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Workplace spirometry monitoring for respiratory disease prevention: a methods review

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SUMMARY

This report reviews methods applicable in workplace spirometry monitoring for the identification of individuals with excessive lung function decline. Specific issues addressed include 1) maintaining longitudinal spirometry data precision at an acceptable level so that declines due to adverse physiological processes in the lung can be readily detected in an individual; 2) applying interpretative strategies that have a high likelihood of identifying workers at risk of developing lung function impairment; and 3) enhancing effectiveness of spirometry monitoring for intervention and disease prevention. Applications in ongoing computerized spirometry monitoring programs are described that demonstrate approaches to improving spirometry data precision and quality, and facilitating informed decision-making on disease prevention.

KEY WORDS: spirometry; spirometry monitoring; periodic spirometry; chronic obstructive pulmonary disease; medical screening

WORKPLACE INTEGRATED HEALTH, safety and productivity management programs are increasingly identified as important components for reducing a company's workforce health-related costs.[1,2] With escalating health care costs, the expenses related to medical benefits for employees and loss of productivity due to illness or injury are increasing.[2] Chronic obstructive pulmonary disease (COPD) is a preventable disease characterized by airflow limitation that is usually progressive and not fully reversible.[3,4] COPD is an important cause of morbidity and mortality in the United States population,[3–5] and is especially prevalent among blue collar workers, where tobacco smoking, occupational exposure and socio-economic status often contribute to increased risk of disease.[6] In occupational settings with respiratory hazards, the prevention of the development of respiratory disease, including COPD, is important for both the company's and the individual's health-related expenses.[7]

Occupational exposure contributes significantly to the population burden of COPD,[6,8,9] and can lead to impaired lung function as well as its excessive rate of decline,[10–12] both significant predictors of increased morbidity and mortality.[5,13,14] Current knowledge of the pathogenesis of COPD indicates that chronic inhalation of toxic particles and gases can lead to progressive tissue injury via a cascade of inflammatory processes in the lung.[15] Once initiated, the inflammatory processes and the associated tissue destruction often persist after exposure ceases in susceptible individuals.[15] Intervention early on in the disease process helps to prevent the establishment and progression of the self-perpetuating disease process that leads to an increased risk of COPD and cardiovascular disease.[16,17]

Workplace health monitoring using periodic spirometry has been recommended as a tool for prevention of respiratory disease.[18–24] Workplace spirometry monitoring can potentially provide a valuable tool for early recognition and prevention of the development of respiratory disease through interventions in excessive lung function decline. In practice, this potential is often under-utilized, primarily because interventions for airways respiratory disease prevention are not mandatory.[25,26] The current focus on workplace disease prevention and management may lead to more effective utilization of workplace spirometry-based medical monitoring for respiratory disease prevention.[1]

This report reviews the methods applicable to spirometry monitoring, focusing on the identification of individuals who are experiencing excessive decline in lung function. Specific issues addressed include 1) maintaining longitudinal spirometry measurement precision at an acceptable level to detect biologically significant declines due to adverse physiological processes in the lung in an individual; 2) applying interpretative strategies that have a high likelihood of identifying

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workers at risk of developing lung function impairment; and 3) enhancing effectiveness of spirometry monitoring for intervention and disease prevention. To facilitate the practical application of these methods, a computerized approach to periodic spirometry data management and evaluation is also described.[27]

This report is organized into the following sections: 1) epidemiology of lung function decline; 2) estimating the rate of lung function decline in individuals; 3) identifying individuals with excessive declines in forced expiratory volume in one second (FEV_1) using the limit of longitudinal decline (LLD) in the early years of follow-up;[22,23,28,29] 4) maintaining acceptable precision and quality of spirometry data; 5) interpretation and decision-making for prevention; and 6) optimization of the frequency of spirometry testing.

EPIDEMIOLOGY OF DECLINE IN LUNG FUNCTION

Measurements of forced vital capacity (FVC) and FEV_1 are recommended for the diagnosis of COPD[3,4] and other work-related respiratory diseases. Of the spirometry volumes, the FEV_1 is the most reproducible and best suited for measuring longitudinal (over time) changes in lung function due to obstructive or restrictive impairment.[30]

Longitudinal change of lung function

The life cycle of lung function change has been described as consisting of three phases: growth to adulthood, a possible plateau and an age-related decline.[30–32] Based on this model, at least three factors determine lung function at a specific point in adult life: the maximal attained level of lung function, the age of onset of decline and the rate of decline. Figure 1 shows longitudinal reference curves for FEV_1 and FVC derived from asymptomatic non-smokers aged 5–95 years selected from a population-based longitudinal study.[33] Four age-related periods corresponding to growth, growth spurt, decreased rate of growth and decline in lung function were estimated. For FEV_1, these periods for males were respectively at ages 0–12.3, 12.4–17.4, 17.5–25.8 and ⩾25.9 years, and for females at ages 0–9.5, 9.6–15.5, 15.6–27.4 and ⩾27.5 years. The estimated mean decline in FEV_1 was linear with age, at a rate of 27 ml/year for males and 26 ml/year for females.

Risk factors for accelerated decline in lung function

Important risk factors for excessive FEV_1 decline in worker populations include tobacco smoking, occupational exposure, pre-existing lung disease (e.g., asthma, tuberculosis, pneumonia) and abdominal fat deposition.

Several seminal longitudinal studies provide evidence of the potential magnitude of occupational effects on lung function decline. In a 12-year follow-up study of French factory workers initiated in 1960, the adjusted mean rate of FEV_1 decline was estimated as 44 ml/year in workers without hazardous occupational exposure, whereas mean rates of about 60 ml/year were observed in workers exposed to mineral and organic dusts.[34] Large longitudinal studies of miners provide the most comprehensive evidence on risk factors for increased rate of lung function decline. The following factors were identified: tobacco smoking, cumulative coal dust exposure,[35,36] bronchial responsiveness,[37] childhood pneumonia, childhood passive smoking and certain work practices.[38] Furthermore, FEV_1 decline above 60 ml/year was associated with early retirement from coal mining, and increased morbidity and mortality from cardiovascular disease and non-malignant respiratory disease.[13,14] Another well-studied exposure is cotton dust. The mean rate of FEV_1 decline was higher than expected in Yugoslavian female (59 ± 9 ml/year) and male cotton dust-exposed workers (68 ± 6 ml/year);[39] in US cotton workers, the excess rate ranged between 9 and 28 ml/year.[40] Recent longitudinal studies demonstrated excessive decline associated with occupational exposure in Norwegian tunnel workers,[41,42] US steelworkers,[43] paper and pulp mill workers[44] and individuals exposed to fumes.[45] There are also documented examples of spirometry monitoring coupled with intervention successes, where excess decline in FEV_1 and FVC associated with workplace exposure among firefighters and grain workers has been mitigated after the introduction of respiratory protection and exposure control.[46,47]

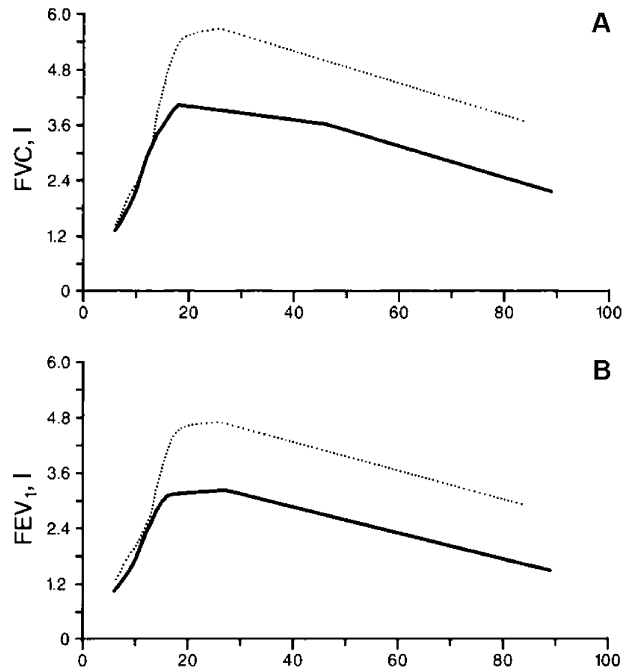

Figure 1 Lung function change with age predicted from longitudinal reference equations estimated for FVC (**A**) and FEV_1 (**B**) on healthy never smokers of average height, for females and males. Source: Sherrill et al.[33] Solid line = females; dashed line = males; FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 second.

Tobacco smoking is the most important risk factor for the development of obstructive airway disease. Compared to non-smokers, smokers have an increased rate of FEV_1 decline, and an accelerated decline increases the risk of developing COPD.[48] Longitudinal studies of middle-aged smokers with mild COPD established that only complete smoking cessation leads to attenuation in the rate of decline in FEV_1.[16,17] However, the pathological processes initiated as a result of inhalant-related lung injury can continue after exposure ceases in susceptible individuals.[15] Although not all smokers go on to develop severe COPD, reduced lung function and increased rate of decline are proportionally related to increased mortality rates; thus, any excessive loss of lung function is undesirable.[5,13,14,17] Because tobacco smoking can potentiate the effect of occupational exposure, prevention of smoking is particularly important in hazardous exposures.[49,50]

Abdominal adiposity also adversely impacts on the rate of lung function decline.[51]A longitudinal study of middle-aged Irish men showed an excess rate of decline in FEV_1 of 2.9 ml/year per unit increase in body mass index over 10 years ($P < 0.001$).[52] In a cross-sectional study, an increase in waist circumference of 1 cm was associated on average with a 13 ml reduction in FEV_1 and an 11 ml reduction in FVC.[53] In addition to the mechanical effects of body fat on ventilation, inflammation associated with central adiposity may also lead to reduced lung function and cardiovascular and all-cause mortality.[54]

ESTIMATING RATE OF LUNG FUNCTION DECLINE IN INDIVIDUALS

Among healthy adult never-smokers, the expected rate of decline in FEV_1 averages 20–30 ml/year.[30,33] However, because of the inherent variability in repeated spirometry measurements, 5–8 years of follow-up are generally required to estimate the rate of FEV_1 decline reliably.[55–57] It is nevertheless important, during the early years of spirometry monitoring, to determine whether the decline is within a normal limit based on the expected FEV_1 within-person variability. For that purpose, the LLD has been proposed.[22,23,28,29] This section outlines methods for estimating an individual's rate of lung function decline and variability, while the next section describes the proposed LLDs.

Estimating the rate of decline and within-person variation in FEV_1

For an individual, longitudinal FEV_1 measurements fluctuate around 'true' age-related values. For an adult individual with a sufficient spirometry follow-up, the linear regression model can be applied for predicting FEV_1 in relation to age as follows:[58]

$$FEV_1 = a + b\,(\text{age} - 25) + e \qquad (1)$$

for an age range of 25–65 years.[33] In this model, the parameter a represents the FEV_1 value at 25 years of age, b represents the rate of decline in FEV_1 with age and e is an error term that represents the deviation of the observed FEV_1 value from the predicted value at a specific age. The basic assumptions of the model are that the decline in lung function is linear and the error terms are normally distributed with a mean of zero and a variance, termed the within-person variance, σ^2_w.[58] The linear model provides a good approximation of longitudinal FEV_1 values in healthy non-smokers aged 25–65 years.[33] In smokers, lung disease or abdominal obesity, the rate of FEV_1 decline can escalate at a specific period of life (e.g., in emphysema after 40 years of age with increased elastic tissue degradation),[48] then the linear model may not fit well to data collected over a long period (e.g., $\geqslant$8 years) and a model with a quadratic age term provides a better fit. Also, monitoring the rate of decline over 8-year segments of follow-up time provides a visual means of detecting an accelerated rate of decline.[27]

Sources of the within-person FEV_1 variation can be categorized as those due to variability in measurement procedures (i.e., spirometer-, subject- or technician-procedural variability), those due to a person's innate fluctuation in lung function, and those due to response to environmental inhalants.[55–57] To distinguish the signal from the noise, it is important to minimize the measurement error.

Precision of the estimated rate of decline

The variability of longitudinal FEV_1 measurements around the predicted values determines the precision of the estimated rate of decline b, which is measured by its standard error, SE(b). The magnitude of SE(b) depends on the duration of the follow-up time t, the within-person standard deviation σ_w and the number of equally spaced (in practice, the tests do not need to be equally spaced, see below) repeated P measurements performed during follow-up, as follows:[59,60]

$$\text{SE}(b) = \sigma_w\sqrt{12(P-1)}/t\sqrt{P(P+1)}. \qquad (2)$$

The 95% confidence limit (CL) for the person's rate of decline b is then calculated as $b \pm 1.96$ SE(b). Accordingly, the one-sided upper 95%CL (95%UCL) for the upper rate of decline is then defined as follows:

$$95\%\ \text{UCL} = b + 1.645\ \text{SE}(b). \qquad (3)$$

Follow-up needed to estimate the 'true' rate of decline

Using the relationship in equation 2, it can be shown why it takes at least 5–8 years of follow-up to estimate an individual's rate of FEV_1 decline with acceptable level of reliability in prospectively collected spirometry data. Figure 2 (absolute) shows the size of SE(b) in ml relation to the duration of follow-up for three individuals whose inherent FEV_1 within-person variation σ_w

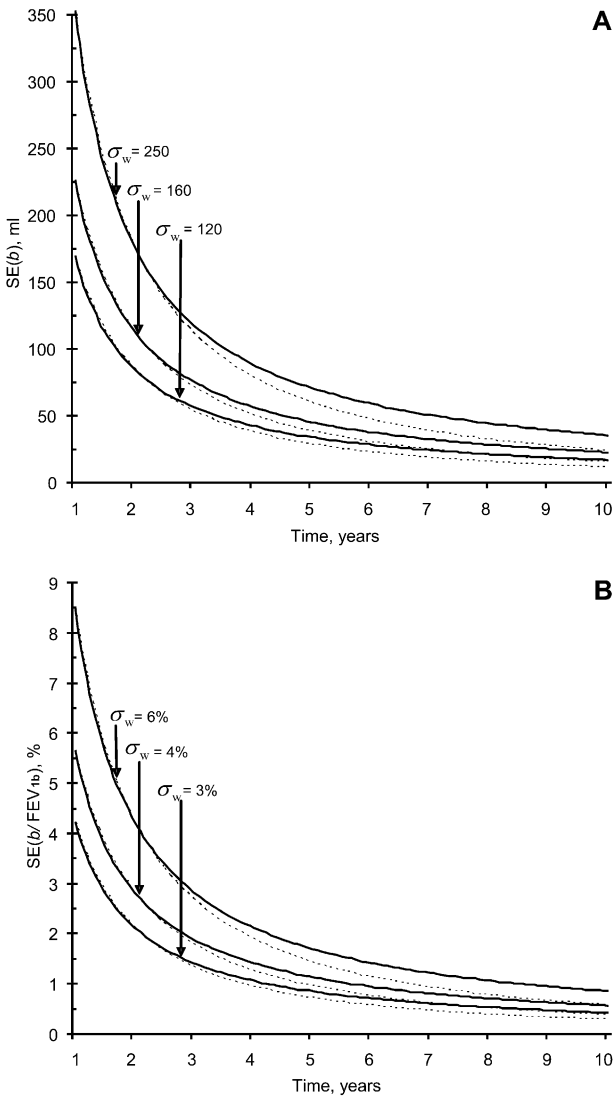

Figure 2 Change in the absolute SE(b) (**A**) and relative SE(b/FEV_{1b}) (**B**) with duration of follow-up, for three individuals with different within-person variation. Solid line = estimates based on two measurements (baseline and at time t); dashed line = estimates based on annual measurements; SE = standard error; FEV_1 = forced expiratory volume in 1 second.

ranges from a small value of 120 ml to a large value of 250 ml and whose mean FEV_1 is 4000 ml. Initially, the SE(b) is large, but it changes little after about 5–8 years of follow-up, depending on the size of the within-person variation. As both the decline and the within-person variation are related to the size of the FEV_1, it is useful to express the rate of decline and SE(b) as a percentage of the baseline FEV_1 (FEV_{1b}).[29] The corresponding relative SE(b/FEV_1) for a baseline FEV_1 of 4000 ml and comparable relative within-person variation σ_w of 3%, 4% and 6% is shown in Figure 2 (relative). It follows from Figure 2 that only relatively large declines can be identified as exceeding the 95%UCL during the initial years.

Figure 2 also demonstrates that increasing the number of measurements from $P = 2$ (i.e., two measurements, one at baseline and one at follow-up time t; see solid line) to P = years of follow-up + 1 (i.e., annual measurements, see dotted line) does not substantially affect the shape of the SE(b) or SE(b/FEV_1) curves during the first 3 years. The period between tests can thus be extended up to 3 years without much loss of precision. However, to maintain precise spirometry data, i.e., to minimize the measurement error and to identify excessive declines as soon as possible, annual measurements are preferable.

IDENTIFYING EXCESSIVE DECLINE OR VARIABILITY USING THE LIMIT OF LONGITUDINAL DECLINE

As the estimated rate of decline may be imprecise during the early (1–7) years of follow-up, it is important during this early period to identify individuals whose lung function decline is excessive using a 'normal' limit based on the expected within-person FEV_1 variability. Such a limit assists in identifying individuals who may have excessive FEV_1 decline or excessive variability, and in maintaining precise spirometry data so that the former function can be accomplished. Four limits have been proposed for the above purpose.

Proposed limits of longitudinal decline

The American Thoracic Society limit

The American Thoracic Society (ATS) considers that for an individual, a decline of 15% in 1 year is clinically meaningful.[61] The ATS annual limit of 15%, when interpreted in terms of the LLD_r parameters (equation 3), assumes an average within-person variation of about 6% (Figure 2, relative). This magnitude of mean within-person variation has been observed in a study of individuals with early COPD, where the spirometry quality was high.[16,29] The ATS limit therefore appears to be appropriate when interpreting high quality spirometry in individuals with early COPD, many of whom have increased variability potentially related to bronchial hyperreactivity.[29] The advantage of this limit is its simplicity. However, evaluating annual declines using the ATS limit of 15% has a low sensitivity for detecting chronic or acute adverse health effects among working populations.[28]

The American College of Occupational and Environmental Medicine proposed limit

Based on the ATS recommended limit of 15%, the American College of Occupational and Environmental Medicine (ACOEM) recommends that the observed FEV_1 should not decline from baseline FEV_1 below a critical level of FEV_1, calculated as follows:[22,23]

$$FEV_1 = FEV_{1b}(1 - 0.15) - (\text{predicted } FEV_{1b} - \text{predicted } FEV_1). \quad (4)$$

This limit is intended for longitudinal evaluation over several years, and is thus better suited than the ATS

limit for monitoring working populations, primarily because the precision of the estimated rate of decline increases with increasing duration of follow-up. However, the limit also assumes a relatively large relative within-person variation of 6% (Figure 2). In a relatively healthy workforce, the limit is thus less useful for maintaining acceptable data precision than a limit that has the flexibility to reflect an existing or desirable longitudinal data variability. This can result in a lower sensitivity for predicting disease processes in the lung.[28,29]

Limits of longitudinal decline that reflect variability in the longitudinal spirometry

Alternatively, a monitoring program can develop absolute or relative limits that reflect existing or desirable longitudinal data variability. Such limits have more flexibility for maintaining data precision at an acceptable level so as to maximize the likelihood of detecting signals due to pathological changes.

Using the statistical framework described above (equation 3), the absolute limit of longitudinal decline (LLD_a) from baseline to time t can be calculated as follows:[28,29]

$$LLD_a = t[b + 1.645 \times SE(b)], \quad (5)$$

where b is the expected rate of decline (e.g., 30 ml/year)[33] and the $SE(b)$ is obtained from equation 2 by substituting a program's average within-person variation for σ_w. The program's average within-person variation can be derived from the program data (see below); alternatively, published values can be used.[29,62,63]

To adjust for demographic characteristics that affect the average magnitude of the within-person variation in a group of workers (for example, males have a larger average within-person FEV_1 variation than females), a relative limit of longitudinal decline (LLD_r), which standardizes for baseline FEV_1 value, has been proposed as:[29]

$$LLD_r = t[b/FEV_{1b} + 1.645 \times SE(b/FEV_{1b})]. \quad (6)$$

When interpreting longitudinal spirometry data using the limits of longitudinal decline, the observed FEV_1 should not decline below a critical level of FEV_1, which is calculated using LLD_a or LLD_r as follows:

$$FEV_1 = FEV_{1b} - LLD_a, \text{ or} \quad (7)$$

$$FEV_1 = FEV_{1b}\,(1 - LLD_r) \quad (8)$$

Figure 3 shows an example of a real individual whose decline was identified as being excessive by the relative limit LLD_r, but not by the ACOEM limit.

Studies of data from workplace monitoring programs[28,29,60,62,63] indicate that a mean relative within-person variation of 4% is attainable when ATS/ERS (European Respiratory Society) standards[64] are adhered to and desirable for effective use of the spirometry data in prevention.

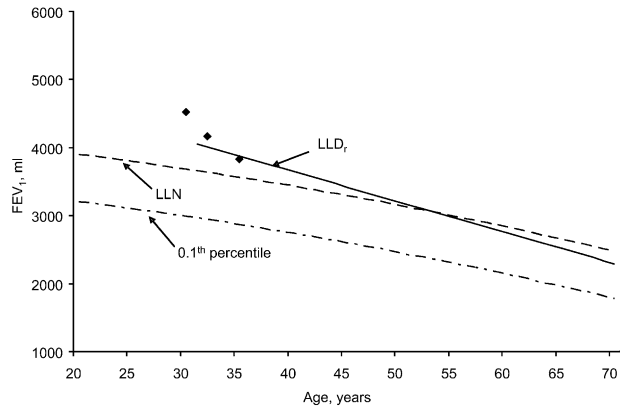

Figure 3 Longitudinal FEV_1 measurements (◆) interpreted in relation to the LLD_r based on program's average within-person variation of 4%, the cross-sectional LLN, and the 0.1 percentile (≈ 60% predicted). FEV_1 = forced expiratory volume in 1 second; LLD_r = relative limit of longitudinal decline; LLN = lower limit of normal.

Detectable excess rates of FEV_1 decline

As individuals' or programs' within-person variations are often unknown in prospectively collected data, two referent limits are suggested to determine the critical rates of decline (%/year) over the first 1–7 years of follow-up. Figure 4 provides a quick reference on the per cent rates of decline (%/year; i.e., LLD_r) that may be considered excessive depending on an individual's or group's relative within person-variation and duration of follow-up (see equation 6). The vertical lines in Figure 4 demonstrate the two suggested limits. For an average within-person variation of 4%, the critical

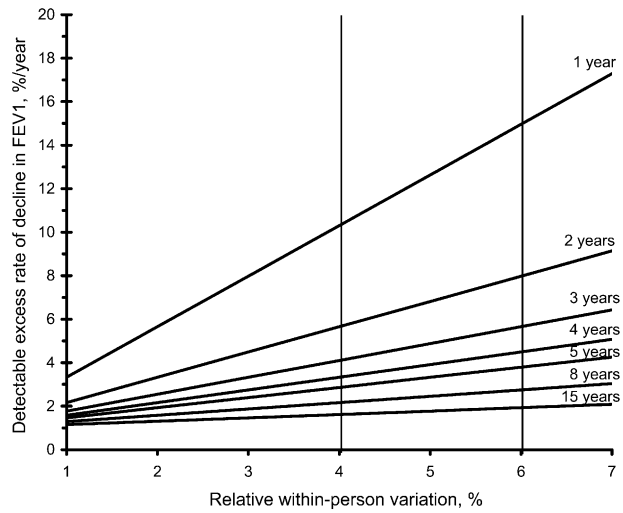

Figure 4 Detectable excess rate of decline in FEV_1 (%/year) by relative within-person variation and duration of follow-up (1–15 years). Indicated are two recommended limits (two vertical lines) based on monitoring programs with good data quality (within-person variation of 4%) and by the ACOEM (within-person variation of 6%). FEV_1 = forced expiratory volume in 1 second; ACOEM = American College of Occupational and Environmental Medicine.

rates of decline/year are respectively ≈10%, 6%, 4%, 3.5%, and 3%, for a follow-up of 1 to 5 years. A limit based on a relative within-person variation of 6%, as recommended by ACOEM,[22,23] corresponds to critical rates of decline/year of respectively ≈15%, 8%, 6%, 4.5%, and 4%.

Because of the pivotal role of baseline observation(s) in the evaluation of longitudinal changes over time, it is important to obtain accurate initial spirometry. To achieve this, it may be helpful to retest employees on several occasions within the first 3 years of employment.

MAINTAINING PRECISION AND QUALITY OF SPIROMETRY DATA

The following steps should help to minimize FEV_1 measurement variability arising from procedural measurement errors: 1) applying good quality control for individual tests and following the ATS/ERS guidelines;[64] 2) monitoring the spirometry quality grades assigned by a spirometer for each testing session,[65] by individual technicians; 3) monitoring of longitudinal data precision in individuals; and 4) monitoring of the overall longitudinal data precision in the spirometry program. Computer-based approaches can automate steps 2 to 4.[27]

Quality control for individual tests

Adherence to professional guidelines developed for performance of spirometry[64] and using computerized assessment of test quality[65] help to minimize biological and technical sources of variation. Each monitoring program should document quality control procedures, as well as technician training.[66] Central quality control monitoring and feedback to technicians on their performance is helpful.

Monitoring quality grades by spirometry technician

Some spirometry systems provide quality grades for each testing session.[65] Monitoring of the percentage of tests that did not meet the ATS/ERS criteria of acceptability and repeatability for FVC and FEV_1, by a technician, helps to identify technicians who may need further training.[27]

Monitoring FEV_1 data precision in an individual

Plotting and evaluating each individual's longitudinal FEV_1 data against age, and with respect to the longitudinal and cross-sectional limits, facilitates identification of excessive FEV_1 decline or variability (Figure 3). During the initial years, when the individuals' within-person variation is unknown, the limit of longitudinal decline identifies individuals who may have either excessive variability or excessive decline. Appraisal of spirometry data quality and short-term retesting of these individuals helps to increase the precision of the estimated rate of decline.[22,23]

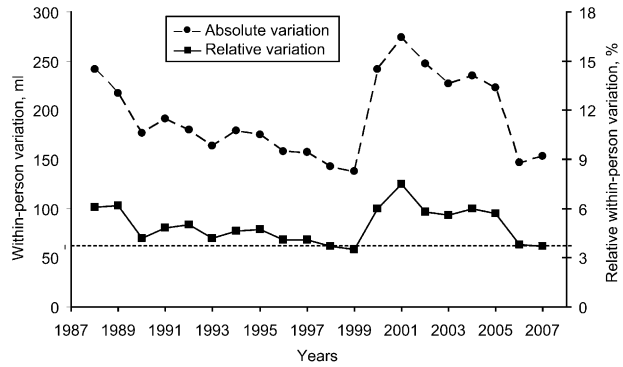

Figure 5 The absolute and relative pair-wise within-person person variation values plotted by year for a real ongoing monitoring program. Time-related increase in longitudinal data variability from the year 2000 and subsequent improvement following an intervention in 2005.

Monitoring of longitudinal data precision in a program

The precision of the spirometry program's longitudinal FEV_1 data can be monitored retrospectively and prospectively on an annual basis using the pair-wise within-person variation (absolute, s_p or relative, s_r).[27–29] These statistics can easily be calculated using the average annual within-person difference in FEV_1 measurements in a group. The average pair-wise within-person variation calculated over all years of follow-up can be used to derive the program-specific LLD_a or LLD_r. When the testing interval is >1 year, a small random sample of individuals (≈30–50) can be retested throughout the following year for monitoring data precision.

A computerized approach, as used for example by the Spirometry Longitudinal Data Analysis (SPIROLA) software (National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Atlanta, GA, USA),[27] facilitates ongoing monitoring of data quality and longitudinal data precision. Figure 5 shows an example of the annual pair-wise within-person variation values for an ongoing monitoring program of ≈4000 firefighters. Note the increase in data variability from the year 2000, mainly due to an introduction of a new spirometer and related procedural errors. The initiation of monitoring of data precision using SPIROLA software in 2004 led to an intervention on test quality (training, replacement of a spirometer and central quality control) in 2005 and subsequent improvement in data variability. Monitoring of the s_p or s_r statistics can thus help to identify and remove extraneous sources of variation as soon as these arise.

INTERPRETATION AND DECISION-MAKING FOR PREVENTION

Each individual's spirometry data needs to be interpreted by a qualified health care professional familiar

with the ATS/ERS guidelines. Interpretation of longitudinal spirometry usually involves 1) evaluation of the current level of lung function against cross-sectional reference criteria, 2) evaluation of the FEV_1 decline, and 3) evaluation of the FEV_1 data variability. A computerized approach to data evaluation facilitates a more comprehensive evaluation of longitudinal data by monitoring the ongoing performance of the spirometry technicians and the longitudinal data precision, which may help to explain some changes in the individuals' longitudinal data.

Interpretation of the level of lung function

If a spirometry test meets the criteria for acceptability and repeatability,[64] the next determination traditionally involves comparing the observed spirometry measurements (i.e., FEV_1, FVC, FEV_1/FVC ratio) with the predicted values derived from appropriate reference equations.[21,67] If a value falls below the lower limit of normal (LLN), which typically represents the 5th percentile for a healthy unexposed population, the probability that the observed value is normal is $<5\%$. The per cent predicted values can then be used to determine the severity of impairment.

Interpretation of decline in FEV_1

Repeated testing over time is especially helpful in 1) confirming an abnormal lung function level in an individual and determining whether that individual may progress to more severe impairment; and 2) identifying individuals whose level of lung function remains in the normal range, but who have excessive declines that over time may lead to severe impairment. During the early years of follow-up, if the current FEV_1 measurement falls below the critical FEV_1 value determined by the limit of longitudinal decline, LLD (Figure 3), spirometry quality should be reviewed and retesting performed within an appropriate period. This provision helps to maintain longitudinal data precision at a predetermined level set by the LLD criteria.

The percentage rates of decline (%/year) that may be considered excessive are shown in Figure 4, and depend on the individual's relative within-person variation and the duration of follow-up. As individual within-person variation is usually unknown in prospectively collected data, two referent limits based on within-person variations of 4% and 6% (solid vertical lines) can be applied depending on the expected data precision and needs of the program. A simplified approach based on Figure 4 can also be adopted. For example, the per cent FEV_1 declines that can be considered excessive are 10% for the first year, plus an additional 2%, approximately, for each additional year. These longitudinal limits should be used only for the first 1–7 years of follow-up; after that some individuals identified as showing excessive declines may actually be normal.

In those with $\geqslant 8$ years of follow-up, the estimated rate of decline and the current level of lung function both determine the risk of developing lung function impairment and at what age. Also, if the rate of decline exceeds benchmark values that have been associated with adverse health outcomes (e.g., 60 or 90 ml/year),[13,14] preventive action should be considered. Computerized approaches facilitate more complex data evaluation, considering the lung function level, the rate of decline estimated over segmented follow-up time, and variability, when evaluating the risk of developing important impairment (Figure 3).

Interpretation of FEV_1 variability

In workplace monitoring programs with good data precision, the average relative within-person variation of 4% with 95%CL (1.5%, 7%) is achievable (Figure 5).[29] Then individuals with a relative within-person variation of above 7% have a probability of only about 2.5% of being normal, and explanations for the excessive variability (e.g., bronchitis, bronchospasm, excessive exposures to irritants, etc.) should be sought.

Decision making

When quality control criteria are satisfied, and the test repeated if needed, individuals identified with abnormal lung function, excessive decline or excessive variability should be evaluated by a physician for consideration of further clinical diagnostic studies depending on the severity of impairment, more frequent monitoring and interventions on potential risk factors.

Preventive measures

Worker education and increasing awareness of the occupational hazards and the potentiating effect of smoking on respiratory disease, is an important aspect of primary and secondary respiratory disease prevention.[18–22] In secondary prevention, spirometry monitoring provides an opportunity to preserve lung function and improve life expectancy through early intervention on environmental risk factors (e.g., smoking, occupational exposures), lifestyle factors (e.g., weight, nutrition, exercise), and treatment of respiratory conditions (e.g., asthma, chronic bronchitis, tuberculosis). Because of confidentiality issues and the possibility of workplace reprisal, information about the health of individual employees should not be disclosed to employers by the health care provider without a worker's consent. However, aggregated data from medical monitoring programs (presented so that no individual workers can be identified) should be supplied to the employer to enable them to assess the effectiveness of disease prevention and exposure control activities. The data can be periodically examined for jobs, departments, tasks or workgroups with an elevated risk of development of disease; this permits the identification of risk factors that might otherwise go undetected.

OPTIMIZATION OF FREQUENCY OF SPIROMETRY TESTING

In spirometry monitoring, it is very important to establish a good quality baseline lung function measurement, preferably by repeat testing during the first several years of potential exposure, or at first employment. This provides a solid baseline and also helps to detect early responses to occupational exposure.[68] Ideally, yearly spirometry tests should be performed. However, the results in Figure 2 demonstrate that the precision of the estimated slopes will not be greatly affected if the frequency of testing is reduced to every 2–3 years. Thus, when lung function monitoring is performed on a large, stable workforce, where toxicities are well characterized and unlikely to cause severe declines within a short time, and where cost is a limiting factor, the period between tests can be extended up to 3 years. In settings with exposures of unknown toxicity or where excessive declines within short times are recognized,[69] the frequency of measurements should be increased proportionally to the risk.[70] The frequency of individual testing should also be guided by age, duration of exposure and the individual's risk of impairment.

CONCLUSION

Methodologies applicable to spirometry monitoring programs were reviewed, focusing on identification of individuals with excessive decline in lung function. The above methods can be effectively computerized to facilitate automated data evaluation and maintenance of longitudinal data quality and precision at a level required to detect pathological processes in the lung at an early stage. The knowledge of overall precision and quality of the spirometry measurements helps health care professionals in their decision making and ultimately leads to preservation of the respiratory health of the workers.

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RÉSUMÉ

Cet article passe en revue des méthodes applicables dans le suivi spirométrique sur les lieux de travail pour l'identification d'individus dont la fonction pulmonaire décroit de manière excessive. Les problèmes spécifiquement étudiés comportent 1) le maintien de la précision des données longitudinales de spirométrie à un niveau acceptable en sorte que le déclin dû à des processus physiologiques défavorables du poumon puisse être facilement détecté chez un individu ; 2) l'application de stratégies d'intervention ayant une haute probabilité d'identification des travailleurs comportant un risque de développer une limitation de la fonction pulmonaire ; et 3) le renforcement de l'efficience du suivi spirométrique pour l'intervention et la prévention des maladies. Les applications dans les programmes de suivi des spirométries computérisées en cours sont décrites ; elles font ressortir les approches pour l'amélioration de la précision des données de spirométrie et de leur qualité et pour faciliter les prises de décision de prévention des maladies.

RESUMEN

En el presente artículo se examinan los métodos de espirometría que se pueden aplicar en el lugar de trabajo a fin de detectar a las personas con un deterioro excesivo de la función pulmonar. Se analizan aspectos específicos como 1) el mantenimiento de un grado aceptable de precisión de los datos espirométricos longitudinales, de manera que se detecte en forma temprana el deterioro debido a procesos fisiológicos adversos del pulmón; 2) el establecimiento de estrategias de interpretación con gran probabilidad de detectar a los trabajadores con riesgo de sufrir un deterioro de la función pulmonar; y 3) el fortalecimiento de la eficacia del seguimiento espirométrico en las intervenciones y la prevención de las enfermedades. En el artículo se describen aplicaciones de programas informáticos vigentes de seguimiento espirométrico, que ponen en evidencia enfoques que mejoran la precisión y la calidad de los datos y facilitan la toma de decisiones fundamentada, en materia de prevención de las enfermedades.