrated to relate the measured index to rates of airflow, the integrity of the sensor must be maintained to achieve accurate measurements of pulmonary function. The characteristics of the sensor may become modified during spirometry tests if the sensor is damaged, blocked, or if moisture condenses on or mucus obstructs a resistance element, turbine, or hot wire. Such altered sensor characteristics or other electronic problems may produce test results that are erroneous, eg, flow rates that exceed the maximum flow capability of the instrument, exhaled volumes that far exceed those expected for the subject, or results that continually improve during a test session for every subject tested. It is critical that users be alert for such subtle indications of malfunction.

Unlike respirators, spirometers are not certified or approved by a government or private agency. However, as shown in Table 3, for both types of spirometers, the ATS recommends minimal performance criteria (including size of graphical display), validation of spirometers to determine whether specific models meet the performance criteria, and frequent quality control (calibration) checks to ensure that spirometers remain accurate during use. The requirements of the Social Security Administration and the Federal Coal Mine Health and Safety Act differ from the ATS recommendations in some details; these regulations should be consulted before conducting spirometry tests for impairment/disability evaluations.

The 1994 ATS Update presents a spirometer testing protocol for validating the accuracy and precision of each spirometer model. This testing can be performed by a spirometer manufacturer or by an independent testing laboratory. The validation protocol uses standard waveforms to drive a mechanical syringe, deliv-
erating known volumes at known speeds into the spirometer and software to be tested. The 1994 ATS Update testing protocol is far more rigorous than previous ATS recommendations, so users should be certain that their spirometer was tested using the 1994 ATS protocol. The ACOEM recommends that users request written verification from the manufacturer indicating that a particular spirometer has successfully passed its validation checks, and that the tested spirometer and software version correspond with the model and software version that is being purchased. However, it must be stressed that such validation under laboratory conditions does not guarantee that a device will retain its accuracy and precision under field conditions. The importance of frequent calibration checks in the field cannot be overstated.

Even when spirometers meet the minimal criteria set out by the ATS, they still vary in the accuracy and precision with which they measure expired volumes of air, in the completeness of the visual display presented to the technician for recognizing testing errors, in the availability of extensive computer-derived technical quality indicators, in the information that is saved as a testing session progresses and after the session is completed, and finally, in whether data points from tracings are saved so that the tracings can be recalled at a later date for comparison with other tests or for quality control reviews of spiromgrams (Table 3). The best systems far exceed ATS recommendations for accuracy and precision, provide real-time visual displays of the expiratory maneuver as well as computer-derived technical quality indicators, store all information from a test session, and save data points so that tracings can be reconstructed electronically at a future time. Users must remember that the highest degree of precision and accuracy is needed when serial spirometry measurements will be evaluated for small changes over time.

Unless the spirometry system saves electronic copies that permit whole spiromgrams from past test sessions to be displayed or printed, ACOEM recommends that hard copies of tracings should be maintained so that the technical quality of tests can be examined when necessary. This is particularly important for clinics and practices that provide occupational health services, in which providers of medical services may change periodically. The capability of examining volume–time curves to check the end of test and flow–volume curves to check the beginning of exhalation is essential in determining whether spirometry test results are probably valid or reflect obvious testing artifacts.

Calibration tracings and records support the validity of spirometry tests conducted on a particular day with a particular spirometer. Because OSHA requires that medical records be retained for 30 years after termination of employment, ACOEM recommends that these calibration records be saved and a log kept of any problems found and solved or any changes in protocol, computer software, or equipment that were made. Thermal paper should be photocopied because it fades rapidly over time.

It is important to note that a new National Institutes of Health–sponsored program, the National Lung Health Education Program (NLHEP), is being developed to encourage primary care physicians to screen smokers for chronic obstructive pulmonary disease. NLHEP requires less rigorous testing procedures and documentation than are required for occupational spirometry testing and encourages the use of new, inexpensive “office spirometers.” Occupational medicine physicians must be cautioned that many of NLHEP’s testing procedures and “office spirometers” are not acceptable for diagnostic spirometry or for occupational screening, surveillance, and impairment evaluations.

Testing Technique

OSHA, the Social Security Administration, the Federal Coal Mine Health and Safety Act, and the ATS make specific recommendations regarding performance of the forced expiratory maneuver and measurement of the spirogram. Key elements from the 1994 ATS Update and changes from the 1987 ATS guidelines are summarized below and in Table 4.

Testing should be conducted at ambient temperatures between 17°C and 40°C. However, temperatures ≥23°C are preferable to avoid a large temperature difference between spirometer temperature and body temperature. If a large difference exists, the exhaled air cannot fully cool down to the spirometer temperature within the first second of exhalation. In this case, an inappropriate correction factor, based on the spirometer temperature, will usually be selected to adjust the exhaled volume from spirometer to body temperature (body temperature and pressure saturated with water vapor [BTPS] correction), causing inflated measurements of BTPS-corrected FEV1.

The technician must demonstrate correct performance of a spirometry test, as well as describe it verbally, to the subject being tested. The technician must enthusiastically coach the subject to record “acceptable” maneuvers, which have good starts, are free from artifacts, and have satisfactory exhalations (Table 4). Specifically, the subject must: (1) exhale with a hard, fast “blast” of air so that the volume of air leaked out before the blast (the “extrapolated volume”) is less than 5% of the FVC, or 0.150 L, whichever value is greater; (2) exhale smoothly, with no cough or glottis closure in the first second, and no leak, obstruction of the mouthpiece, or variable effort; and (3) exhale completely, for at least 6 to 10 seconds and/or until a 1-second FVC plateau is reached, unless the subject cannot exhale for this long because
The testing goal is to record at least three acceptable maneuvers with the best FVC and the best FEV₁ reproduced to within 0.20 L, attempting up to eight maneuvers if necessary.²² Failure to meet these criteria does not rule out interpretation of results, because some impaired subjects may have difficulty in attaining them.⁴⁴⁻⁴⁶ However, when interpreting such results, it must be borne in mind that tests failing to meet the testing goal usually underestimate true pulmonary function.

The need for electronic or hard copies of a test session to support the “acceptability” of the test session cannot be overstated. Adequacy of the end of test is best checked by examining flow-volume curves for evidence of an FVC plateau and length of expiration (Fig. 1). The beginning of exhalation is best checked by examining flow-volume curves from each maneuver for an immediate rise to a sharp peak in expiratory flow rate (Fig. 2). Unacceptable spiromograms are depicted in the 1994 ATS Update²² and in some reference books.³⁰ Examination of hard copy or electronic tracings is probably the only way of evaluating whether trends in spirometry test results are real or obviously reflect testing artifacts. ACOEM strongly recommends that hard copies and/or electronic copies of spiromograms be saved from all spirometry test sessions.

Measurement of Results

The largest FVC and the largest FEV₁ from the acceptable curves are reported for a subject, even if they are not derived from the same maneuver (Table 5). Also, the largest FEV₁ may come from a curve that is acceptable except for its early termination.²² All expiratory flow rates are drawn from the single acceptable tracing having the largest sum of FEV₁ + FVC. Users should check their spirometers to ensure that their spirometry software selects the correct values for the test report. All observed volumes and flow rates are corrected to body temperature (BTPS).

Technician Training

In 1978, OSHA prescribed elements of standardization for spirometry in the occupational setting when it promulgated the Cotton Dust Standard.²⁸ The need for technician training is emphasized in the Preamble to the Standard: “The key to reliable pulmonary function testing is the technician’s way of guiding the employee through a series of respiratory maneuvers. The most important quality of a pulmonary function technician is the motivation to do the very best test on every employee. The technician must also be able to judge the degree of effort and cooperation of the subject. The test results obtained by a technician who lacks these skills are not only useless, but also convey false information which could be harmful to the employee.”

On the basis of the “Qualifications of personnel administering the test” given in Appendix D of the Cotton Dust Standard, NIOSH developed a program that reviews and approves spirometry training courses. Cotton Dust Standard Appendix D outlines the content of NIOSH-approved spirometry courses and states that the goal of these courses is to provide technicians with “the basic knowledge required to produce meaningful results.” For many exposures, OSHA requires that technicians attend courses “sponsored by an appropriate academic or professional institution” or a NIOSH-approved course.²⁸,⁴⁷,⁴⁸ Although attendance at a NIOSH-approved course is not required for technicians outside of the cotton industry, most companies view NIOSH approval as minimal assurance that the course will adequately teach the basic principles of spirometry. NIOSH currently approves about one course per year; 50 courses that have been approved are currently active. ACOEM,⁴⁹ NIOSH,⁴³ ATS,²² and
the American Association of Occupational Health Nurses30 all recommend technician training to ensure accurate pulmonary function testing. Spirometry refresher classes are not mandated by any OSHA regulations, nor does NIOSH approve the content of refresher courses. However, the need for repeated training of technicians was recognized and documented in the National Institutes of Health-sponsored multicenter Lung Health Study37 and the NIOSH-monitored spirometry of the third National Health and Nutrition Examination Survey (NHANES III).38 and ACOEM has recommended “periodic, eg, every 3 years,” refresher courses for many years.49 Spirometry refresher courses keep technicians informed of changes in occupational pulmonary function testing and reinforce the need for vigilance in conducting spirometry tests. Technician drift and apathy develop if no feedback is provided on test quality, and on the importance of active coaching and recognition of testing errors. Intensive refresher courses designed for experienced technicians are recommended instead of attending part of a NIOSH-approved spirometry course.

The 1994 ATS Update strongly emphasizes the importance of technical quality in achieving valid spirometry results; figures showing many technical errors that plague spirometry testing are presented in the Update.22 ATS recommends that spirometers be reviewed periodically to provide regular feedback on the quality of each technician’s testing. Quality control reviews can be performed on tracings that are saved electronically during the testing session or on photocopies of randomly selected spirograms.

As summarized in Table 5, ACOEM strongly recommends that spirometry technicians in the occupational setting complete a NIOSH-approved spirometry course as part of their training. Increasingly, clinics and practices engaged in providing occupational medical services may argue that such training is not needed for adequate performance of the test. However, recognition of the technical pitfalls of spirometry is critical in the occupational area, and NIOSH-approved courses are specifically geared toward training technicians to conduct screening spirometry tests and to recognize these pitfalls. In addition, ACOEM continues to recommend that technicians attend spirometry refresher courses every 3 years to discuss testing problems. Such courses encourage technicians to remain vigilant and enthusiastic during spirometry testing of workers. If feasible, a program providing quality assurance review of spirograms is also highly recommended.

### Interpretation of Results

Interpretation of spirometry results should always begin with an assessment of test quality.22 Once the validity of the measurements has been established, evaluation of the test subject’s lung function can proceed. Interpretation of results is summarized in Tables 6 and 7 and Fig. 3.

### Selection of Reference Values

The first step in interpreting pulmonary function results is usually to determine where the subject’s spirometry values fall relative to the normal range. Ideally, this normal range would be based on a population similar to the workers being examined, with spirometry measurements made and analyzed in accordance with the most recent ATS recommendations, using equipment and testing technique similar to that employed in testing the workers under consideration.23 However, reference “predicted” values that define the normal range are often drawn from relatively small numbers of

---

**Table 5**

**Measurement of Results and Technician Training**

**Measurement of results**
- Report largest FVC and largest FEV₁ from acceptable curves even if not on same curve.
- All expiratory flow rates come from one acceptable tracing with largest sum of FEV₁ + FVC.
- Check your spirometer to be sure correct values are selected for test report.
- Correct all observed volumes and flow rates to body temperature (BTPS).

**Technician training**
- From Preamble to OSHA Cotton Dust Standard, 1978:
  
  "The key to reliable pulmonary function testing is the technician’s way of guiding the employee through a series of respiratory maneuvers;
  
  The most important quality of a pulmonary function technician is the motivation to do the very best test on every employee;
  
  The technician must also be able to judge the degree of effort and cooperation of the subject;
  
  Test results obtained by a technician who lacks these skills are not only useless, but also convey false information which could be harmful to the employee." [emphasis added]
- ACOEM strongly recommends that spirometry technicians in the occupational setting complete a NIOSH-approved spirometry course as part of their training.
- ACOEM recommends that technicians attend spirometry refresher courses every 3 years.
- If feasible, a program providing periodic quality assurance review of spirograms is highly recommended.
TABLE 6
Selection and Race-Adjustment of Reference Values

Selection of reference values
- Pulmonary function related to age, height, and sex in an asymptomatic non-smoking reference group; summarized in regression equations, usually named after the primary investigator.
- To check the fit of reference values to a particular setting, ATS recommends testing 20–40 local, non-smoking healthy subjects and determining their % of predicted using the intended reference equations.
- Knudson prediction equations widely used in the occupational setting because Knudson’s 1976 equations were mandated by OSHA Cotton Dust Standard in 1978.
- Knudson data re-analyzed in 1983 to conform to ATS recommendations: changed predicted values considerably, particularly for forced expiratory flow rates.
- In January 1999, equations specific for Caucasians, African-Americans, and Hispanics were published from the NHANES III, based on a random sample of the US population.
- ACOEM recommends that occupational settings consider adopting NHANES III equations for general use as they become available in spirometry systems, unless testing is conducted under a regulation/guideline that requires other reference values.

Race adjustment of predicted values
- Race-adjustment of Caucasian predicted values for African-Americans has been widespread in the occupational setting since 1978, when the OSHA Cotton Dust Standard mandated that Caucasian predicted FEV<sub>1</sub> and FVC be multiplied by 0.85 for African-Americans to adjust for ethnic differences.
- ATS recommends using race-specific prediction equations such as NHANES III, if possible, or using a 0.88 scaling factor to race-adjust Caucasian predicted values for African-Americans.
- Use subject’s self-declared race or ethnic group as a basis for race-adjusting or selecting race-specific predicted values.
- Less consensus on adjustment of predicted values for non-Caucasian ethnic groups other than African-Americans.
- Until NHANES III equations become widely available, ACOEM recommends cautious race-adjustment of Caucasian predicted FEV<sub>1</sub> and FVC for African-American, Chinese, and Japanese subjects using ATS scaling factor of 0.88, unless testing under a regulation/guideline that requires specific race-adjustment factors.

It should be noted that an important alternative source of spirometry reference values has recently become available for both the clinical and the occupational settings. In January 1999, race/ethnic group-specific equations were published from the NHANES III, based on a random sample of the US population and using standardized, state-of-the-art spirometry testing methodology. The NHANES III data permitted reference equations to be calculated separately for Caucasians, African-Americans, and Hispanics. Although a few regulations and guidelines continue to require the use of specific sets of reference values, ACOEM recommends that the NHANES III equations be considered for general use in the occupational setting as these equations become available in computerized spirometry systems.

Race Adjustment of Predicted Values

Publication of the NHANES III prediction equations is an important
TABLE 7
Interpreting Results: Lower Limit of Normal (LLN) and Flow Rates

LLN
- Use 5th percentile LLN instead of 80% of predicted to classify employees as “normal” or “abnormal”; because 5th percentile LLNs tend to decline with age, largest difference will be seen for older workers.
- Obtain 5th percentile LLN from same reference group as predicted values, from tables or equations in the reference, or calculate LLN = 1.645 × SEE.*

Interpreting forced expiratory flow rates
- FEF25-75% and instantaneous flows should not be used to diagnose small airway disease in individuals or to assess respiratory impairment because of the wide variability in flow rates within and between healthy subjects.
- If FEV1 and FEV1/FVC are in the normal range, FEF25-75% and other flow rates should not be interpreted, although an FEF25-75% percent of predicted <LLN can be used to confirm the presence of airways obstruction in the presence of a borderline FEV1/FVC.
- Flow rate variability determines the 5th percentile LLN for the FEF25-75%: Using Knudson’s 1983 reference values, the 5th percentile LLN for FEF25-75% for a man 40 years or older is 40.3% of predicted. If such a man’s observed FEF25-75% is half of his predicted value, he is still within the normal range.

* SEE, standard error of estimate.

---

Fig. 3. Spirometry interpretation flowchart. LLN, lower limit of normal.

step forward, not only because the reference values are based on a random sample of the US population that was examined in the past few years, but also because predicted values specific for African-Americans and Hispanics, based on randomly selected subjects from the US population, are now available. Until this time, the most widely used reference values have been derived from Caucasian populations in North America. Before 1978, when workers in the cotton industry were evaluated using these reference values for Caucasians, more abnormal spirometry results were noted among African-American than among Caucasian workers. Because race-specific reference equations were not in general use in 1978, OSHA mandated that “the predicted FEV1 and FVC for blacks should be multiplied by 0.85 to adjust for ethnic differences” (Table 6). At the time, OSHA recognized that “this correction may not be precisely correct,” but it relied on the current state-of-the-art “to provide proper interpretation of spirometry measurements for blacks without inadvertently fostering discrimination in hiring practices.”28 The practice of adjusting Caucasian predicted values for FVC and FEV1 for African-American subjects has remained widespread in the occupational setting since 1978. However, race-adjustment is less widely used in the clinical setting.

The 1991 ATS Official Statement on “Lung Function Testing: Selection of Reference Values and Interpretative Strategies” recommends use of race-specific prediction equations such as the NHANES III6 if “possible and practical,” or cautious use of a scaling (“race-adjustment”) factor of 0.88 if non-Caucasians are tested infrequently.23 It is important to use a subject’s self-declared race or ethnic group as a basis for select-
In the absence of airways obstruction, the FVC percent of predicted is used to determine whether restrictive impairment is present, with the ATS defining "mild" restriction as an FVC between 60% of predicted and the LLN, "moderate" restriction as an FVC of 51% and 59% of predicted, and "severe" restriction as an FVC of 50% or less of predicted.

Cross-Sectional Evaluation: Normal, Obstructed, Restricted

In its 1991 Interpretation Statement, the ATS recommends that spirometry results be interpreted on the basis of a stepwise algorithm using very few parameters, as summarized in Fig. 3. A value of the FEV/FVC percent of predicted below the lower limit of normal (LLN) indicates probable obstructive impairment. Having established the presence of obstruction, the FEV percent of predicted is used to grade the degree of obstructive impairment. There are several definitions of severity categories available, and Fig. 3 presents the ATS respiratory impairment categories, which define "mild" obstruction as an FEV between 60% of predicted and the LLN, "moderate" obstruction as an FEV of 41% and 59% of predicted, and "severe" obstruction as an FEV of 40% or less of predicted. "Borderline" obstruction may exist when a subject's FEV/FVC percent of predicted is below its LLN but the FEV falls within the normal range. However, the ATS cautions that "the pattern of a low FEV/FVC ratio and greater than average FVC and FEV should be recognized as one that may occur in healthy individuals".

In the absence of airways obstruction, the FVC percent of predicted is used to determine whether restrictive impairment is present, with the ATS defining "mild" restriction as an FVC between 60% of predicted and the LLN, "moderate" restriction as an FVC of 51% and 59% of predicted, and "severe" restriction as an FVC of 50% or less of predicted.

Contrary to long-standing practice, the use of a fixed cutoff of 80% of predicted as LLN is not recommended (Table 7) and should be replaced by the fifth percentile, the point below which 5% of normal subjects fall. The LLN should be obtained from the same source as the predicted values, from tables or equations presented in the reference, or calculated as: LLN = 1.645 \times \text{SEE} (standard error of estimate). LLNs calculated in this way tend to decline with age and thus can have an impact on whether a 50- to 60-year-old employee is labeled as "normal" or "abnormal." For example, by using the 1983 Knudson prediction equations, the LLN (5th percentile) for FVC for a man of 40 years or older is 73.4% of predicted, which is significantly below the previously used 80% of predicted.

Finally, because of the wide variability within and between healthy subjects, the ATS states that "FEF and the instantaneous flows should not be used to diagnose small airway disease in individual patients" or to assess respiratory impairment. Interpretation of FEF and other flow rates is not recommended if the FEV and the FEV/FVC are within the normal range, although the flow rates "may be used to confirm the presence of airway obstruction in the presence of a borderline FEV/FVC." In other words, an FEF percent of predicted below its LLN can confirm the presence of airways obstruction in subjects falling into the "Possible Borderline Obstruction" category in Fig. 3. However, such interpretations should be used with caution, as the ATS's warning that a low FEV/FVC ratio accompanied by FVC and FEV at or above average, indicates that a man over 40 must be less than half of his Knudson predicted value before he falls below the normal range.

Changes Over Time

In the occupational setting, changes over time in pulmonary function should be examined for two reasons: (1) to evaluate a worker's response to treatment in the clinical setting, and (2) to screen healthy workers for excessive loss of function over time. In the first situation, the ATS recommends a non-algorithmic approach to interpretation, stating that "the clinician seeing the patient can often interpret results of serial tests in a useful manner, not reproducible by any simple algorithm. For example, seemingly stable tests may prove very reassuring in a
patient receiving therapy for a disease that is otherwise rapidly progressive. The same tests may be very disappointing if one is treating a disorder that is expected to improve dramatically with the therapy prescribed. Depending on the clinical situation, statistically insignificant trends in function may be very meaningful to the clinician.23

The second situation, screening healthy workers for excessive loss of pulmonary function, is often encountered in workplace medical surveillance programs. When subjects' spirometry test results are compared with a cross-sectional LLN, as described in the previous section and shown in Fig. 3, excessive loss of pulmonary function will be identified adequately in workers with average or less than average lung size. However, such evaluations will not detect early excessive loss of function in workers whose lung size is above average, ie, above 100% of predicted. Particularly for these subjects, change in pulmonary function over time should be included in a screening program to determine whether the worker’s spirometry test results are decreasing faster than expected over time.23,36,60

Loss of FEV1 or FVC over time can be estimated simply by calculating the difference between volumes measured at two points in time, or by fitting a least squares “slope” through periodic measurements over time for an individual. Because estimates of individual rate of change become more precise as follow-up time increases, loss of FEV1 or FVC should be estimated from measurements made over a minimum of 4 to 6 years.61-64 Measurement frequency has less impact on precision than length of follow-up does.61,62 but periodic measurements are needed to detect workers experiencing rapid declines in pulmonary function and to detect systematic differences between examinations over time.62,64

Interpretation of change over time in the screening setting is complicated by the substantial variation in rates of change that exist both between workers and within an individual worker. Although the FEV1 and FVC can be measured precisely during one test session, biologic and technical variation over time make an individual’s estimated rate of change over time highly variable.61-65 Although within-day variability for a normal subject’s FEV1 and FVC is ≤ 5%, year-to-year variability is ≤ 15%.33,62 Technical variability can be minimized by using very precise spirometers, not changing equipment unnecessarily over time, and maintaining a rigorous spirometry quality assurance program. Biologic variability can be reduced by conducting successive spirometries at about the same time of day and in the same month each year. Because of the precision gained by combining results from many subjects, group estimates of change can be calculated and comparisons made between groups in epidemiologic studies.

Epidemiologic data have indicated that for adult smokers “to develop clinically significant airflow obstruction, the average rate of decline of FEV1 . . . probably needs to be greater than 90 ml/year, or about three times that seen in non-smokers and twice the rate seen in the ‘non-susceptible’ smokers”.63 One study found that about 4% of their combined smoking and non-smoking male population had FEV1 slopes of 100 ml/year or greater when calculated over 4 to 11 years of follow-up.64 However, studies differ in their estimates of change over time, and, to date, neither longitudinal predicted values nor 5th percentile LLNs have been recommended for the evaluation of individual rates of change over time in occupational or clinical settings.62

To meet the need for longitudinal LLNs, the ATS recommends a conservative strategy to minimize false positives in the screening setting, stating that: “The greatest errors occur when one attempts to interpret serial changes in subjects without disease because test variability will usually far exceed the true annual decline, and reliable rates of change for an individual subject cannot be calculated without prolonged follow-up. Thus, in subjects with “normal” lung function, changes in FVC or FEV1 over 1 year should probably exceed 15% before any confidence can be given to the opinion that a meaningful year-to-year change has occurred.”23 NIOSH adopted this definition of significant change in a 1995 Criteria Document, stating that “because of considerable short-term variability in FEV1, a year-to-year change of greater than 15% should occur before a change in FEV1 is considered significant.” NIOSH concluded that “evidence of impaired lung function is present when there is a confirmed finding of a decline in FEV1 (adjusted for the expected interval decline in FEV1) of 15% or greater” and that such a decline “is considered significant and warrants further medical evaluation”.67

Because FEV1 and FVC decline with age from the about the mid-30s on, with some acceleration of the rate as aging advances,68,69 an allowance for the expected loss due to aging should be made before labeling a 15% decline as “significant.”36,67 As Appendix G of the NIOSH Criteria Document67 states: “The LLN for the follow-up FEV1 is computed by taking 85% of the baseline value minus the expected decline over the time period. An individual’s expected decline over the time period is dependent on his/her age, but for practical considerations, a constant value of 25 ml/year is often recommended. For example, an individual whose initial FEV1 is 4.00 L would be considered to have an accelerated decline in FEV1 if his/her FEV1 is below 3.15 L, 10 years after the baseline value was determined [(0.85 × 4.0 L) - (10 years × 0.025 L/year) = 3.15 L].” Such a loss over 10 years would be labeled “significant” and would warrant medical
When screening subjects with "normal" lung function, ACOEM recommends that: (1) an FEV1 to be considered significant. Pre- to post-bronchodilator changes in the FEF 25-75% should not of initial FEV1 ~15% ~0.2 L to be significant.

Fire Protection Association examination protocol, which recommends spirometry testing every 3 years for those under age 29, every 2 years for ages 30–39, and annually for ages 40 and above.

Pre- to post-bronchodilator changes in pulmonary function
- ATS and the National Heart, Lung, and Blood Institute’s National Asthma Education and Prevention Program consider a pre- to post-bronchodilator increase of ≥12% of initial FEV1 and ≥0.2 L to be significant.
- Attention should focus on FEV1, because varying lengths of expiration may complicate changes in FVC or FEF25-75%. If examined, initial FVC should change by ≥15% to be considered significant. Pre- to post-bronchodilator changes in the FEF25-75% should not be interpreted.
- Failure to achieve such responses to bronchodilators in the laboratory does not completely exclude the possibility of reversible airways disease.
- The best values for FVC and FEV1 should be used in impairment determinations, whether recorded before or after bronchodilator administration.

In summary, as shown in Table 8, ACOEM recommends that spirometry be conducted every 1 to 2 years when indicated because of workplace exposures, unless otherwise specified by applicable regulations or recommendations. The frequency of testing may vary with age and length of exposure, as in the National Fire Protection Association examination protocol, which recommends spirometry testing every 3 years for firefighters under age 29, every 2 years for ages 30 to 39, and annually for ages 40 and above. Change in FEV1 and FVC over time should be evaluated as part of a screening program once measurements have been made over at least 4 to 6 years. A decrease in FEV1 or FVC of 90 to 100 mL/year, calculated over at least 4 to 6 years, should trigger further scrutiny of a worker’s pulmonary function measurements over time. Loss of 15% or more of the baseline observed FEV1, or FVC, after allowing for the expected decrease due to aging, should be regarded as a significant decline over time. If the low results are confirmed on a re-test, a medical review is warranted, even if the worker’s values still remain above the cross-sectional LLN.

Pre- to Post-Bronchodilator Changes in Pulmonary Function
- The ATS and the National Heart, Lung, and Blood Institute Lung Health Study regarded a 15% increase in FEV1 as significant.
- Attention should be limited to changes in the FEV1 because interpreting changes in the FVC or FEF25-75% is likely to be complicated by varying lengths of expiration recorded before or after the bronchodilator. If changes in the FVC are examined, the ATS recommends that a change of at least 15% of initial FVC be considered significant, ie, suggestive of airway reactivity. The ATS does not endorse interpretation of pre- to post-bronchodilator changes in the FEF25-75%.
- On the basis of these sources, ACOEM recommends that a post-bronchodilator increase in FEV1 should be at least 12% of initial FEV1 and at least 0.2 L to be considered significant, ie, suggestive of reversible obstructive airways disease. However, it should be noted...
that failure to achieve such a response to bronchodilators in the laboratory does not completely exclude the possibility of reversible airways disease. ACOEM also concurs with the ATS and the American Medical Association that impairment determinations should use a worker’s best values for FVC and FEV₁, whether recorded before or after bronchodilator administration.

Acute Work-Related Changes in Pulmonary Function

Work-related bronchoconstriction, causing decreased pulmonary function across a work shift or increased variability in pulmonary function across a longer period at work, can be elicited by bronchial irritants and sensitizers and is often reversible. Patterns of work-related change are an important element in the diagnosis of a number of occupationally related respiratory disorders, particularly occupational asthma (Table 9). Spirometry measurements should be made as close to the work environment as possible to avoid a long time lapse between the worker’s occupational exposure and the measurement of pulmonary function. As discussed below, when occupational asthma is suspected, additional measurements should also be made at home at the conclusion of the workday to capture any delayed work-related declines in function. The spirometry measurements most commonly examined are the FEV₁ and the peak expiratory flow (PEF) rate, although interpretation of FEV₁ decline is better standardized than interpretation of PEF variability. Newly marketed portable spirometers are becoming available for serial spirometry measurements in the workplace in addition to the traditionally used peak flow meters.

In 1978, the OSHA Cotton Dust Standard defined an across-shift decrease in FEV₁ of 5% or 0.2 L, whichever is greater, as a significant drop if confirmed within 1 month. In 1986, a drop in FEV₁ of 5% or 0.15 L, whichever is greater, was labeled as significant, if confirmed on a second occasion. An FEV₁ decrease of 10% would be considered significant if only one pre- to post-shift study was performed. When considering such small declines in FEV₁ as significant, it is critical to maintain the testing environment and the spirometer at 23°C (73°F) or above. FEV₁ declines of several percent can be produced as an artifact if the testing environment and the spirometer warm up by several degrees between the pre- and post-shift tests. Usually the BTPS correction factor is selected on the basis of the spirometer temperature, and not the temperature of the accumulated exhaled gas 1 second after the expiration commences. With a cold pre-shift spirometer, a large BTPS correction factor may be applied to exhaled air that is still closer to body than to spirometer temperature, resulting in an inflated “observed” FEV₁. With a warmer post-shift spirometer, the temperature of the accumulated exhaled air is closer to the spirometer temperature so that the selected BTPS factor is appropriate. Subsequently, calculation of a pre- to post-shift change in FEV₁ finds an FEV₁ decline that depends on the warming of the spirometer across the work shift rather than employee exposures in the work environment.

On the basis of the sources described above, ACOEM recommends that a single pre- to post-shift study finding a decline in FEV₁ of at
Throughout this position statement, ACOEM makes detailed recommendations to ensure that each of these areas of test performance and interpretation follow current recommendations/standards in the pulmonary and regulatory fields.

Submitted by the Occupational and Environmental Lung Disorder Committee on November 16, 1999. Approved by the ACOEM Board of Directors on January 4, 2000. At the time of the preparation of this position statement, Occupational and Environmental Lung Disorder Committee members were:

James E. Lockey, MD, MS, Chair
Henry Velez, MD, Vice Chair
Arch I. Carson, MD, PhD
Clayton T. Cowl, MD, MS
George L. Delclos, MD, MPH
Bret J. Gerstenhaber, MD
Philip I. Harber, MD, MPH
Edward P. Horvath, MD, MPH
Athena T. Jolly, MD, MPH
Shadrach H. Jones, IV, MD
Gary G. Knackmuhs, MD
Larry A. Lindesmith, MD
Thomas N. Markham, MD, MPH
Lawrence W. Raymond, MD, SM
David M. Rosenberg, MD, MPH
David Sherson, MD
Dorsett D. Smith, MD
Mary C. Townsend, DrPH
Stephen F. Wintermeyer, MD, MPH

Acknowledgments

The authors thank Drs John L. Hankinson and Robert O. Crapo for many helpful suggestions and comments regarding this position statement. In addition, we thank the other members of the American Thoracic Society who shared their views and insights as this position statement was developed.

Appendix: Glossary of Terms and Abbreviations

ATPS: Ambient temperature and pressure saturated with water vapor. Volumes read directly off the volume–time spirogram are at ATPS.

Back extrapolation: In the calculation of FEV₁, a method for determining the time zero. A straight line is drawn through the steepest portion of the volume–time curve back to the baseline. Where this straight line intersects the baseline is the zero point for timing the FEV₁.

Best curve: The curve that gives the largest sum of FEV₁ and FVC. The best curve is used in the calculation of the FEF₂₅–₇₅% and the instantaneous flow rates. In contrast, the largest FVC and the largest FEV₁ are reported for the test session, even if they are not from the same curve.

BTPS: Body temperature and pressure saturated with water vapor. All spirometric volumes and flows must be corrected to BTPS.

Calibration check: Periodic determination of a spirometer’s ability to accurately measure volume. Calibration checks should be performed at least daily using a 3-L syringe. The instrument should maintain an accuracy of ±3% of the reading. Additional checks include checking for leaks (daily for volume spirometry) and, every 3 months, verifying the accuracy of a timed chart and checking the linearity of volume recording.

End of test: That point during the forced expiratory maneuver when a plateau at least 1 second long is noted on the volume–time tracing.

Extrapolated volume: The volume determined by a line drawn through the zero time point perpendicular to the baseline on a volume–time curve. The extrapolated volume is read where this perpendicular line intersects the volume curve; it should be less than 5% of the PVC or 150 mL, whichever is greater.

FEV₁/FVC%: Forced expiratory volume in one second expressed as a percentage of the forced vital capacity.

Flow-measuring spirometer: Indirectly measures volume of exhaled air by measuring the rate at which air is exhaled and deriving the volume. Examples include pneumotachometer, mass flow, and turbine instruments.

Forced expiratory volume in one second (FEV₁): Volume of air exhaled during the first second of the FVC.

Forced expiratory volume in six seconds (FEV₆): Volume of air exhaled during the first six seconds of the FVC. Because it is easier for obstructed subjects to reach the FEV₆ than the FVC, there is growing interest in measuring the FEV₆ and the FEV₁/FEV₆ in screening spirometry.

Forced expiratory maneuver: Technique during spirometry in which the subject takes the deepest possible inspiration from a normal breathing pattern and blows into the mouthpiece as hard, fast, and completely as possible. Also known as the forced vital capacity maneuver.

Forced vital capacity (FVC): The maximal volume of air exhaled from the point of maximal inspiration using a maximally forced expiratory effort.

Mean forced expiratory flow during the middle half of the FVC (FEF₂₅–₇₅%): Average flow rate over the middle half of the expiration. Formerly called the maximal mid-expiratory flow rate (MMEF).

Predicted normal values: Expected values for various lung volumes and flow rates derived from healthy populations.

Reproducibility: In the absence of disease-related changes, the ability of a test to obtain the same result from an individual repeatedly tested over a period of time. Reproducibility of the FEV₁ and FVC within a test session should be 0.20 L or less.

Residual volume: Volume remaining in the lungs following a maximal expiration.

Spirogram: A graphic recording of a forced expiratory maneuver, as either a volume–time or flow–volume tracing.

Spirometer: An instrument for measuring lung volumes and flow rates.

Total lung capacity: Total lung volume following a maximal inspiration.

Valid test: A spirometry test consisting of at least three acceptable
forced expiratory tracings for which the best FVC and the best FEV₁ are reproduced within 0.2 L.

**Volume-measuring spirometer:** Spirometers that directly accumulate and measure the volume of exhaled air as a function of time. Examples include water-seal, dry rolling seal, and bellows instruments.

**Zero time point:** In the measurement of FEV₁, the point selected as the start of the test.

## References

41. The National Lung Health Education Program Executive Committee. Strategies in preserving lung health and preventing COPD and associated diseases:


