



**ACOEM Position Paper
Spirometry in the Occupational Setting
Abstract**

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

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Spirometry in the Occupational Setting

This position paper 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, though spirometry data are also analyzed for groups of workers in respiratory surveillance programs and epidemiologic research studies. The topics reviewed by the statement are presented in [Table 1](#). A glossary of pulmonary function terms and abbreviations is provided in [Appendix A](#).

PRINCIPLES OF SPIROMETRY

Spirometry is the most basic and frequently performed test of pulmonary function, measuring the ventilatory function of the respiratory system, i.e., 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 spirometry has displayed expired volume as a function of expiratory time ([Figure 1](#)). Since the mid-1970's, flow-volume spirometry has also become common, showing expiratory flow rate as a function of expired volume ([Figure 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 based on their 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, and 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 prevention of respiratory disease in the workplace (1).

In the *primary* prevention of respiratory disease, spirometry can be used in pre-placement and fitness-for-duty examinations of individuals, in situations where: a) the physical demands of a job require a certain level of cardiopulmonary fitness, e.g., heavy manual labor or fire fighting; or b) the characteristics of respirator use can impose a significant burden on the cardiopulmonary systems, e.g., 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 (2,3). Though not required routinely under the OSHA Respiratory Protection Standard, 29 CFR 1910.134, spirometry may be used in the evaluation of respirator users in some situations (2,3,4).

In addition to the 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 following 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 (1). 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, e.g. 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, e.g. Silicosis. The contents of the OSHA-mandated physical examinations are summarized in a 1998 publication from the U.S. Department of Defense "Occupational Medical Surveillance Manual" (5). The National Institute for Occupational Safety and Health (NIOSH) also recommends respiratory surveillance for more than two dozen additional exposures that do not have OSHA-mandated surveillance programs (6). 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 the statement, the limitations of spirometry must be borne in mind when

interpreting periodic spirometry test results in individuals. While spirometry can detect large changes over a short time or smaller changes cumulated over a longer observation period, spirometry 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, since 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 (SSA) (7), the Federal Coal Mine Health and Safety Act (CMHSA) (8), and in the workers' compensation setting (9,10). Though 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 (10)." Additional measures of functional impairment, such as the determination of diffusing capacity for carbon monoxide (11), measurement of lung volumes (12), exercise tolerance testing (13), or methacholine challenge testing (14) are beyond the scope of this 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 (15-17). 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 (18). 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, since 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 (19), it has only been in the past two 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 (20), 1987 (21), and 1995 (22), as well as

interpretation guidelines issued in 1991 (23). Recommendations for infection control and hygiene during spirometry testing are included in the most recent Spirometry Update (22), and current research supports the continued validity of these recommendations (24-27).

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. Though the details of each of these topics are extensively discussed in the 1994 ATS Spirometry Update (22) and in applicable regulations (7,8,28), some key aspects, 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, while *flow-type* spirometers indirectly measure airflow during exhalation and integrate the flows to obtain expired volume (19,29-33). While 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 spiograms if the spirometry software is programmed appropriately.

In general, volumetric and flow-type spirometers each have advantages and disadvantages. In a volumetric spirometer, the subject's expired air may: a) cause a collection bell to rise in a water jacket (water-sealed spirometer); b) displace a piston horizontally in a cylinder, causing the seal between the piston and cylinder to roll on itself (dry rolling seal spirometer); or c) fill a bellows (bellows spirometer). The air-collecting part of the spirometer often has a direct pen linkage, inscribing a volume-time spirogram on moving chart paper during a subject test. In general, volumetric spirometers are precise, operate simply, and are easily maintained. The chief disadvantage of volume spirometers is their size, since they must be able to accumulate 8 liters of expired air.

Flow-type spirometers, on the other hand, are lightweight and portable, since 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 (33). Different flow-type spirometers measure: a) pressure differentials created as expired air passes through an orifice or across a resistance element, e.g., composed of parallel capillary tubes or a mesh screen (pneumotachometer); b) rotation speeds of a turbine as expired air flows across it (turbine); or c) 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, i.e. pressure, turbine speed, or electrical current, and flow rate is not always linear, and many flow sensors perform better at high flow rates, encountered early in the forced expiration, than they do at low flow rates, seen at the end of the maneuver, particularly in subjects with airways obstruction. Flow-type spirometers, in general, exhibit more variability (less precision) than volumetric spirometers, which can adversely affect interpretation of the serial spirometry measurements of medical surveillance programs (33).

Since 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, e.g. 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 insure that spirometers remain accurate during use (22). The requirements of the SSA (7) and the CMHSA (8) differ from the ATS recommendations in some details; these regulations should be consulted prior to 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 (22). This testing can be performed by a spirometer manufacturer or by an independent testing laboratory. The validation protocol uses standard waveforms (34) to drive a mechanical syringe, delivering known volumes at known speeds into the spirometer and software to be tested (35). 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. American College of Occupational and Environmental Medicine (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 (36-39), 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 spirograms ([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 spirograms 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 in the case of clinics and practices providing occupational health services, where 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 (22).

Calibration tracings and records support the validity of spirometry tests conducted on a particular day with a particular spirometer. Since OSHA requires that medical records be retained for 30 years after termination of employment (40), ACOEM recommends that these calibration records should 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 since 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 (COPD) (41). NLHEP requires less rigorous testing procedures and documentation than are required for occupational spirometry testing, as well as encouraging the use of new inexpensive "office spirometers." Occupational medicine physicians need to 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 (28), SSA (7), CMHSA (8), and the ATS (22) 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 - 40° C. However, temperatures $\geq 23^\circ$ C are preferable to avoid a large temperature difference between the spirometer temperature and body temperature (42). 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 (BTPS correction), causing inflated measurements of BTPS-corrected FEV₁ (42,43).

The technician must *demonstrate* correct performance of a spirometry test, as well as describing 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: a) 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; b) exhale smoothly, with no cough or glottis closure in the first second, and no leak, obstruction of the mouthpiece, or variable effort; and c) exhale completely, for at least 6 to 10 seconds and/or until a one second long FVC plateau is reached, unless the subject cannot exhale this long because of discomfort, airways obstruction, or advanced age.

The testing *goal* is to record at least 3 acceptable maneuvers with the best FVC and the best FEV₁ reproduced to within 0.20 L, attempting up to 8 maneuvers if necessary (22). Failure to meet these criteria does not rule out interpretation of results, since 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 volume-time curves for evidence of an FVC plateau and length of expiration ([Figure 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 ([Figure 2](#)). Unacceptable spiromograms are depicted in the 1994 ATS Spirometry Update (22) 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 may be real or obviously reflect testing artifacts. ACOEM strongly recommends that hard copies and/or electronic copies of spiromograms be saved from 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, 29 CFR 1910.1043 (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."

Based on 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). Though 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 Nurses (AAOHN) (50) 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 multi-center Lung Health Study (37) and the NIOSH-monitored spirometry of the National Health and Nutrition Examination Survey III (NHANES III) (38), and ACOEM has recommended "periodic, e.g. 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, rather than attending part of a NIOSH-approved spirometry course.

The 1994 ATS Spirometry Update strongly emphasizes the importance of technical quality in achieving valid spirometry results; figures of many technical errors that plague spirometry testing are presented in the Update (22). ATS recommends that spirograms 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, recognizing 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.

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 subjects resident in a single geographic location, often near or accessible to an interested research investigator. Reference values may be derived from an institutional or occupational group, a population-based epidemiologic study, or subjects chosen specifically to create reference equations (23). Within the study group, the relationship between pulmonary function and age, height, and sex is summarized in regression equations, which are usually named after the primary investigator. In clinical medicine, many laboratories use the equations of Morris (51), Crapo (52), or Knudson (53), depending to some degree on which equations are programmed into the automated spirometry equipment (54).

In the occupational setting, Knudson's prediction equations have been widely used because the 1976 equations (55) were mandated by the OSHA Cotton Dust Standard: they were the only equations available at the time that studied both males and females, were based on non-smokers, and used back-extrapolation to define time zero. The Knudson data were re-analyzed in 1983 (53) using data selection criteria that conform to ATS recommendations, resulting in equations that predict considerably different values than in 1976, particularly for the forced expiratory flow rates. Crapo's prediction equations (52) are also used in the occupational setting since they were adopted by the American Medical Association (AMA) as the standard reference in the 4th Edition of the AMA Guides to the Evaluation of Permanent Impairment (9). Many reference equations are listed in the ATS Interpretative statement (23), and the 1997 NIOSH Spirometry Training Guide demonstrates the varying results obtained when different prediction equations are used (43). As recommended by the ATS, the fit of a set of reference values to a particular occupational setting can be checked empirically by testing 20-40 local non-smoking healthy subjects and determining their percentages of predicted using the intended reference equations (23).

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 third National Health and Nutrition Examination Survey (NHANES III), based on a random sample of the U.S. population using standardized state-of-the-art spirometry testing methodology (56). The NHANES III data permitted reference equations to be calculated separately for Caucasians, African-Americans, and Hispanics. Though a few regulations and guidelines continue to require the use of specific sets of reference values (8,9,28), 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 step forward, not only because the reference values are based on a random sample of the U.S. population that was examined in the last few years, but also because predicted values specific for African-Americans and Hispanics, based on randomly selected subjects from the U.S. population, are now available. Until this time, the most widely used reference values have been derived from Caucasian populations in North America. Prior to 1978, when workers in the cotton industry were evaluated using these Caucasian reference values, more abnormal spirometry results were noted among African-American than among Caucasian workers. Since 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 OSHA 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 (54).

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 III (56) 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 selecting appropriate race-specific predicted values or for deciding whether or not to race-adjust Caucasian predicted values. Though using race-adjusted Caucasian predicted values for African-American subjects is preferable to using non-adjusted Caucasian predicted values (57), recent studies conclude that a single adjustment factor is not optimal and that race-specific equations should be used (57,58).

There is less consensus on the adjustment of Caucasian predicted values for other ethnic groups, such as Hispanics, Asians, and Pacific Islanders than there is for African-Americans (59). Current sources and studies do not recommend race-adjustment for any of these groups except some Asians, i.e. Chinese and Japanese, in addition to African-Americans (37,59).

As noted above, ACOEM recommends that occupational settings consider adopting the NHANES III equations for general use as they become available in spirometry systems. Until these equations are available, ACOEM recommends that Caucasian predicted values should be race-adjusted for African-American, Chinese, and Japanese subjects, applying the ATS recommended scaling factor of 0.88 to the Caucasian predicted FEV₁ and FVC ([Table 6](#)). However, if testing is conducted under the few regulations and guidelines that have specific recommendations/requirements regarding race-adjustment factors (8,9,28), those requirements should be followed.

Cross-sectional Evaluation: Normal, Obstructed, Restricted

In its 1991 Interpretation statement, the ATS recommends that spirometry results be interpreted based on a stepwise algorithm using very few parameters (23,30), as summarized in [Figure 3](#). A value of the FEV₁/FVC % of predicted below the Lower Limit of Normal (LLN) indicates probable obstructive impairment. Having established the presence of obstruction, the FEV₁ % of predicted is used to grade the degree of obstructive impairment. There are several definitions of severity categories available (9,10,23,30), and Figure 3 presents the ATS respiratory impairment categories (10), which define "mild" obstruction as an FEV₁ between 60% of predicted and the LLN, "moderate" obstruction as an FEV₁ of 41-59% of predicted, and "severe" obstruction as an FEV₁ of 40% or less of predicted. "Borderline" obstruction *may* exist when a subject's FEV₁/FVC % of predicted is below its LLN, but the FEV₁ falls within the normal range. However, the ATS cautions that "the pattern of a low FEV₁/VC ratio and greater than average VC and FEV₁ should be recognized as one that may occur in healthy individuals" (23).

In the absence of airways obstruction, the FVC % 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 51-59% of predicted, and "severe" restriction as an FVC of 50% or less of predicted (10).

Contrary to long-standing practice, the use of a fixed cut-off of 80% of predicted as a LLN is not recommended ([Table 7](#)), and should be replaced by the fifth percentile, the point below which 5% of normal subjects fall (23). The LLN should be obtained from the same source as the predicted values, from tables or equations presented in the reference (53, 56) or calculated as: LLN = 1.645 x SEE (23). LLNs calculated in this way tend to decline with age, and thus can have an impact on whether a 50-60 year old employee is labeled as "normal" or "abnormal." For example, using the 1983 Knudson prediction equations (53), 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, due to wide variability within and between healthy subjects, the ATS states that "FEF_{25-75%} and the instantaneous flows should not be used to diagnose small airway disease in individual patients" (23) or to assess respiratory impairment (10). Interpretation of FEF_{25-75%} and other flow rates is not recommended if the FEV₁ and the FEV₁/FVC are within the normal range, though the flow rates "may be used to confirm the presence of airway obstruction in the presence of a borderline FEV₁/VC" (23). In other words, an FEF_{25-75%} % of predicted below its LLN can confirm the presence of airways obstruction in subjects falling into the "Possible Borderline Airways Obstruction" category in [Figure 3](#). However, such interpretations should bear in mind the ATS's warning that a low FEV₁/FVC ratio accompanied by FVC and FEV₁ that are above average, i.e. > 100% of predicted, can occur in healthy individuals (23).

The degree of variability in the FEF_{25-75%} is reflected in the low value of its 5th percentile LLN. Using the 1983 Knudson prediction equations, the 5th percentile LLN for FEF_{25-75%} for a man of

40 years or older is 40.3% of predicted, indicating 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: a) to evaluate a worker's response to treatment in the clinical setting, and b) 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 Figure 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, i.e., 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. Since 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 4-6 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 exists both between workers and within an individual worker. Though the FEV₁ and FVC can be measured precisely during one test session, biological and technical variation over time make an individual's estimated rate of change over time highly variable (61-65). Though within-day variability for a normal subject's FEV₁ and FVC is $\leq 5\%$, year-to-year variability is $\leq 15\%$ (23,62). Technical variability can be minimized by using very precise spirometers, not changing equipment unnecessarily over time, and maintaining a rigorous spirometry quality assurance program; biological 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" (65). 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 measured over 4-11 years of follow-up (66). 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 VC 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" (70).

Since FEV₁ and FVC decline with age from the about the mid-30's on, with some acceleration of the rate as aging advances (67,68), an allowance for the expected loss due to aging should be made before labeling a 15% decline as "significant"(36,70). As Appendix G of the NIOSH Criteria Document (70) 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 x 4.0 L) - (10 years x 0.025 L/year) = 3.15 L]." Such a loss over 10 years would be labeled "significant," and would warrant medical evaluation once the low value was confirmed by a re-test (36,70).

In summary, as shown in [Table 8](#), ACOEM recommends that spirometry should be conducted every 1-2 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 (NFPA) examination protocol, which recommends spirometry testing every 3 years for fire fighters under age 29, every 2 years for ages 30-39, and annually for ages 40 and above (69). Change in FEV₁ and FVC over time should be evaluated as part of a screening program once measurements have been made over at least 4-6 years. A decrease in FEV₁ or FVC of 90-100 ml/ year, over at least 4-6 years, should

trigger further scrutiny of a worker's pulmonary function measurements over time. Loss of 15% or more of the 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 (23,71) and the NHLBI National Asthma Education and Prevention Program (NAEPP) (72) recommend that a pre- to post-bronchodilator increase in FEV₁ should be at least 12% of initial FEV₁ and at least 0.2 liters to be called significant, i.e. a bronchodilator response that is suggestive of airways hyperreactivity (Table 8). The Global Initiative on Asthma (GINA) (73) and the NHLBI Lung Health Study (74) regarded a 15% increase in FEV₁ as significant.

Attention should be limited to changes in the FEV₁ because interpreting changes in the FVC or FEF_{25-75%} is likely to be complicated by varying lengths of expiration recorded before or after the bronchodilator (23). If changes in the FVC are examined, the ATS recommends that a change of at least 15% of initial FVC be considered significant, i.e. suggestive of airway reactivity. The ATS does not endorse interpretation of pre- to post-bronchodilator changes in the FEF_{25-75%} (23).

Based on these sources, ACOEM recommends that a pre- to post-bronchodilator increase in FEV₁ should be at least 12% of initial FEV₁ and at least 0.2 liters to be considered significant, i.e., 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 ATS (10) and AMA (9) that impairment determinations should utilize 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 work day to capture any delayed work-related declines in function. The spirometry measurements most commonly examined are the FEV₁ and the Peak Expiratory Flow Rate (PEF or PEFR), though 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 it is confirmed within a month (28). In 1986, a drop in FEV₁ of 5% or 0.15 L, whichever is greater, was labeled as significant, if it is confirmed on a second occasion (60). An FEV₁ decrease of 10% would be considered significant if only one pre- to post- shift study was performed (60,75).

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 (42,43). 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-shift and post-shift tests. Usually the BTPS correction factor is selected based on the spirometer temperature, and not the temperature of the accumulated exhaled gas one 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 (43).

Based on the sources described above, ACOEM recommends that a single pre- to post-shift study finding a decline in FEV₁ of at least 10% is significant and worthy of follow-up. In addition, an across-shift decline in FEV₁ of at least 5% or 0.2 L, whichever is greater, that is confirmed on a second occasion, should be reviewed and followed up. However, when only a few shifts are monitored, declines in FEV₁ of about 5% must be interpreted cautiously since this amount of variation can be seen within a day in normal subjects (23).

Unlike the other spirometry evaluations discussed in this position paper, serial PEF monitoring currently is used not as a screening test, but rather to confirm suspected associations between a worker's respiratory symptoms and exposures on the job, and to identify potential triggering exposures. Monitoring PEF in relation to work exposures and respiratory symptoms is more complex than examining pre- to post-shift changes in FEV₁ because of the PEF's variability and effort-dependence; a long time period and many measurements made during periods of work exposure and periods away from work are needed to document patterns of PEF (76). Although there is no uniformly accepted protocol, comparable to the 1994 ATS Spirometry Update, for conducting and evaluating serial PEF measurements in relation to workplace exposure, the protocols recommended by the American College of Chest Physicians Consensus statement (77), the NAEPP (72), the European Respiratory Society (78), and the Subcommittee on Occupational Allergy of the European Academy of Allergology and Clinical Immunology (79,80) generally agree that: a) every two hours, or at least four times each day, three PEF measurements should be made and the highest of the three analyzed, with one measurement made on first awaking and another made close to the midpoint of the waking day to capture the worker's lowest and highest PEFs (81-84); and b) if possible, workers should be monitored for at least two weeks at work and two weekends to 10 days away from work, as needed, to identify or exclude work-related

changes in PEF (72,77-79). Interpretation of PEF measurements can be confounded by use of bronchodilator or steroid medications and by the normal diurnal variation in airway caliber, which produces lower flow rates upon awaking and higher flow rates 6-8 hours later. This normal pattern can mask the workplace-related decrement of an immediate reaction in a day worker (85).

PEF measurements can be evaluated by calculating their daily variability, with a mean diurnal variation of 20% or more probably indicating asthma (72,77,79,81). A more sensitive, specific, and certainly more difficult technique is to visually inspect graphs of the maximum, mean, and minimum daily PEFs. These graphs, when examined by experienced interpreters, can be used to investigate patterns of expiratory flow rates during workplace exposures and during the time away from work (72,76-78).

Major factors can interfere with interpreting serial PEF measurements: a) reliance on self-reporting by the monitored worker, requiring the worker's motivation and honesty - though development of electronic peak flow meters that store measurements, symptoms, and medication information may improve compliance (72,76,78); b) occurrence of intermittent exposure to suspect agents in the workplace; c) delay in making the first PEF measurement after waking on days away from work; and d) use of more than one PEF meter (72,76). The 1994 ATS Update provides specifications for the accuracy and precision of peak flow monitoring devices (22), and peak flow meters have been evaluated (86). However, visual interpretation of PEF patterns over time requires experience, and work is ongoing to quantify the qualitative judgments that are made (76,78).

Summary

This position paper reviews several aspects of spirometric testing in the workplace, where spirometry is employed in the primary, secondary, and tertiary prevention of occupational lung disease. Primary prevention includes pre-placement and fitness-for-duty examinations as well as research and monitoring of health status in groups of exposed workers; secondary prevention includes periodic medical screening of individual workers for early effects of exposure to known occupational hazards; and tertiary prevention includes clinical evaluation and impairment/disability assessment.

For all of these purposes, valid spirometry measurements are critical, requiring: documented spirometer accuracy and precision, a rigorous and standardized testing technique, standardized measurement of pulmonary function values from the spirogram, adequate initial and refresher training of spirometry technicians, and ideally, quality assessment of samples of spirograms.

Interpretation of spirometric results usually includes comparison with predicted values and should also evaluate changes in lung function over time. Response to inhaled bronchodilators and changes in relation to workplace exposure may also be assessed. Each of these interpretations should begin with an assessment of test quality and, based on the most recent ATS recommendations, should rely on a few reproducible indices of pulmonary function (FEV_1 ,

FVC, and FEV₁/FVC.) The use of forced expiratory flow rates, e.g., the FEF_{25-75%}, in interpreting results for individuals is strongly discouraged except when confirming borderline airways obstruction. And finally, use of serial PEF measurements is emerging as a method for confirming associations between reduced or variable pulmonary function and workplace exposures in the diagnosis of occupational asthma.

Throughout the statement, ACOEM makes detailed recommendations to ensure that each of these areas of test performance and interpretation follows current recommendations/standards in the pulmonary and regulatory fields.

Acknowledgment: The authors would like to thank Drs. John L. Hankinson and Robert O. Crapo for their many helpful suggestions and comments on this position paper. In addition, we want to thank other members of the American Thoracic Society, who shared their views and insights as this position paper was developed.

Appendix A

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. That curve which gives the largest sum of FEV₁ and FVC. The best curve is used in the calculation of the FEF_{25-75%} 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 three liter syringe. The instrument should maintain an accuracy of 3% of the reading. Additional checks include checking for leaks (daily for volume spirometers), 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 one second long is noted on the volume-time tracing

Extrapolated volume. That 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 FVC 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 second (FEV₆). Volume of air exhaled during the first six seconds of the FVC. Since 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 where 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 (FEF_{25-75%}). 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 liters 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 where the best FVC and the best FEV₁ are reproduced within 0.2 L.

Volume-measuring spirometer. Spirometers which 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.

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ACOEM Position Paper Spirometry in the Occupational Setting

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**TABLE 1. ACOEM Position Paper
Spirometry in the Occupational Setting**

- 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
-

TABLE 2. TYPES OF SPIROMETERS

1. Volumetric Spirometers:

- Accumulate and directly measure exhaled air volume as a function of time;
- Examples are water-sealed, dry rolling seal, and bellows spirometers;
- Provide direct volume-time tracing;
- In general, are precise, simple to operate, and easy to maintain;
- May be slightly unwieldy due to size and weight.

2. Flow-Type spirometers:

- Indirectly measure airflow during exhalation; integrate the flows to obtain expired volume;
 - Examples are pneumotachometer, turbine, hot wire anemometer spirometers;
 - Large range of flows are measured during a forced expiration: Flow sensors may perform better at high flow rates (early in maneuver) than at low flow rates (end of maneuver);
 - Often more variable (less precise) than volumetric spirometers;
 - Integrity of sensors must be maintained for accurate spirometry measurements - if sensor is damaged, blocked, or has moisture condensation or obstruction by mucus, test results may be erroneous;
 - Malfunctions in sensors, transducers, and electronics can go unnoticed - users must be alert for anomalous results;
 - Lightweight and portable.
-

TABLE 3. EQUIPMENT PERFORMANCE RECOMMENDATIONS

1. For volumetric and flow-type spirometers, American Thoracic Society (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 insure 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 National Lung Health Education Program (NLHEP) testing procedures and "office spirometers" are not acceptable for diagnostic spirometry or for occupational screening, surveillance, and impairment evaluations.

TABLE 4 - SPIROMETRY TESTING TECHNIQUE

- Test at ambient temperatures 17 - 40 °C, with spirometer ≥ 23 °C, if possible;
 - Technician describes and *demonstrates* the test, and enthusiastically coaches the subject;
 - "Acceptable" maneuvers have good starts, are free from artifacts, and have satisfactory exhalations:
 - a) exhale with hard fast "blast" of air, with little air leaked out before the blast;
 - b) exhale smoothly, no cough or glottis closure in the first second, and no leak, obstruction of the mouthpiece, or variable effort; and
 - c) exhale completely, for at least 6-10 sec and/or until an FVC plateau is recorded for one sec, unless subject must stop due to discomfort, airways obstruction, or old age;
 - Testing *goal*: Record at least 3 acceptable curves, with up to 8 attempts if necessary; and achieve reproducibility of 0.20 L for both the FVC and the FEV₁;
 - Test results can be interpreted even if they fail to meet testing goal (impaired subjects may have trouble); note that such results probably *underestimate* subject's true pulmonary function;
 - Obtain electronic or hard copies of tests to check "acceptability":
 - Check end of test using volume-time curves: FVC plateau and length of expiration;
 - Check start of test using flow-volume curves: flow rate should rise immediately to sharp peak;
 - As noted earlier, ACOEM strongly recommends that hard copies and/or electronic copies of complete spirometry test sessions.
-

TABLE 5. MEASUREMENT OF RESULTS AND TECHNICIAN TRAINING

Measurement of Results

- Report largest FVC, 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.
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Figure 1. Volume-Time Curve



Figure 2. Flow-Volume Curve
