Best practice in the use of spirometry

Booker R (2005) Best practice in the use of spirometry. *Nursing Standard*. 19, 48, 49-54.
Date of acceptance: March 18 2005.

Summary

This article examines spirometry as a method of detecting lung disease, particularly chronic obstructive pulmonary disease (COPD). Methods of producing an accurate assessment and identifying acceptable traces are outlined, and contraindications are discussed.

Author

Rachel Booker is COPD module leader and head of student support, the National Respiratory Training Centre, Warwick.
Email: r.booker@nrtc.org.uk

Keywords

COPD, Lung disorders, Respiratory system and disorders

These keywords are based on the subject headings from the British Nursing Index. This article has been subject to double-blind review. For related articles and author guidelines visit our online archive at **www.nursing-standard.co.uk** and search using the keywords.

RESPIRATORY DISEASE is a major cause of morbidity and mortality in the UK. More people die from respiratory disease than coronary heart disease or cancer, and respiratory illness is the most common reason for emergency hospital admission. Almost a third of the population will visit their GP with a respiratory condition at least once a year (British Thoracic Society (BTS) 2000). Objective diagnosis, monitoring and appropriate management of respiratory disease require measurement of lung function. The latest asthma guideline (BTS and Scottish Intercollegiate Guidelines Network (SIGN) 2003) highlights the need for objective diagnosis and recommends spirometry to assist with this.

The first national guideline on the management of chronic obstructive pulmonary disease (COPD) (BTS 1997) recommended spirometry for the early and accurate diagnosis of COPD. The recent COPD management guideline from the National Institute for Health and Clinical Excellence (NICE) (National Collaborating Centre for Chronic Conditions (NCCCC) 2004) supports the use of spirometry for diagnosis and monitoring of COPD, and recommends that spirometry be widely available in all healthcare settings. There has been an increase in spirometry use and nurses are more frequently performing the procedure and interpreting results.

Definition

A spirometer is a piece of equipment that an individual blows into through a mouthpiece. It is used to measure lung volume and the rate at which air can be exhaled during forced exhalation.

There are a variety of spirometers available. The simplest, volumetric spirometers, measure volume directly. Types of volumetric spirometers include:

- Water-sealed spirometers.
- Rolling-seal spirometers.
- Wedge bellow spirometers.

Volumetric spirometers tend to be large. A wedge bellow spirometer, for example, is the size of a large microwave and water-sealed and rolling-seal spirometers are even larger.

Volumetric spirometers are most commonly used in secondary care settings in outpatient clinics and pulmonary function laboratories where they do not need to be moved around. They cost between £1,500 and £3,000, although may cost more. Other spirometers use a variety of technologies to sense airflow and electronically calculate volume from flow. They are smaller and generally more suitable for use by health professionals in primary care and community settings. These include:

- Pneumotachographs.
- Anemometers.
- Turbine spirometers.
- Ultrasound spirometers.

They range from 'desktop' models, which are about the size of a laptop computer, to small hand-held devices. These spirometers range in price from £300-500 for a basic hand-held spirometer to £1,000-1,500 for a desktop spirometer. Compared with volumetric spirometry, the performance is the same as long as the equipment is used appropriately. The main difference is that the technique is less easy to assess with some electronic flow measuring devices.

Measurement

A spirometer measures accessible lung volume – vital capacity. 'Accessible' refers to the fact that

spirometers can only measure the air that is exhaled and inhaled. There is always some air remaining in the lungs at the end of the exhalation that cannot be measured with a spirometer. This is known as the residual volume. The residual volume plus the vital capacity make up the total lung capacity.
Accessible lung volume is measured in two ways:

- Relaxed vital capacity (RVC). A relaxed exhalation from maximal inhalation to maximal exhalation.
- Forced vital capacity (FVC). A forced exhalation from maximal inhalation to maximal exhalation using maximum effort.

The volume of air exhaled in the first second of forced exhalation is also measured:

- Forced expired volume in one second (FEV_1).

These lung volumes are expressed as both absolute volumes, in litres, and as a percentage of the predicted reference value for someone of that age, gender, height and ethnic group. Normative values for the UK population are available (Quanjer *et al* 1993, NCCCC 2004).

The FEV_1 is also expressed as a percentage of FVC or RVC (if this is greater):

- FEV_1% or FEV_1/FVC, FEV_1/RVC.

FEV_1% is the marker of airflow obstruction. Values of less than 70 per cent are diagnostic of obstructive airways disease. Abnormal spirometry, however, cannot confirm a diagnosis. Spirometry must only be interpreted in the light of a good history and other diagnostic tests.

RVC, FVC, FEV_1 and FEV_1% are the most important parameters of lung function. Most electronic spirometers will also produce an array of other measurements, most of which are not essential for simple spirometry.

BOX 1

Calculation of forced expired volume in one second as a percentage of forced or relaxed vital capacity (FEV_1%)

If FVC is greater than RVC:

$$FEV_1\% = \frac{FEV_1}{FVC} \times 100$$

If RVC is greater than FVC:

$$FEV_1\% = \frac{FEV_1}{RVC} \times 100$$

FVC = forced vital capacity; RVC = relaxed vital capacity

Spirometry results can be presented graphically in two ways:

- A volume/time graph of volume exhaled in litres (vertical axis) against the time taken in seconds to exhale completely (horizontal axis).
- A flow/volume graph of flow rate in litres per second (vertical axis) against volume in litres (horizontal axis).

Disease and spirometry measurement

In patients with normal lung function:

- The FVC should be the same or slightly greater than RVC.
- The FVC should be greater than 80% of the predicted value for an individual of that age, gender, height and ethnic group.
- The FEV_1 should be greater than 80% of the predicted value for an individual of that age, gender, height and ethnic group.
- The FEV_1% (that is, the FEV_1 expressed as a percentage of the FVC or RVC if that is greater) should be between 75 and 85% to be within normal range.
- The FEV_1% is a different measurement from the FEV_1 as a percentage of the predicted FEV_1.

Obstructive lung diseases, such as asthma and COPD, obstruct airflow and will reduce the volume of air exhaled in one second (FEV_1), so that it is less than 80% of the predicted value, and reduce FEV_1%. An FEV_1% that is less than 70% is diagnostic of airflow obstruction.

FVC and FEV_1 will be less than 80% of the predicted value where lung volumes are restricted, for example, in pulmonary fibrotic diseases such as fibrosing alveolitis, or musculoskeletal disease such as kyphoscoliosis. However, these disorders do not obstruct airflow and FEV_1% is unaffected. In restrictive disorders, FEV_1% is more than 75% and is often greater than 85%.

In severe airflow obstruction, dynamic airway collapse during forced exhalation traps air in the lungs and reduces FVC causing restriction and obstruction. In such cases, RVC will be significantly higher than FVC and will more accurately reflect vital capacity than FVC . Calculation of FEV_1 as a percentage of RVC (Box 1) may reveal a reduced FEV_1% indicative of airflow obstruction that may otherwise be missed.

Table 1 summarises the parameters of lung function affected in various respiratory diseases. The effects of obstructive, severe obstructive and restrictive diseases on volume/time and flow/volume traces are shown in Figures 1 and 2.

Peak expiratory flow

Peak expiratory flow (PEF) is defined as: 'the maximum flow achieved during an expiration delivered with maximal force starting from maximal lung inflation' (American Thoracic Society 1995).

Measurement of PEF is easy. PEF meters cost less than £10, are portable and available on prescription. This makes them suitable for patients to use and keep at home, and they are useful for detection and ongoing monitoring of variable airflow obstruction: the hallmark of asthma. PEF is of limited use in other respiratory conditions.

PEF measures flow rate in the first tenth of a second of a forced exhalation. PEF measures flow rate and FEV_1 is a measure of volume. They are not interchangeable and PEF cannot be predicted from FEV_1 or vice versa. Reference predicted PEF values are less robust than spirometric values. PEF is insufficiently sensitive to detect early airflow obstruction in COPD and can seriously underestimate the degree of airflow obstruction in more severe COPD. Therefore, spirometry is more suitable for assisting in the diagnosis of COPD (NCCCC 2004). A further limitation of PEF is that, unlike spirometry, it does not measure lung volumes and cannot be used to detect restrictive lung diseases, such as pulmonary fibrosis.

Criteria for optimal spirometry

The BTS and the Association for Respiratory Technology and Physiology (ARTP) (BTS and ARTP 1994) suggest four optimal criteria for a spirometer (Box 2).

Most mid-price range and desktop electronic spirometers fit the above criteria. Hand-held spirometers are relatively cheap, but may not have a visual display. Unless they are linked to a computer, it is not possible to verify adequacy of the technique and hard copies of results may not be produced. Charts of reference values may have to be used to manually calculate and interpret the results, creating the potential for error.

Some electronic spirometers have additional mechanisms for checking the adequacy of the patient's technique. They will detect errors, such as a slow start to the forced blow, early stoppage, hesitation, and poor effort. An additional feature of some electronic spirometers is the ability to interface with the patient's computerised medical record. This allows easy storage and retrieval of

TABLE 1

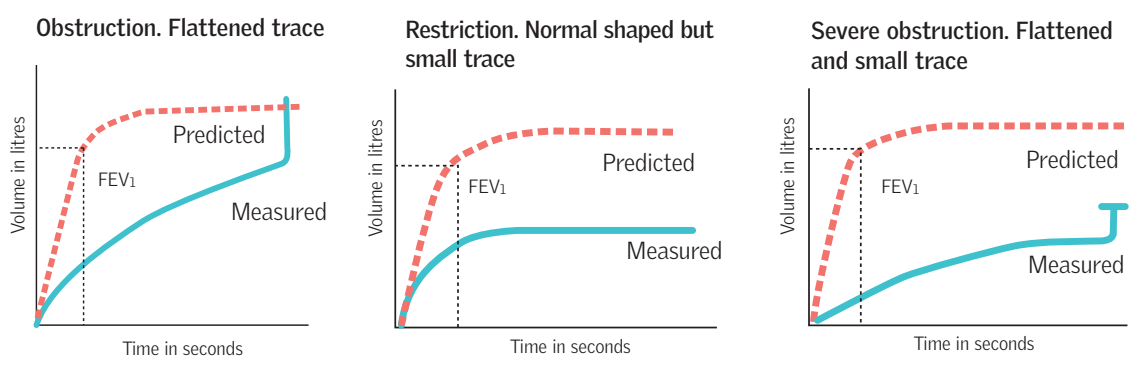
Effect of respiratory disease on spirometry

	Normal	Obstruction	Severe obstruction	Restriction
RVC	Same as or less than FVC	Same as or greater than FVC	Greater than FVC	Same as or less than FVC
FVC	More than 80% of predicted	More than 80% of predicted	Less than 80% of predicted	Less than 80% of predicted
FEV_1	More than 80% of predicted	Less than 80% of predicted	Less than 80% of predicted	Less than 80% of predicted
FEV_1%	75-85%	Less than 70%	Less than 70%	75-85% or higher

RVC = relaxed vital capacity; FVC = forced vital capacity; FEV_1 = forced expired volume in the first second of exhalation

FIGURE 1

Abnormal volume/time traces



results, or emailing of results for quality-control purposes (Box 3).

Performance and interpretation

Spirometry, like PEF, is a relatively easy measurement, but it does require effort and co-operation from the patient. It is also essential that the health professional taking the measurements is trained in the technique and is able to recognise technically acceptable results and correct technique errors. It is also vital that whoever interprets the results is trained and competent. Poorly performed and interpreted spirometry is likely to lead to misdiagnosis or missed diagnosis (Woolhouse and O'Hickey 1999). The NICE COPD guideline recommends that quality-control mechanisms are set up to support primary care spirometry services (NCCCC 2004). In accordance with their *Code of Professional Conduct* (NMC 2004), nurses responsible for recording or interpreting spirometry must ensure they are appropriately trained.

BOX 2

Four optimal criteria for a spirometer

- A spirometer that produces a hard copy of the results.
- Print out a hard copy of the volume/time graph that is of sufficient size to enable manual verification of results. A flow/volume graph is an optional extra, but is extremely useful for the detection of early airflow obstruction. It is available with most modern electronic spirometers.
- Calibration should be checked using a calibration syringe. Some electronic spirometers will allow updating of calibration, others require the spirometer to be sent back to the manufacturer for recalibration.
- A visual display of the blow, preferably a 'real-time' display of volume/time or flow/volume graphs as the patient is blowing, enables assessment of the patient's technique.

(BTS and ARTP 1994)

Contraindications

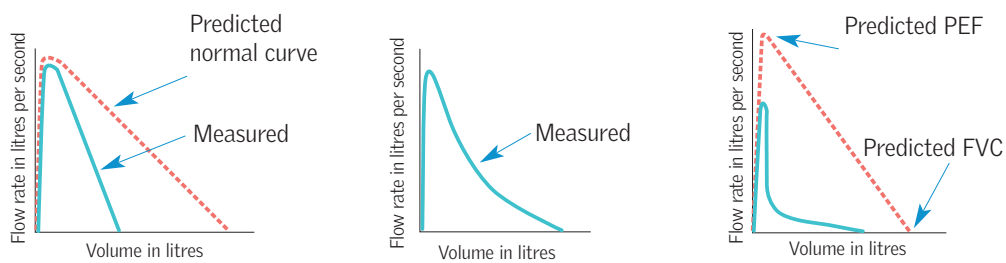
There are no absolute contraindications to spirometry but common sense should be exercised. Where there are any grounds for concern, assessment at a lung function laboratory may be advisable.

Forced expiration using maximum effort raises intracranial, intrathoracic and intra-abdominal pressure. Therefore, consider deferring spirometry for about six weeks in patients who have had recent eye, chest or abdominal surgery, or who have recently had a myocardial infarction or cerebrovascular accident (BTS and ARTP 1994).

Spirometry can produce bronchospasm, particularly in patients with chest infections and bronchial hyperreactivity. Spirometry readings will progressively worsen with each effort and further attempts should be abandoned. Spirometry should be performed when the patient is clinically stable and free of infection whenever possible.

FIGURE 2

Abnormal flow/volume traces



Restriction. Normal PEF; reduced FVC; narrow, 'domed' trace

Mild obstruction. 'Scooped', concave trace

Severe obstruction. Markedly 'scooped' out trace; reduced PEF and FVC

PEF = peak expiratory flow; FVC = forced vital capacity

Cross-infection and risk minimisation

Contamination of spirometry equipment and the potential for cross-infection need to be considered. Although there is no study or case report that has demonstrated that spirometry poses a significant risk to patients, common sense and good hygienic practices should be used.

Ultrasonic and anemometer spirometers use disposable single-patient-use mouthpieces that prevent cross-infection. The use of one-way mouthpieces with other spirometers can prevent accidental inhalation through the spirometer, and are a minimum requirement to reduce infection risk.

If inhalations are required, a bacterial and viral filter will be needed. Patients suspected of having active chest infection, particularly tuberculosis, should not be tested. If spirometry is clinically necessary, patients with chest infection should be tested at the end of the day with equipment that can be disinfected after use. Patients who are immunocompromised should be tested at the beginning of the day on newly disinfected equipment.

Flow sensors, such as pneumotachographs and turbines need to be cleaned and disinfected according to manufacturers' instructions. Flow sensors cannot be autoclaved and the use of inappropriate sterilising fluids can damage or destroy them. Disinfection of volumetric spirometers is difficult and costly. Therefore, it is essential that the correct mouthpieces are used and care is taken to protect patients from cross-infection.

BOX 3

Essential features of a spirometer

A 'good' spirometer is one that is:

- Simple to use.
- Robust and reliable.
- Easy to clean and disinfect.
- Supplied by a company providing reliable technical support and assistance.
- Suitable for the workplace.
- Meets the British Thoracic Society and Association for Respiratory Technology and Physiology (1994) criteria.

Spirometer calibration

Calibration of all spirometers should be regularly checked and a log kept of this procedure. Electronic spirometers should be checked before each session using a calibration syringe. Although current flow sensors are often robust and reliable, it is necessary to check that the equipment is recording accurately.

Technically acceptable and meaningful results

RVC should be recorded as a baseline measurement. It is important to ensure that the patient has taken a maximal inhalation. The mouthpiece is positioned so that the tongue and teeth do not occlude it and the lips are sealed around it to prevent air leaks. A nose clip is used to prevent air leakage down the nose.

The patient needs to exhale steadily, in a relaxed manner until he or she is unable to exhale any further. This should be repeated at least twice, or until the two best readings vary by less than 5% and 100ml.

A minimum of three forced exhalations needs to be recorded so that the best two readings of FEV_1 and FVC vary by less than 5% and 100ml. If necessary, eight exhalations can be undertaken to achieve this level of reproducibility. Vigorous verbal

References

American Thoracic Society (1995) Standardization of spirometry, 1994 update. *American Journal of Respiratory and Critical Care Medicine.* 152, 3, 1107-1136.

British Thoracic Society and the Association for Respiratory Technology and Physiology (1994) Guidelines for the measurement of respiratory function. *Respiratory Medicine.* 88, 3, 165-194.

British Thoracic Society (1997) BTS guidelines for the management of chronic obstructive pulmonary disease. *Thorax.* 52 (Suppl 5), S1-S28.

British Thoracic Society (2000) *The Burden of Lung Disease.* BTS, London.

British Thoracic Society and Scottish Intercollegiate Guidelines Network (2003) British guideline on the management of asthma. *Thorax.* 58 (Suppl 1), i1-94.

Department of Health (2003) *Investing in General Practice: The New General Medical Services Contract.* www.dh.gov.uk/assetRoot/04/07/19/67/04071967.pdf (Last accessed: July 29 2005.)

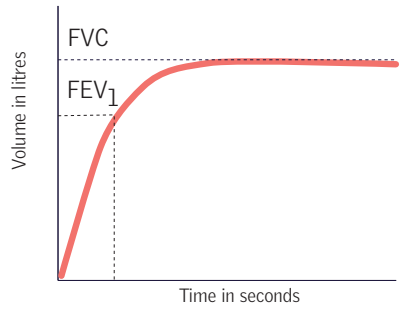
Halpin DMG, Rudolph M on behalf of the BTS COPD Consortium (2002) Implementing the BTS COPD Guidelines: how far have we come? *European Respiratory Journal.* 20 (Suppl 38), 1637.

National Collaborating Centre for Chronic Conditions (2004) Chronic obstructive pulmonary disease. National clinical guideline on management of chronic obstructive pulmonary disease in adults in primary and secondary care. *Thorax.* 59 (Suppl 1), 1-232.

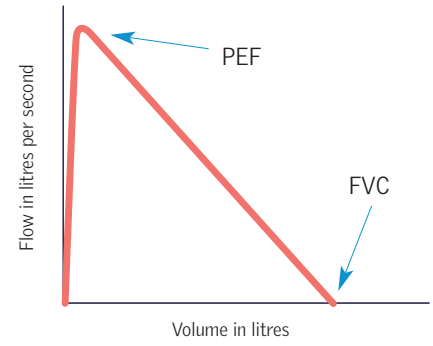
FIGURE 3

Acceptable volume/time and flow/volume traces

Volume/time. Smooth trace that reaches a plateau



Flow/volume. Rapid, almost vertical rise to peak expiratory flow (PEF); trace merges with baseline at forced vital capacity (FVC)



encouragement to exhale continuously with force will help ensure maximum effort to FVC.

The acceptability of the forced exhalations needs to be checked by looking at graphic traces of volume/time and flow/volume. Traces should be smooth and free of irregularity. The volume/time trace should curve smoothly upwards to a plateau and the flow/volume trace should rise almost vertically to a peak and should merge smoothly with the horizontal axis. Inadequate blows must be rejected. Spirometry cannot be interpreted unless acceptability and reproducibility criteria are met. Technically acceptable traces showing normal lung function are shown in Figure 3.

Conclusion

Spirometry was, until recently, only available routinely in secondary care settings. The publication of disease management guidelines (BTS 1997, BTS and SIGN 2003, NCCCC 2004) has prompted increased spirometry use in primary care (Halpin and Rudolph 2002). The new General Medical Services Contract (Department of Health 2003), which financially rewards general practices for diagnosing and monitoring COPD with spirometry, has prompted the widespread use of spirometers in general practice.

There are concerns about the quality of spirometry practice in primary care and the ability of some primary healthcare professionals to interpret results (Woolhouse and O'Hickey 1999). However, with appropriate training, continued practice and good quality control, respiratory patients in all healthcare settings can have lung function objectively assessed and be diagnosed and treated appropriately (Schermer *et al* 2003) **NS**

References continued

Nursing and Midwifery Council (2004) *The NMC Code of Professional Conduct: Standards for Conduct, Performance and Ethics*. NMC, London.

Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC (1993) Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. *European Respiratory Journal Supplement*. 16, 5-40.

Schermer T, Eaton T, Pauwels R, van Weel C (2003) Spirometry in primary care: is it good enough to face demands like World COPD Day? *European Respiratory Journal*. 22, 5, 725-727.

Woolhouse I, O'Hickey SP (1999) Accuracy of spirometry measured in general practice compared to a hospital pulmonary function laboratory. *European Respiratory Journal*. 14 (Suppl 30), 273s.

RESOURCES

Short course in basic spirometry and interpretation is available from The National Respiratory Training Centre: www.nrtc.org.uk

Certification of competence in spirometry and its interpretation is available from The Association for Respiratory Technology and Physiology: www.artp.org.uk

British Thoracic Society chronic obstructive pulmonary disease consortium publications: www.brit-thoracic.org.uk/iqs/copd-publications-library.html