REVIEW ARTICLE

A guide to spirometry as applied to occupational health

Neil White, Rodney Ehrlich, David Rees

In the context of occupational health, spirometric testing of respiratory function has a number of important applications. These applications can be expected to become more widespread in view of extensive changes to occupational health and compensation legislation in South Africa. Spirometry is an essential component of pre-assignment medical examinations at the commencement of employment; of medical surveillance of workers exposed to hazardous substances so as to intervene when early changes in pulmonary function are detected; of medical evaluation of functional impairment for appropriate job relocation or compensation; and of research. These applications of spirometry each have special considerations which are detailed.

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Spirometry is a widely applied clinical tool. It measures the mechanical properties of the respiratory system in terms of volumes and flow rates during slow or forced expiration or inspiration. Spirometry can make a number of measurements. The two most important are the vital capacity (VC) and forced expiratory volume in 1 second (FEV_1).

Spirometric tests are relatively quick and apparently simple to perform, yet poor test performance and a lack of insight into test interpretation can negate the benefits of using spirometry in the occupational health context. Standardisation of spirometry is therefore necessary for its successful application in different contexts.[1,2] Technical specifications for apparatus, together with standardised methods for performing and interpreting spirometry, have been developed for South Africa so as to accord with accepted practices elsewhere.[3]

The application of spirometry to occupational health is advocated for pre-assignment examinations, monitoring or screening of employees for effects of exposures,[4] research and evaluation of disability/impairment. All of these uses,

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together with the specific issues raised by the selection of reference values for spirometry and interpretive strategies, are the focus of this article. The development of this guide to spirometry follows on debate[5,6] and consultation over a number of years among members of the South African Pulmonology Society, the South African Society for Occupational Medicine, the National Centre for Occupational Health and other members of the academic community.

Sources of variation

All clinical measurements, including pulmonary function tests, are subject to technical influences related to the instrument used and how the test is performed.[7] The interest of clinical medicine is in evaluating the influence of non-technical (i.e. biological) factors on observed differences in measurements in individuals or populations. Effective use of spirometry is aided by an understanding of factors that influence spirometry. The objective of this understanding is to make spirometric measurements that strengthen the *signal*, i.e. the source of variation of interest, and minimise *noise*, essentially all other sources of technical or biological variation. In occupational health, the signal is usually the effect of occupational exposure.

The recognised technical and biological influences resulting in variation in spirometric lung functions have been reviewed elsewhere[7] (Table I). Original documents should be consulted for an in-depth view, since this guide will only detail items of special relevance to the South African context.

Table I. Biological sources of variation in spirometric measurements pertinent to the field of occupational medicine

Variation	Source
Within-subject	Body and neck position Forced expiratory manoeuvres and their influence on lung mechanics Recent exposures and activities Diurnal (circadian) rhythms Weekly, seasonal and year effects Cyclical hormone effects
Between-subject	All of the above Personal characteristics, including gender, size (reflected in standing height, sitting height, weight), age Inherited characteristics, including race and predisposition to develop certain respiratory conditions Past and present illness experiences Past and present exposures Tobacco smoke Occupation Others, such as residence (urban/rural, indoor and community air pollution) Socio-economic factors
Within- and between-population	All of the above Selection factors (exemplified by the 'healthy worker' and 'healthy smoker' effects) into and out of a study population Altitude/geographical region Date of study Other (unidentified)

Adapted from Becklake and White,[7] with permission.

Technical sources of variation

Almost without exception, technical sources of variation constitute noise. Improper performance of the test has long been recognised as the largest source of variability in results.[8,9] Correct test performance is addressed in well-developed guidelines.[2,10,11] Stringency in minimising noise due to technical factors is of key importance in occupational medicine, where a common outcome of interest is the variation in an individual's spirometric measurements carried out on different occasions (e.g. FEV_1 change over a shift, or decrease in FEV_1 per year).

Standardised procedures such as regular instrument calibration and uniform method of test administration can minimise technical sources of variation related to the instrument and the subject. The overall contribution of these sources of variation should be small, estimated at 3%, if good quality control procedures are followed.[1]

Spirometric volumes must always be expressed at a standardised temperature and barometric pressure (37°C, pressure at sea level, saturated with water vapour (BTPS)). When spirometers are used on site in the workplace, where temperatures may rise during the day, incorrect estimations may result if the BTPS correction factors are not changed accordingly.[12] If the temperature rises from 20°C to 32°C volumes will change by 4%. This is particularly important when measurements are made across a work shift, as detailed later. Daily accounting for changes in barometric pressure is of less importance, provided allowance is made for usual barometric pressures at the place of measurement. The usual difference in barometric pressure between Cape Town (760 mmHg) and Johannesburg (640 mmHg) is considerable. The time of day at which a recording is made may also be of importance since individuals' spirometric measurements usually increase from morning to evening as a part of the diurnal rhythm.

Test failure, or the inability of a subject repeatedly to produce measurements that vary by less than 5%, or 100 ml, from one another, may be interpreted as a lack of effort or understanding on the part of the patient or subject.[13] However, there has been increasing evidence that the forced expiratory manoeuvre itself, as well as the maximum inspiration which proceeds it, can induce changes in the lungs' mechanical properties, resulting in airflow limitation in some subjects. In other words, the manoeuvre itself can induce changes in a subject and test failure may represent signal (hyper-responsive airways), rather than noise.

Biological sources of variation

Differences in spirometric measurements in the same individual, at different times, are of particular importance in occupational health for two reasons. First, spirometry is frequently used to assess and/or measure acute work-related changes (e.g. cross-shift change in FEV_1). Second, spirometry is also used in health monitoring (e.g. annual spirometry). As detailed in Table I, diurnal rhythms and other sources of variation may be responsible for noise in measurements made in the same individual. In the interval between measurements illness experiences and exposures may influence an individual's spirometry.

The most important sources of variation in spirometry between individuals are size (of which standing height is the

measure most frequently used), age, gender, and exposure to tobacco smoke. These must all be taken into account before the effects of an occupational exposure can be assessed. Awareness of all potential sources of variation in the same individual and between individuals (Table I) is important in workforce studies because attenuation or exaggeration of signal may result from the causes listed. Use of appropriate reference values[2] is central in reducing noise in comparisons of individuals or populations, as detailed below.

Race has consistently been shown to be an important determinant of lung function.[2] When compared with populations of European ancestry, values related to standing height for most other races usually show smaller lung volumes (by 6 - 15%) and lower forced expiratory flow rates, but similar FEV_1/forced vital capacity (FVC) ratios.[13] The reason for the differences between the races is unclear. Environmental factors such as nutrition and socio-economic influences are thought to contribute to these differences,[13,14,15] as well as anthropometric differences (in particular relationships of trunk to standing height).

Reference values for spirometry

Use of spirometry often implies evaluating the pulmonary function values of an individual or a population in comparison with the measurements made in a reference population. This contains an implicit question: are these results below the 'lower limit of normal'? Understanding the answer to this question requires an understanding of the statistical limitations of reference values together with their source and reason for selection.

Statistical considerations

Multiple linear regression is the most commonly used model to describe pulmonary function data in adults. Prediction equations derived from linear regression take into account the contribution of age and height to lung function. These equations are algebraic descriptions of a straight line, e.g.:

$$FVC = a + b_1 (age) + b_2 (height),$$

where a is termed the intercept and b_1 and b_2 are the regression coefficients.

Such equations perform less well at the edges of their data distribution, such as for the very tall or very obese. This is of particular relevance for age, since most reference populations have included relatively few people in the older age groups. The contribution of gender and race is usually taken into account by stratification, i.e. separate equations are provided for each group.

The most commonly reported measures of how well regression equations fit the data they describe are the square of the correlation coefficient (R^2) and the standard error of the estimate (SEE). The proportion of variation in lung function explained by the variables age and height is measured by R^2. The SEE is the average standard deviation around the regression line, therefore describing the range of FEV_1 or FVC expected at any given age and height. When reference equations are applied to a different population, it can be expected that SEE will be larger and R^2 smaller.

A 'lower limit of normal' can be estimated from regression models. For spirometry, values below the 5th percentile of the distribution are taken as below the 'lower limit of normal', while those above the 5th percentile (the remaining 95%) are taken as within the expected range. The value of the 5th percentile can be roughly estimated as: 'lower limit of normal' = predicted value – 1.645 x SEE.[2] This approach implies that 5% of the reference population was abnormal.

The use of 80% of predicted for a lower limit of normal for adult lung function is less satisfactory than the 5th percentile.[16] Despite this, the '80% of predicted criterion' is still widely used and is a part of a number of algorithms relating spirometry to pulmonary impairment.[2,17] It must be noted that this criterion only works reasonably well for average persons and for FEV_1 and FVC. Its use causes major errors when applied to mid-expiratory and peak flow rates.

Lower limits of normal are often used in clinical practice without reflection on their inherent limitations. Although clinical interpretation is usually straightforward when a pulmonary function result is well above or below a 'lower limit of normal', this is not so when a measured value falls close to the 'lower limit of normal'. Lower limits of normal have inherent limitations and therefore should not be considered as thresholds that correctly classify all patients into normal and abnormal groups.

Sources of reference values

Reference values for most clinical applications should be based on cross-sectional studies of subjects free of respiratory symptoms and disease.[1] It is preferable to choose reference values for men and women from the same population source. Reference equations should be based on non-smokers, since making adjustments for the biological effects of smoking is problematic in routine clinical interpretation.[1] Ideally, reference values should be recent, derived in the same geographical region and at an appropriate altitude.[13] Methodological criteria require that reference values should be based on data obtained by trained operators using equipment and techniques that meet appropriate criteria, such as those of the American Thoracic Society.[1]

Finally, the reference population must be appropriate to the question or use to which the reference equation is applied. The 'healthy' worker effect is a sample selection factor that is pertinent here. Workers, as select populations, are usually healthier than the general population. This also means that spirometric measurements in sample populations of workers are higher than those in community sampling.[13,18] One way of dealing with this effect is to make comparisons only between working populations.

Since the 1960s a number of prediction equations for spirometric measurements have been published, based on primary data gathered in South Africa.[19-27] Most of these prediction equations are derived from population-based data gathered in epidemiological studies carried out for other purposes. The most recent studies are all of populations defined by occupation, are methodologically comparable and have generally yielded a similar range of results.[13] In addition there have also been recent studies in the Asian and European[28] populations in South Africa. Among the studies of black South Africans, only three[20,23,26] have studied both men and women.

South Africa's ethnically heterogeneous population could be taken as requiring use of a variety of racially specific prediction equations for spirometry. While this is done in practice,[29] it remains a valid question, given the general limitations of reference values, whether use of racially specific equations adds much to the accuracy of predictions. An alternative and justifiable approach is simply to use one set of reference values for everyone.[14]

Prediction equations for FEV_1 and FVC, in men and women, for age and height from a number of studies are provided in Table II. The prediction equations for men are sufficiently similar to be practically equivalent. The South African studies all share the observed limitation that they will tend to under-predict in people with European ancestry and over-predict in those with Indian ancestry.

Table II. Prediction equations and standardised values of FEV_1 and FVC based on age and height in men and women

	Regression coefficients			Value*
Intercept	Age (yrs)	Height (cm)	SEE	(litres)
Men				
Coetzee and Becker[24]				
FVC -4.50	-0.016	+0.055	0.50	4.30
FEV_1 -3.01	-0.021	+0.043	0.43	3.55
Goldin[27]				
FVC -3.31	-0.018	+0.048	—	4.21
FEV_1 +0.72	-0.021	+0.02	—	3.44
Mokoetle *et al.*[26]				
FVC -3.85	-0.021	+0.053	—	4.42
FEV_1 -1.15	-0.036	+0.035	—	3.47
ECCS[28]				
FVC -4.34	-0.026	+0.058	0.61	4.59
FEV_1 -2.49	-0.029	+0.043	0.51	3.76
Women				
Mokoetle *et al.*[26]				
FVC -3.04	-0.023	+0.045	0.41	3.26
FEV_1 -1.87	-0.028	+0.034	0.39	2.28
ECCS[28]				
FVC -2.89	-0.026	+0.044	0.43	3.12
FEV_1 -2.60	-0.025	+0.0395	0.38	2.73

* Value for FVC or FEV, standardised to 171 cm, 38 years (men) or 159 cm, 38 years (women).

One widely used set of prediction equations is based on the European Community for Coal and Steel (ECCS).[28] These equations have the advantages of wide availability in current software programmes, together with providing prediction equations for lung function measurements other than FVC and FEV_1 from the same source. The ECCS equations predict slightly higher values and a less rapid decline with age than do most South African studies. The ECCS equations are routinely used at the Respiratory Clinic, Groote Schuur Hospital, without any form of accounting for race.

Interpretative strategies

The first step in interpretation is to evaluate and comment on the quality of the test.[2] The number of test indices (e.g. FVC, FEV_1, etc.) used in interpretation should be limited to avoid possible false-positive results. The primary guides for spirometric interpretation are VC (slow or forced), FEV_1, and FEV_1/FVC. Interpreters of lung function tests must be conservative in suggesting specific diagnoses based only on pulmonary function abnormalities, particularly since most occupational lung diseases exhibit features consistent with disease processes involving both airways and parenchyma. 'Borderline normal' values must be interpreted with caution. Such interpretations should, when possible, use clinical information in the decision as to what is normal and what is abnormal.

The FEV_1/FVC ratio is the primary guide for distinguishing obstructive from non-obstructive patterns. The severity of airflow obstruction should, however, be based on FEV_1 rather than on FEV_1/FVC. Evaluation of bronchodilator response is a further part of the evaluation of patients with airflow obstruction. Significant reversibility is inferred from either a 200 ml or a 15% increase in FEV_1 following administration of bronchodilator according to a standard protocol.[3,10]

Peak flow and mid-expiratory flow rates (e.g. MEF, $FEF_{25-75\%}$, etc.) may be used to confirm the presence of airflow obstruction in the presence of a borderline FEV_1/FVC ratio. Abnormalities in mid-expiratory flow rates due to small airways disease often precede the changes in larger airways that reduce FEV_1. The major limitation of peak flow and mid-expiratory flow rates is their high coefficient of variation, resulting in a wide range of values being considered as within the normal range. Evaluation of changes in an individual's mid-expiratory flow rates over time is therefore likely to be more informative than their comparison with reference values.

The diagnosis of a restrictive lung abnormality is, by definition, based on a reduced total lung capacity (TLC). TLC cannot be measured by a spirometer, but a reduced FVC, in the presence of a normal or increased FEV_1/FVC, may be used to suggest, but not diagnose, the presence of restriction. However, if restriction is the likely interpretation, assessment of severity may be based on FVC.

Abnormalities of lung function may be used to infer functional impairment and a number of schemes have been developed for this purpose.[2] One such approach[17] is contained in Table III, in which degree of impairment is related to percentage of predicted spirometric indices. Approaches such as those in Table III must be understood as guides rather than precise definitions. In situations where there is an apparently poor correlation between spirometric findings and other clinical indicators of impairment, formal exercise testing may be indicated to evaluate pulmonary or other forms of impairment.[17]

Computer algorithms have aided standardisation of spirometry through on-line evaluation of repeatability, performance of back-extrapolation, and other procedures used to derive spirometric values from analysis of tracings.[30] Algorithms have similarly been applied to interpretation and reporting of spirometry. However, users are strongly cautioned against uncritical acceptance of such reports, particularly when inappropriate reference values are part of the software.

Use of spirometry in special situations

Because interpretation of lung function tests from an individual patient are best made in the light of the clinical question asked of the tests, the next sections deal briefly with the four main settings in which lung function tests are used in occupational health.

Pre-assignment screening

Spirometry is increasingly a part of pre-employment or pre-assignment screening examinations. The objective of pre-assignment screening is to prevent persons with abnormal pulmonary function, or a predisposition to certain respiratory conditions, from working in an environment that may worsen their abnormality. In first-time or once-off examinations the normality of values is evaluated by comparing them to reference values. For those not excluded from employment at this point, pre-employment examinations provide a baseline record for future comparison of lung function.

Monitoring for exposure effects

The Occupational Health and Safety Act (1993) contains provisions that will result in more widespread use of spirometry for monitoring for effects of hazardous exposures. Two important uses of spirometry are the detection of (*a*) short-term and (*b*) longer-term effects of hazardous exposure.

Spirometric measurements to evaluate short-term or acute effects are appropriate in the contexts of exposures to organic dusts[31] and a range of sensitising[32] or otherwise toxic substances. Acute exposure effects are usually assessed by short-term changes in an individual's spirometry (e.g. change in FEV_1 across the first shift of the working week).[31] Once again the correct testing for acute effects can maximise the reliability of the estimate.

Both the pre- and post-shift tests should meet the usual criteria for an acceptable test. As far as is practicable, neither measure should be confounded by recent non-occupational exposures such as smoking. The pre-shift test should ideally be conducted 48 hours after the last exposure (e.g. after a weekend) and before exposure begins again. Assurance must be sought that the person tested did their usual job involving exposure during the test period. The post-shift test should be conducted when the worker experiences symptoms of bronchospasm or, if this test is negative or the worker does not experience symptoms, after at least 6, but preferably 8, hours of exposure (a complete shift). If there has been a moderate or severe reduction in FEV_1, a bronchodilator can be administered and the effect observed 10 minutes later.

Acute effects of exposure on FEV_1 across a shift have been classified as: no effect — an increase or consistent decline < 5%; mild effect — consistent decline of 5 - 10%; moderate effect — consistent decline of 10 - 20%; severe effect — consistent decline of > 20%.

Before deciding to change a person's employment status on the basis of measured acute effects, it is important to confirm that the effect is reproducible. Three repeat measures (e.g. on succeeding weeks) have therefore been recommended to evaluate consistency of acute effects, provided that this is not deemed to be hazardous to the individual concerned.[31]

The longer-term evaluation of changes in an individual's spirometric measurements over years is important in periodic medical examinations that include spirometry for the early detection of lung disease. The objective of repeated measures is to identify individuals with accelerated declines in lung function. Individuals with accelerated declines can be identified as those with previously normal lung function who subsequently fall below the 'lower limit of normal' when compared with reference values.

A more sensitive method of evaluating an individual's spirometric measurements over the years is to compare repeat measures with previous measures, thus using the individual as her/his own control. This enables a more reliable evaluation of lung function decline than does repeated comparison with reference values.[33]

An important source of noise in measurements made years apart is the 'learning effect'. With repeated measures many people improve on their initial test performance and record better spirometric values because of greater familiarity with the test. The learning effect can be reduced by special attention to pre-test training when people are first introduced to spirometric testing.

Attributing an annual decline in lung function to workplace exposure is complicated by the normal decline in spirometric values with aging. Spirometric decline with age can be estimated from the range of estimates of the age effect observed in the various South African cross-sectional studies of healthy adults:[19-26]

	Men	*Women*
FEV_1	18 - 36	13 - 34 ml/year
FVC	16 - 33	15 - 27 ml/year

These figures may be used as a guide, although it is known that these estimates have limitations. They can be compared with an estimate of the usual additional occupationally related annual decline in FEV_1 in a goldminer of 7 ml/year, or an estimated additional decline of 8 ml/year related to smoking 20 cigarettes per day.[34]

The frequency of periodic spirometric tests must be related to the actual occupational health risk and the respiratory disease that surveillance seeks to detect. In the example of the goldminer who is at risk from chronic obstructive airways disease (COAD), there will be an expected occupationally related decline in FEV_1 of 35 ml over 5 years. Detecting even a 35 ml additional decline in FEV_1 is at the limits of the accuracy of spirometry. In this example spirometry would not have to be annual but could be timed according to what is known about the usual progression of COAD in this situation. A guide to the minimum frequency for scheduling of periodic examinations to detect COAD could be: (*i*) every year for the first 3 years of service (to minimise noise due to learning effects); (*ii*) every 5 years until over 10 years in low- or moderate-risk situations and every 2 years in higher-risk situations; and (*iii*) every 2 years after 10 - 15 years of service.

Record-keeping and evaluation of repeated measures over many years can be a challenging task. A simple and practical approach to help with this is based on percentile charts similar in concept to those used to evaluate growth in children[35] (see Figs 1 - 4). At each spirometric test the height-corrected measurement is plotted on the chart. Individuals who show excessive decline in their percentile position on the chart can be considered to fall outside limits of normality.

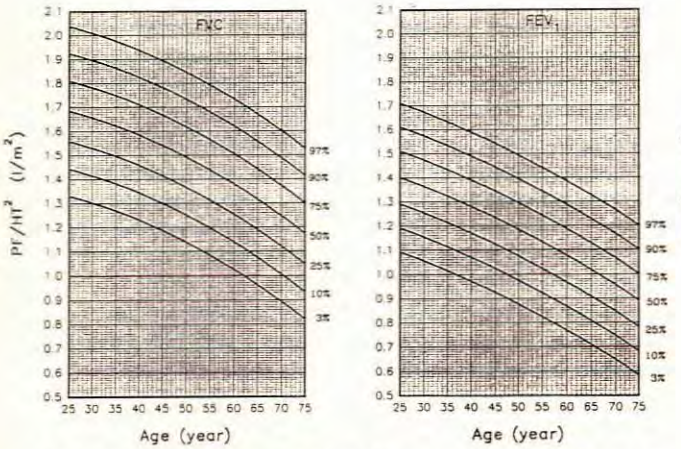

Fig. 1. Percentiles of lung function (l) divided by height (m) squared (PF/ht^2) for asymptomatic, never-smoking white males aged 25 - 74 years from six US cities[35] (published with permission).

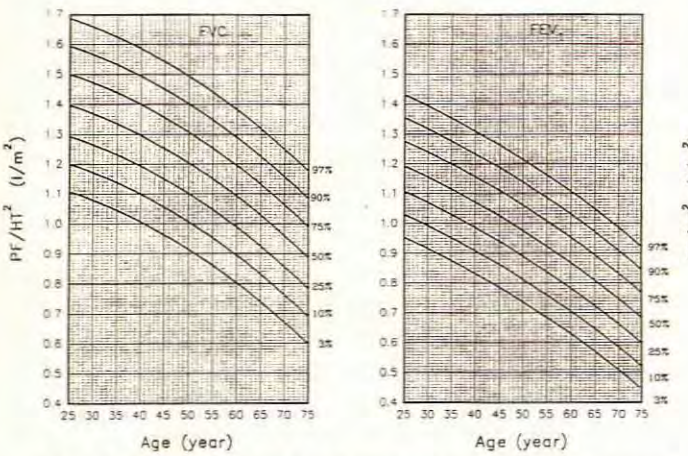

Fig. 2. PF/ht^2 for asymptomatic, never-smoking white females aged 25 - 74 years from six US cities[35] (published with permission).

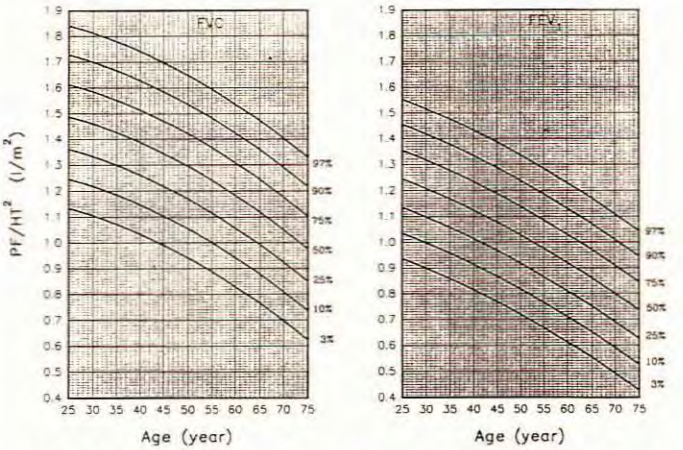

Fig. 3. PF/ht^2 for asymptomatic, never-smoking black males aged 25 - 74 years from six US cities[35] (published with permission).

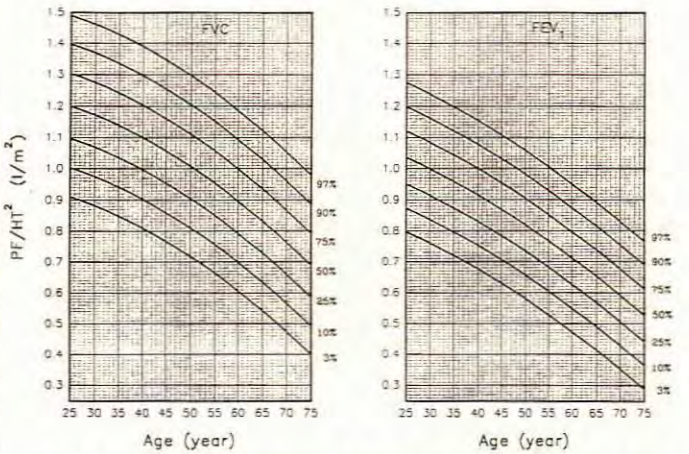

Fig. 4. PF/ht^2 for asymptomatic, never-smoking black females aged 25 - 74 years from six US cities[35] (published with permission).

At the outset of the introduction of periodic spirometric examinations there must be a protocol for how and when to intervene when abnormal results are encountered. This may mean identifying individuals who should be examined more frequently or to establish a list of priority candidates for relocation as less exposed jobs become available over time. Individuals with abnormal spirometry will always include a disproportionate number of smokers, and the demonstration of a worsening abnormality is an important opportunity to make an intervention that will encourage smokers to quit. A few individuals will require reports to be submitted for compensation if there is evidence for occupationally related partial or total permanent disability.

Research

Although they have to collect statistics, most occupational health practitioners unfortunately do not see themselves as collectors of potentially interesting and more broadly useful information. Sometimes it is only apparent to outsiders that a seldom documented situation is being monitored or events with public health interest are observed. Sadly, if the information collected over the years in periodic examinations cannot pass the test of peer review, it will not be published and will serve no broader useful social purpose.

We strongly encourage publication of South African workplace studies describing occupational health indicators such as spirometry. Public health information in this area remains sparse and often outdated. Consequently occupational health practitioners are encouraged to consider the public health interest in their work. If research possibilities emerge that involve spirometry, attention should be given early on to considering in more detail the various sources of noise in studies of spirometry, together with the various strategies to deal with noise.[7] Afterwards is too late.

Compensation

The Compensation of Occupational Injuries and Diseases Act (1994) has greatly extended the schedule of occupational diseases. Many of the newly scheduled conditions are lung diseases, and spirometry plays an essential role in properly evaluating all of them. Recent legislative changes concerning mining-related diseases will also require more use of spirometry in evaluations.

In the interests of fairness, criteria used in evaluation of respiratory impairment for compensation purposes should be easily understood public documents that encourage

uniform practices. Specific criteria will be needed for conditions such as occupational asthma.[36] Development of these criteria will need to be a consensus-seeking process that consults all important stakeholders. In the absence of specific South African criteria, the evaluation of permanent pulmonary impairment can follow algorithms such as that outlined in Table III.

Table III. Guide for grading pulmonary impairment according to percent of predicted spirometry*

	FEV_1	FVC	FEV_1/FVC
Normal	≥ 80%	≥ 80%	≥ 75%
Mildly impaired†	60 - 79%	60 - 79%	60 - 74%
Moderately impaired‡	41 - 59%	51 - 59%	41 - 59%
Severely impaired§	≤ 40%	≤ 50%	≤ 40%

* The original guidelines recommended both forced spirometry and measurement of gas transfer as the first step in evaluating respiratory impairment. Gas transfer is not included here.
† Not usually associated with diminished ability to do most jobs.
‡ Progressively lower levels of lung function associated with diminished ability to meet the physical demands of many jobs.
§ Unable to meet the physical demands of most jobs, including travel to work.

Equipment

The foundation of a screening programme is a good initial choice of spirometer. Initial costs of a good computer-compatible spirometry system may be in excess of R15 000. Once the capital and training costs are met, the unit costs of tests are low. Spirometric screening need not be costly, but it will only be effective if close attention is paid to training in standardised techniques and interpretative skills.

In comparing flow versus volume spirometers, both may be said to have advantages and disadvantages.[37] For most routine applications a volume/time spirometer is adequate since the emphasis is on the recording of FEV_1 and FVC. Instruments need to be robust, and calibration must be easy to check and must produce a permanent, identifiable record. Spirometers must be sturdy with long expected operating lives and good service back-up. These are essential if useful data is going to be collected over the years. Introduction of a new spirometer can seriously interfere with the interpretation of longer-term changes caused by between-instrument differences. If a new instrument is introduced, parallel use of the old and new instruments for a trial period is mandatory to document the magnitude and direction of between-instrument differences (if any). Similar possibilities arise if different testers are used.

Effective long-term monitoring is greatly facilitated by user-friendly methods of capturing, storing and analysing data. Locally developed computer software programmes that meet these needs are now available. Skills must be enhanced so that we can take full advantage of these new developments in technology.[32]

Conclusion

To be most effective, spirometry needs to be an integral part of a more general programme to reduce or eliminate effects of harmful airborne exposures in the workplace. Ideally, the provision of appropriate monitoring programmes in industry should be an integral part of primary health care initiatives developed for working people.

A spirometry programme can in itself make a useful contribution to early detection of respiratory disease. Combining spirometry with respiratory symptom questionnaires[11] produces additional quantifiable information[39] that enhances the whole exercise. Appropriate attention to detail in setting up a good programme, followed by the experience gained from following up a group of workers over time, can make spirometry a valuable and creative addition to the tools of the occupational health practitioner.

REFERENCES

1. Becklake MR. Concepts of normality applied to the measurement of lung function. *Am J Med* 1986; **80:** 1158-1163.
2. American Thoracic Society. Lung function testing: selection of reference values and interpretative strategies. *Am Rev Respir Dis* 1991; **144:** 1202-1218.
3. Stewart RI, Basson E. Standardisation of spirometry. *S Afr Med J* 1991; **79:** 401-404.
4. McKay RT, Lockey JE. Pulmonary function testing: guidelines for medical surveillance and epidemiologic studies. *Occup Med State Art Rev* 1991; **6:** 43-57.
5. Davies JCA, Becklake MR. Reference values for lung function — more to be done. *S Afr Med J* 1984; **66:** 830.
6. Louw SJ, Myers J, White N, Davies JCA. Reference values for lung function — still much to be done. *S Afr Med J* 1990; **77:** 173-174.
7. Becklake MR, White NW. Sources of variation in spirometric measurements: identifying the signal and dealing with noise. *Occupational Medicine: State of the Art Reviews* 1993; **8:** 241-264.
8. Rees D. Spirometry: test acceptability and reproducibility in a South African workplace. *S Afr J Epidemiol Infect* 1988; **3:** 5-8.
9. Behringer E, Rees J, Davies JCA. Poorly performed lung function tests — the answer is not blowing in the wind. *S Afr Med J* 1991; **80:** 313-314.
10. American Thoracic Society. Snowbird workshop on standardization of spirometry. *Am Rev Respir Dis* 1987; **136:** 1285-1298 .
11. Ferris BG. Epidemiology standardization project. *Am Rev Respir Dis* 1978; **6** (part 2): 1-120.
12. Becklake MR. Epidemiology of spirometric test failure. *Br J Ind Med* 1990; **47:** 73-74.
13. White NW, Hanley JH, Lalloo UG, Becklake MR. A review and analysis of variation between spirometric values reported in 29 studies of healthy African adults. *Am J Respir Crit Care Med* 1994; **150:** 348-355.
14. Myers JE. Differential ethnic standards for lung functions, or one standard for all? *S Afr Med J* 1984; **65:** 768-772.
15. Steinberg M, Becklake MR. Socio-environmental factors and lung function. *S Afr Med J* 1986; **70:** 270-274.
16. Lebowitz MD, Holberg CJ. Comparisons of spirometric reference values and the proportions of abnormal subjects among male smokers and those symptomatic in a community population. *Am Rev Respir Dis* 1989; **141:** 1491-1495.
17. American Thoracic Society. Evaluation of impairment/disability secondary to respiratory disorders. *Am Rev Respir Dis* 1986; **133:** 1205-1209.
18. Kauffmann F, Drout D, Lellouch J, Brille D. Occupational exposure and 12-year spirometric changes among Paris area workers. *Br J Ind Med* 1982; **39:** 221-232.
19. Goldman HI, Becklake MR. Respiratory function tests: normal values at median altitudes and the prediction of normal results. *Am Rev Tuberc* 1959; **79:** 457-467.
20. Johannsen Z, Erasmus LD. Clinical spirometry in normal Bantu. *Am Rev Respir Dis* 1968; **97:** 585-597.
21. Yach D, Myers J, Bradshaw D, Benatar SR. A respiratory epidemiologic survey of grain mill workers in Cape Town, South Africa. *Am Rev Respir Dis* 1985; **131:** 505-510.
22. Myers JE, Garrisch D, Myers HS, Cornell JE. A respiratory epidemiologic survey of stevedores intermittently exposed to asbestos in a South African port. *Am J Ind Med* 1985; **7:** 273-283.
23. White NW. Byssinosis in South Africa: a survey of 2 411 textile workers. *S Afr Med J* 1989; **75:** 435-442.
24. Coetzee AM, Becker PJ. Lung function screening in industry. *S Afr Med J* 1989; **67:** 550-553.
25. Hessel PA, Sluis-Cremer GK. Prediction equations for lung function in black industrial workers at Phalaborwa mining company. *S Afr Med J* 1989; **76:** 548-549.
26. Mokoetle KE, de Beer M, Becklake MR. A respiratory survey in a black Johannesburg workforce. *Thorax* 1994; **49:** 340-346.
27. Goldin JG. Spirometric and gas transfer measurements among normal adult South African men — an investigation into anthropometric, socio-economic, racial and environmental factors influencing lung function. Ph.D. dissertation, University of Cape Town, 1989.
28. Quanjer Ph H, ed. Report of the Working Party on Standardisation of Lung Function Tests: European Community for Coal and Steel. *Bulletin Europeén de Physiopathologie Respiratoire* 1983; **19:** suppl 5, 7-95.
29. Schoenberg JB, Beck GJ, Bouhuys A. Growth and decay of pulmonary function in healthy blacks and whites. *Respir Physiol* 1978; **33:** 367-393.
30. Gardner RM, Clausen JL, Cotton DJ, Crapo RO, Hankinson JL, Johnson RL. Computer guidelines for pulmonary laboratories. *Am Rev Respir Dis* 1986; **134:** 628-629.
31. WHO Study Group. Recommended health-based occupational exposure limits for selected vegetable dusts. *World Health Organ Tech Rep Ser* 1983; No. 684.
32. Basson E, Stewart RI. The standard of spirometry in the RSA. *S Afr Med J* 1991; **79:** 361-363.
33. Hankinson JL, Wagner GR. Medical screening using periodic spirometry for detection of chronic lung disease. *Occup Med State Art Rev* 1993; **8:** 353-361.
34. Cowie RL, Mabena SK. Silicosis, chronic airflow limitation and chronic bronchitis in South African gold miners. *Am Rev Respir Dis* 1991; **143:** 80-84.
35. Dockery DW. Percentile curves for evaluation of repeated measures of lung function. *Occup Med State Art Rev* 1993; **8:** 323-338.
36. American Thoracic Society. Guidelines for the evaluation of impairment/disability in patients with asthma. *Am Rev Respir Dis* 1993; **147:** 1056-1061.
37. Hankinson JL. Instrumentation for spirometry. *Occup Med State Art Rev* 1993; **8:** 397-407.
38. Chan-Yeung M. Occupational asthma. *Chest* 1990; **98:** suppl 5, 148-161.
39. Becklake MR, Freeman S, Goldsmith C, *et al.* Respiratory questionnaires in occupational studies: their use in multilingual workforces on the Witwatersrand. *Int J Epidemiol* 1987; **16:** 606-611.

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