Spirometry: an essential clinical measurement

Rob Pierce
MD, FRACP, is Professor of Respiratory Medicine, University of Melbourne, and Director, Respiratory and Sleep Medicine and Institute for Breathing and Sleep, Austin Health, Victoria.
r.pierce@medicine.unimelb.edu.au

BACKGROUND Respiratory disease is common and amenable to early detection and management in the primary care setting. Spirometric evaluation of ventilatory function plays a critical role in the diagnosis, differentiation and management of respiratory illness such as asthma, chronic obstructive pulmonary disease and restrictive lung disorders, and is important in the assessment of lung health in smokers and those exposed to occupational and environmental hazards.

OBJECTIVE This article covers the basic theory, fundamentals of test indications, performance and equipment, the interpretation of results and the nuances behind the spirogram and the flow-volume curve.

DISCUSSION The use of spirometry by primary care physicians, practice nurses and physiotherapists is now practicable and supported by a comprehensive range of devices, training courses and reference materials. Systematic use of ventilatory assessment both in the clinic and with patient self monitoring of peak flow and FEV1 has the capacity to improve patient understanding, confidence in self management, and quality of life for those with lung disease. Spirometry may also provide a useful modality for following the progress of those with neuromuscular disease and incipient respiratory muscle weakness and for the promotion of respiratory health in the community setting, although further research in all these areas is required.

Respiration is the process by which oxygen and CO2 are exchanged between the atmosphere and the mixed venous blood to meet the metabolic demands of the body. This is achieved by the integrated physiological processes of ventilation, pulmonary blood flow and gaseous diffusion.

Spirometry is the most widely used noninvasive test of ventilatory function and assesses the mechanical or bellows properties of the pulmonary system by measurement of the dynamic or respired lung volumes and capacities. When combined with the measurement of arterial gas tensions or pulmonary gas exchange, it provides an overall assessment of lung function suitable for the detection, differentiation and diagnosis of various respiratory diseases, and an objective method for following disease progression or improvement and therapeutic response over time.

What is spirometry?

Spirometry is the timed measurement of dynamic lung volumes and capacities during forced expiration and inspiration to quantify how effectively and quickly the lungs can be emptied and filled (left panel *Figure 1*). Measurements usually made are:

- the vital capacity, either forced (FVC) and/or unforced (VC)
- forced expiratory volume in one second (FEV1), and
- the ratio of these two volumes (FEV1/FVC).

Additionally one can measure the maximum expiratory flow over the middle 50% of the vital capacity (FEF 25–75%), which is a sensitive index of small airway function. Corresponding maximal inspiratory measures are the FIV1 and the FIVC.

The FEV1/VC ratio is the most sensitive and specific index to identify airflow obstruction. The lower limit of normality for this index centres around 70% but declines slightly with age. Alternatively, the FEV1/FEV6 from a 6 second forced expiration can be used. The FEV1 percent predicted is used to grade severity of ventilatory defects. A low FVC with a normal or high ratio identifies a restrictive ventilatory defect.

Measures of forced maximal flow during expiration and inspiration can be also made either absolutely, eg. peak expiratory flow rate (PEFR), or as a function of volume thus generating a flow-volume curve, the shape of which also contains information of diagnostic value. The flow-volume curve of a normal subject is shown in the right panel of *Figure 1*. Its characteristic shape results from the fact that during expiration, soon after peak flow is achieved, maximal flow becomes independent of effort and declines linearly with lung volume. On the other hand, during inspiration maximal flow is effort dependant and influenced by the strength of contraction of the diaphragm and chest wall muscles and the patency of the upper airway.

A further spirometric measure undergoing renewed interest is that of inspiratory capacity (IC) which is the maximum volume of air that can be inspired from the end of quiet expiration (functional residual capacity [FRC]) to total lung capacity (TLC). Inspiratory capacity is reduced when hyperinflation is present or develops dynamically, eg. during exercise in patients with chronic obstructive pulmonary disease (COPD) (*Figure 2*).

Fundamentals for obtaining useful results

To achieve optimal results, the FVC manoeuvre must be performed with maximal effort. Immediately following a full inspiration, the patient seals his/her lips around the mouthpiece and blasts the air out as fast and as far as possible until the lungs are absolutely empty, then breathes in again as forcibly and fully as possible (not all spirometers will measure inspiration). Demonstration to the patient of the procedure and the maximal effort required is helpful before starting. For the measurement of IC, scrutiny of the stability of FRC during a short period of tidal breathing before full inspiration is necessary. For PEFR, only the first 1 or 2 seconds of maximal expiration is required.

Remember that, particularly in airflow obstruction, it may take many seconds for the patient to expire fully. Rest for recovery between repeat tests, an erect seated position and the use of a nose clip are recommended. Careful examination of each spirogram or flow-volume curve for acceptability, reproducibility and correction of results to body temperature and pressure (saturated) conditions is needed.

Measurement of spirometry in children requires animation to capture the child's attention and effort, and can usually be achieved in those 5 years of age and over.

Indications for spirometry

- The detection of respiratory disease in patients presenting with symptoms of breathlessness either at rest or on exertion, wheeze, cough, stridor or chest tightness. Spirometry is useful in distinguishing respiratory from cardiac disease as the cause of breathlessness and can be used to screen for

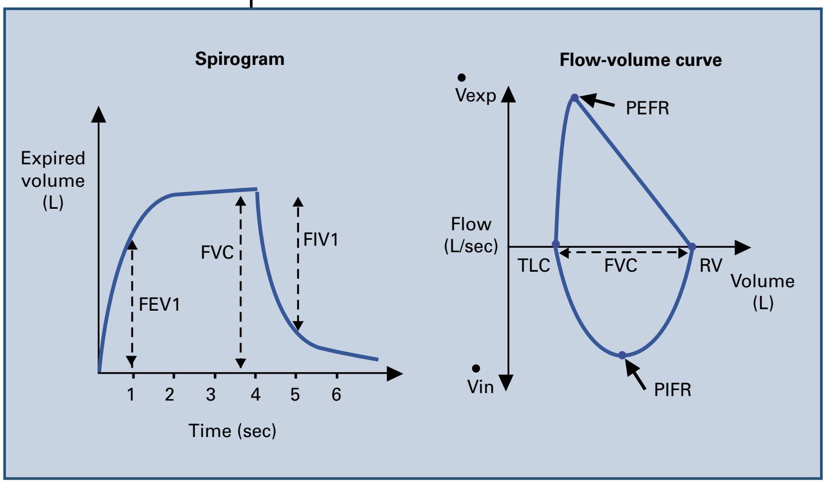

Figure 1. Normal spirogram and flow-volume curve showing the conventional measurements made

FEV1 = forced expiratory volume in 1 second
FIV1 = forced inspiratory volume in 1 second
FVC = forced vital capacity
PEFR = peak expiratory flow rate
IRV = inspiratory residual volume
Vt = tidal volume
FVC = forced vital capacity
TLC = total lung capacity
RV = residual volume
PIFR = peak inspiratory flow rate
ERV = expiratory residual volume

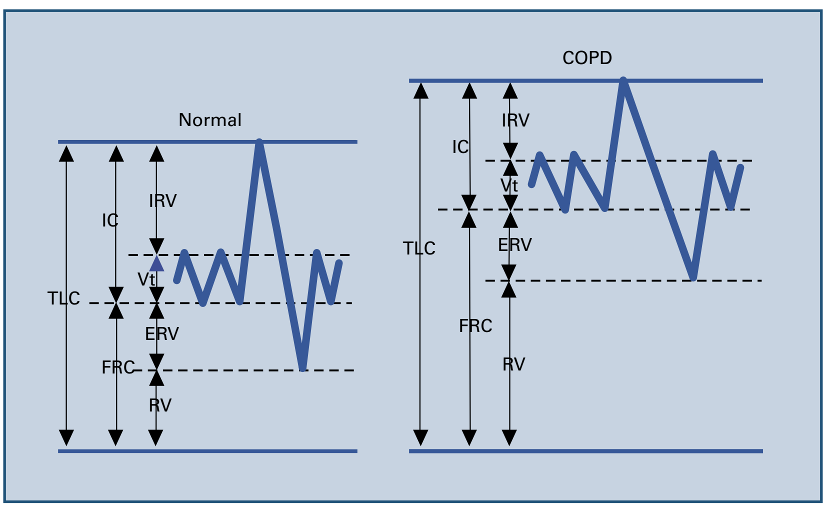

Figure 2. Lung volumes and capacities in normal and hyperinflated (COPD) lungs. The IC is the volume that can be inspired from FRC up to TLC

respiratory disease in certain high risk situations, eg. pre-employment in industries in which occupational asthma is prevalent. It is also used to measure bronchial responsiveness in patients suspected of having asthma and to identify those at risk from pulmonary barotrauma while scuba diving

- The diagnosis of respiratory disease and differentiation of obstructive versus restrictive ventilatory defects, the identification of upper airway obstruction and diseases associated with weakness of the respiratory muscles
- Following the natural history and progression of respiratory and sometimes systemic and neuromuscular diseases
- Assessment of response to treatment in these conditions
- Assessment of impairment from respiratory disease in the workplace and in the settings of pulmonary rehabilitation and compensation for occupational disease
- Pre-operative risk assessment before anaesthesia and abdominal or thoracic surgery.

Interpretation of results

The dynamic lung volumes (eg. FEV1,FVC) and maximum flows (eg. PEFR) of any individual need to be compared with reference values obtained from a normal population using similar test protocols and carefully calibrated instruments.

The presence of ventilatory abnormality can be implied if any of FEV1, FVC, PEFR or FEV1/VC are outside the reference range. Inter-relationships of the various measurements are also important diagnostically. For example, a reduction of FEV1 in relation to the forced vital capacity resulting in a low FEV1/FVC percent (<70%) constitutes an obstructive ventilatory defect as occurs in asthma and emphysema (*Figure 3*).

In restrictive ventilatory defects (as occur in interstitial lung disease, respiratory muscle weakness, and thoracic cage deformities such as kyphoscoliosis), the FEV1/FEVC percent ratio remains normal or high (typically >80%) with a reduction in both FEV1 and FVC. A reduced FVC together with a low FEV1/FVC percent ratio may occur as a feature of a mixed ventilatory defect in which a combination of both obstructive and restrictive types coexist. Alternatively it may occur in airflow obstruction as a consequence of airway closure resulting in gas trapping rather than as a result of small lungs. Measurement of static lung volumes such as the patient's TLC are necessary to distinguish between these possibilities.

It is routine practice to quantify the degree of reversibility of an obstructive defect by measuring spirometry before and after the administration of a bronchodilator. Generally, an improvement in FEV1 of 200 mL or more infers significant reversibility, if the baseline FEV1 is <1.5 L, as does an improvement of >15% if the FEV1 is >1.5 L. Normal subjects generally exhibit a smaller increase in FEV1 of up to 8%. It should also be noted that normal spirometry in a well patient does not exclude the diagnosis of asthma.

Improvement in IC may occur due to increase in

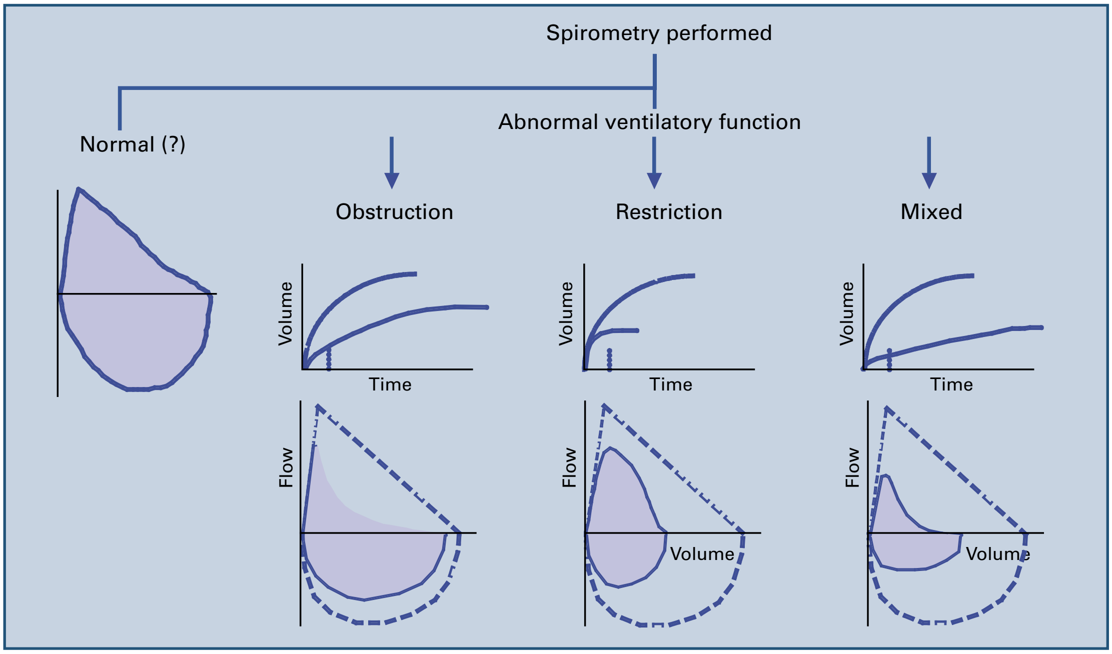

Figure 3. Types of ventilatory defect with typical spirograms and flow-volume curves

TLC and/or to a reduction in FRC with lessening of hyperinflation. Inspiratory capacity may improve significantly without change in FEV1 in patients with 'irreversible' airflow obstruction in COPD. Furthermore, changes in IC following bronchodilator correlate better than other spirometric indices with improvement in dyspnoea and exercise performance.

Similarly, the shape of the expiratory flow-volume curve (*Figure 4*) varies between obstructive ventilatory defects where maximal flow rates are diminished and the expiratory curve is scooped out or concave to the X axis, and restrictive diseases where flows may be increased in relation to lung volumes. Reduction of maximal expiratory flow as residual volume is approached is suggestive of obstruction in the peripheral airways. A plateau of inspiratory flow may result from a collapsible extra-thoracic airway whereas inspiratory and expiratory flow are both limited for fixed lesions. Maximal expiratory flow is selectively reduced for collapsible intra-thoracic airway obstruction (*Figure 4*).

Spirometric monitoring in airways disease

When peak expiratory flow is measured repeatedly and plotted against time (eg. morning and evening values by asthmatic patients) the pattern of results can be of great value in identifying particular aspects of a patient's disease. Typical patterns are: the 'morning dipper' pattern of some asthmatics due to a fall in the early morning hours (*Figure 5*) and fall in PEFR during the week with improvement on weekends and holidays which occurs in occupational asthma. Isolated falls in PEFR in relation to specific allergens or trigger factors can help identify and quantify these for the doctor and patient. A downward trend in PEFR and an increase in its variability can identify worsening asthma and can be used by the doctor or patient to modify therapy, eg. the patient increases his/her treatment as per an 'asthma action plan'. Peak expiratory flow monitoring is particularly useful in asthmatics who have poor perception of their own airway calibre for following response to treatment, and to improve self management in conjunction with an action plan. Response to asthma treatment is usually characterised not only by an increase in PEFR but also by a decrease in its variability (*Figure 5*).

Normal values for spirometry

There are a number of reference value studies that have generated predictive equations for ventilatory function that take into account gender, height, age and ethnicity (see *Resources*). Normal values for PEFR may not be as useful to the individual patient as his/her own 'personal best' target for management of asthma.

Equipment, calibration and quality assurance

Conventional volume displacement spirometers provide a direct measure of expired volume from displacement

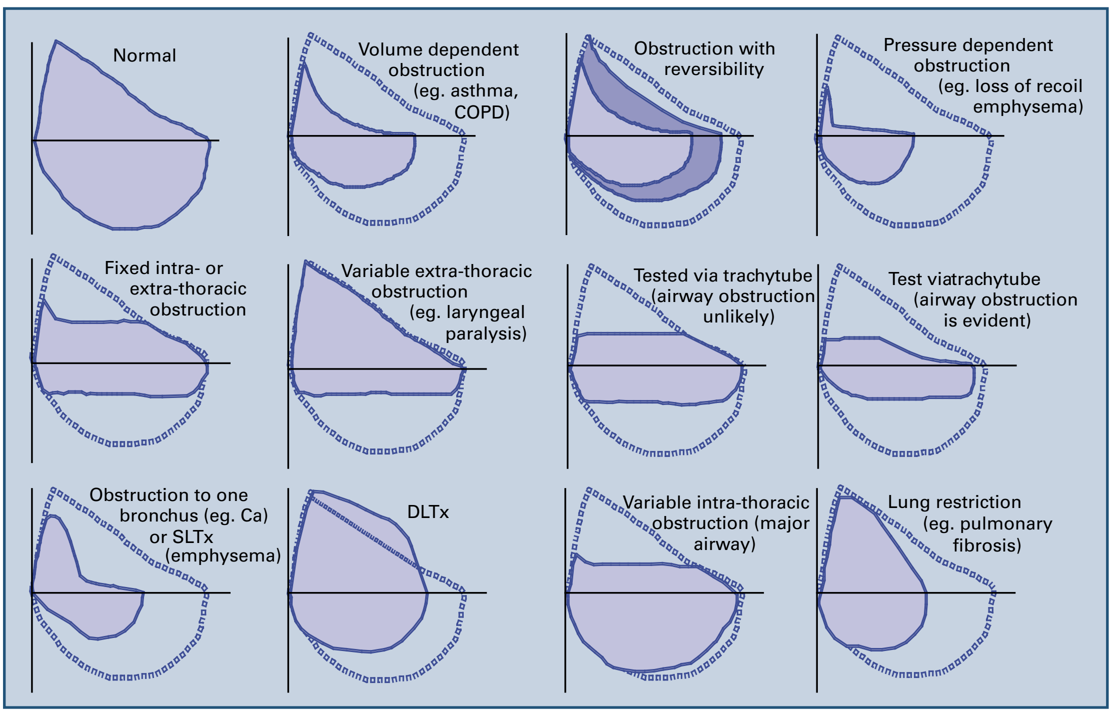

Figure 4. Examples of how various respiratory diseases affect the shape of the flow-volume curve

of a bellows, piston (rolling seal) or bell (water sealed), and are robust, accurate and reliable. They are however, difficult to clean and disinfect, and not very portable. Flow spirometers measure expiratory and inspiratory flow primarily as pressure drop across a grid or orifice, cooling of a hot wire, rotation of a vane or turbine or transmission of ultrasound, and are portable, automatically calculate results and normal values, and print out the spirogram or flow-volume curve.

Standards for equipment, calibration and quality control aspects of spirometry are given by the American Thoracic Society statement on 'Standardisation of spirometry'.[1] Guidelines for both spirometry[2] and infection control[3] in the respiratory laboratory have also been published by the Australian New Zealand Society of Respiratory Science. For spirometers, regular calibration by injecting a known volume of air from a calibrated syringe at varying speeds (to check linearity) and use of a 'biologic control' subject with stable, known lung volumes are recommended. Accuracy of timing devices used for timed volumes (eg. FEV1) should also be assessed.

Conclusion

Measurements of ventilatory capacity are fundamental to the assessment of respiratory health and should be routinely applied in the primary care setting in patients with known or suspected respiratory disease. Spirometric measurement is critical to the diagnosis and management of asthma, COPD and restrictive lung disease. Respiratory disease is common, and the early effects of cigarette smoking, environmental pollution and occupational exposure demand clinical vigilance and objective measurement. Simple reliable devices are now widely available and their more widespread deployment is mandatory if we are to improve breathing health and reduce the burden of respiratory illness in the community.

Summary of important points

- Spirometry should be performed in all people over 40 years of age who have ever smoked, and in those with any symptom of possible respiratory origin.
- COPD is easily detected before symptoms develop, and smoking cessation at this point is of major benefit.
- Spirometry is vital in the management of asthma to assess severity and response to treatment and to guide management.
- An increase in FEV1 of >12% (or >200 mL) suggests asthma, although normal spirometry in a well patient does not exclude it.

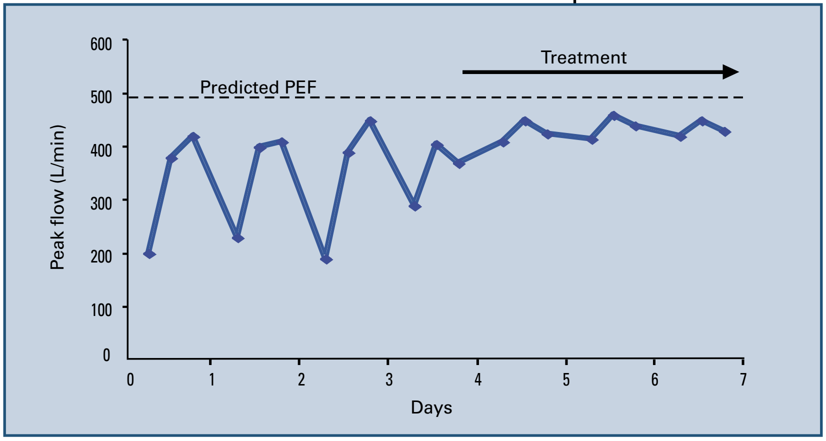

Figure 5. Peak expiratory flow chart in an asthmatic showing the typical 'morning dipper' pattern stabilising with increased treatment

Resources

- Many large teaching hospital respiratory laboratories now provide short courses in spirometry for clinicians with practical 'hands on' familiarisation
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Conflict of interest: none declared.

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