Spirometry in clinical use: practical issues

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None declared.

Educational aims

- To identify practical problems when carrying out spirometry.
- To provide a short 'pathway' to assess spirometry results.
- To provide a standard operational procedure to carry out spirometry from current guidelines.

Summary

'Spirometry is a simple test of lung function'. How often have we heard that statement? Does this come to mind when trying to get an 80-yr-old, ill, somewhat confused patient to follow instructions and perform an acceptable, reproducible test in our department? NO. Of course, there is more to spirometry than the patient being able to follow instructions, but that is another issue. Let's start with the basics. Three things impact on good test results: 1) the operator (be it a technician, scientist, nurse, physiotherapist or doctor); 2) the equipment (in this case a spirometer (desktop or handheld) or hospital department lung function equipment); and 3) the patient (who can be young, interested and co-operative, or elderly, ill and non-cooperative, or somewhere in between). All three can impact in a positive or negative way on your test results; therefore, it is important to optimise the working of each one to rule out problems.

The operator

The operator performing the spirometry testing needs to be properly trained in the technique. Spirometry is carried out for varied reasons to gather information on the patient. In the hospital setting, patients are assessed to diagnose symptoms, to assess pre- and post-operative risks, to assess progress of known lung disease or to screen those at risk of having a lung disease. Testing is also carried out to evaluate therapeutic intervention, for example, improvement post-steroid trial or post-bronchodilator initiation. Patients on toxic drugs are assessed regularly to monitor adverse reactions. Spirometry is also useful when assessing patients beginning pulmonary rehabilitation programmes. In the community, general practice nurses assess chronic obstructive pulmonary disease (COPD) and asthma patients locally, and monitor progress. In the workplace, occupational health nurses assess 'normal' subjects who may be starting a job in a potentially risky environment, *e.g.* with chemicals, or those whose company policy is regular screening of employees. Research nurses, students or scientists also use spirometry to assess subjects in drug trials or for epidemiological studies.

All these operators, with different backgrounds and training, need to be able to communicate with the subject and give proper instructions to get reliable, reproducible test results, recognise errors during the test and correct them, and carry out correct analysis on the test results for reporting purposes. If the operator does not fully understand the principles or

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physiology behind the test they may miss important abnormalities during the test, or misinterpret errors as abnormal function.

There is currently a European Respiratory Society Taskforce working on putting together guidelines for spirometry training, and these should be available some time in 2010. This will offer a syllabus that will enable interested parties access to a standardised training process to carry out accurate spirometry assessment on their patients, locally.

The equipment

To ensure reliable results, spirometry equipment must be well maintained and calibrated regularly. Whether the spirometer is hospital-based or in the community, a log of calibration and repairs is required. A record of software and hardware updates should also be kept on file so that this information can be easily accessed if required.

Calibration is the process for establishing the relationship between sensor-determined values of flow or volume and the actual flow or volume. A 3-L calibration syringe is used to carry out calibration checks, this is the process used to validate that the device is within calibration limits, *e.g.* ±3% of true value. Calibration checks must be undertaken daily or more frequently if there are large temperature changes within the test area or if specified by the manufacturer.

Syringes can also become unstable. If dropped, or if the seal is worn, the syringe will need to be repaired and re-calibrated. Syringes must have an accuracy of ±15 mL or ±0.5% of the full scale. Syringes should also be periodically leak tested, which can be performed by attempting to empty them with the outlet corked.

It is useful to keep a log of lung function (spirometry) for one or two staff members who will not be leaving employment in the foreseeable future. These staff members should be non-smokers, have no lung disease and not be on medication that may impact lung function. These 'biological' tests can be carried out regularly, *e.g.* weekly, to keep a record of equipment performance on 'normal' subjects. A member of staff in the department should take responsibility for these measurements. A folder of relevant information should be kept beside the machine to ensure that whoever is using the spirometer can easily see when the last calibration was carried out and, if problems arise with the machine, can check to see whether similar problems occurred previously and how they were rectified. A regular service of the machine should be organised, which will ensure that all parts are functioning correctly.

The patient

Patients can be very different, some are easy to deal with and follow instructions precisely; however, others need more explanation and encouragement in order to achieve reliable results. Patients in hospital will often be anxious and expecting bad news when tested, therefore, the person carrying out the test will need to be able to relax the patient so they perform with maximal effort. Spirometry is probably the only diagnostic test where the patient is actively involved in the test process. The patient needs to understand what is expected of them and be able to follow instructions precisely and in a timely manner to ensure accurate test results. Patients performing the test for the first time may sometimes require a demonstration with a mouthpiece to help them understand the process. Remember, the better you explain, the easier it is for the patient to perform the test, and the less stressful the test will be for both you and the patient!

The test

There are three phases to spirometry testing: 1) full (maximal) inspiration; 2) 'blast' out with maximal effort; and 3) continuation of this expiratory effort until no air remains in the lungs (exhalation should be for a minimum of 6 s in adults but may take longer in patients with obstructive lung disease). The operator will need to encourage the patient to perform with maximal effort from the start of inspiration, until end expiration. The patient will need to rest between successive attempts. A minimum of three efforts is required, but up to eight may be carried out until reproducible results are achieved (forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) with two best efforts not differing by ≥150 mL).

It is recommended that patients are tested in a seated position to rule out falling down due to syncope as a result of the fast and maximal effort required during the test. Patients with COPD may also become hypoxic due to the prolonged effort required to get to true FVC, but with a rest of ~1 min between efforts (or longer if required) should suffer no ill effects carrying out the test. If you allow a patient to stop their expiratory effort before they reach the end-point you will underestimate FVC, possibly diagnosing them as

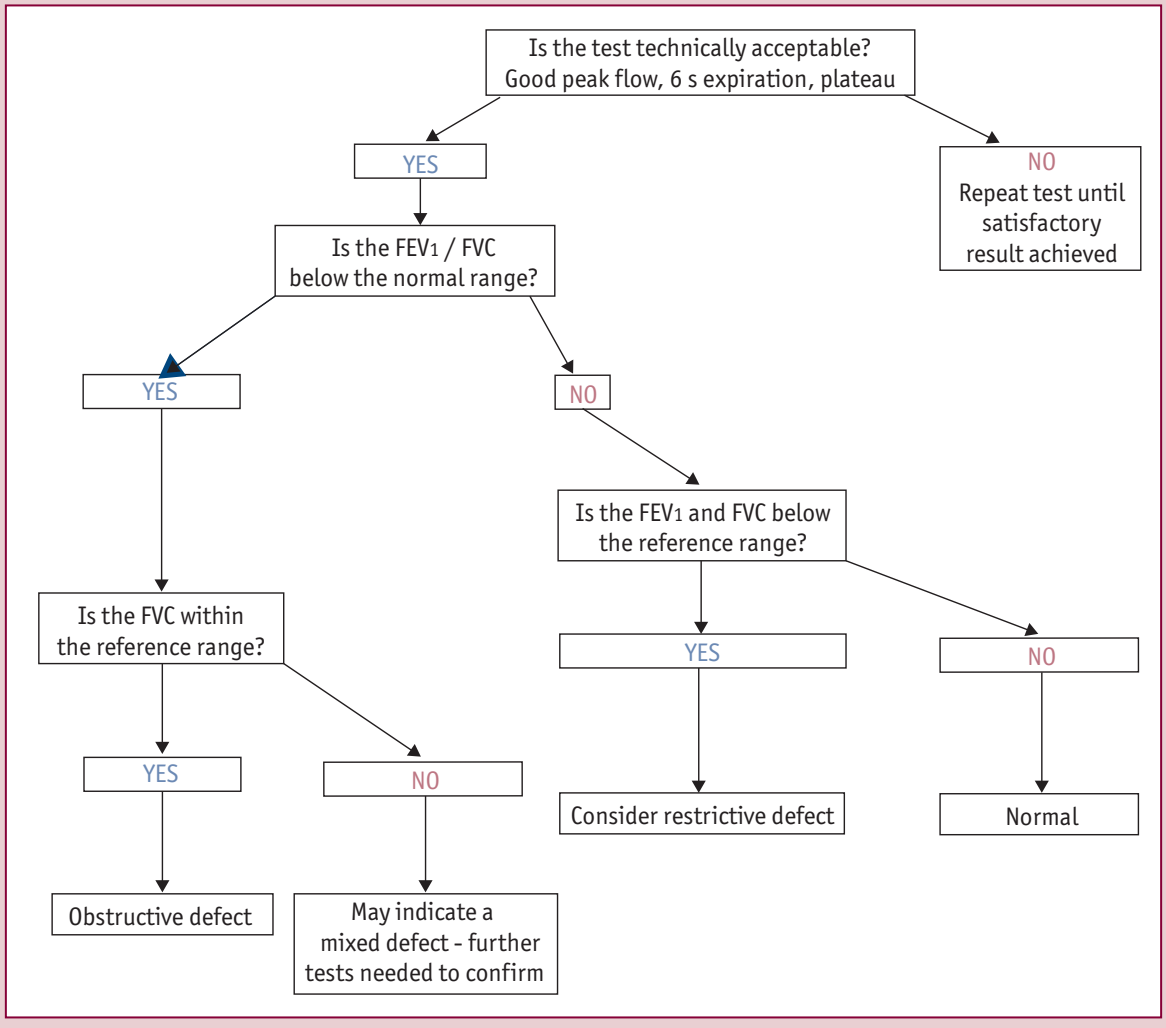
'restricted', or underestimate their real FEV_1/FVC value. The value of forced expiratory volume in 6 s is still controversial, but with adequate rest most patients can achieve a true FVC.

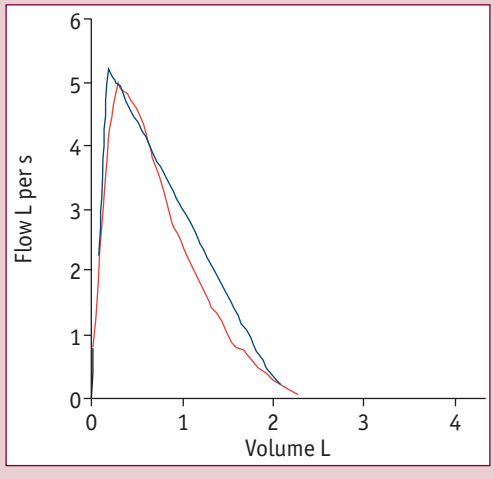
A patient's facial expression will often tell you how distressed they are towards end expiration, but if they become really distressed you should stop the test. A properly trained operator will notice the difference between a really distressed patient and one who has just 'given up' because they feel we are pushing them a little too much!

Errors during testing

1. **Unsatisfactory start of test** – characterised by a slow start or hesitation when starting exhalation. The patient must be encouraged to inhale to total lung capacity, and then immediately 'blast' out until no air remains, *i.e.* to residual volume or for a minimum of 6 s in adults or 3 s in children aged <10 yrs. A slow start will give rise to inaccurate results and efforts with a slow start should not be used for reporting. A slow start can be identified by drift to the right of initial effort on a flow–volume curve, rather than a sharp rise in flow at the start of expiratory effort.
2. **Coughing during the test** – if you notice your patient cough either at the start of the expiratory effort, or at end expiration, you should try to get a test without cough. Sometimes patients cough into the device at start of exhalation which may falsely raise the peak flow measurement. Coughing at end exhalation may cause the patient to stop blowing and result in an underestimated FVC measurement. Measurement of slow vital capacity (SVC) may be needed to accurately assess vital capacity (VC). If SVC is the largest VC achieved then FEV_1/SVC should be reported.
3. **Hesitation or swallowing during the expiratory manoeuvre** – causes a cessation or reduction of flow during the test, and will cause unreliable test results. The patient should be encouraged throughout the test to blow as hard as possible.
4. **Obstruction or leak at the mouthpiece** – patients sometimes try to stick their tongue into the mouthpiece. Encourage the patient to keep their tongue away from and to keep their lips tightly closed around the mouthpiece, to ensure that no air escapes during manoeuvre, reducing test result values.
5. **No extra breath during the test, or towards the end of exhalation** – this may fool the equipment into 'adding' both breaths together and give a higher than accurate FVC. These extra breaths can be seen on the flow–volume curve (as an extra loop at the end of expiration), or on the volume–time curve (as an extra 'hump' on your normal curve, increasing the VC value).

How to assess the results





Flow–volume curves

The shape of the flow–volume curve can be indicative of a certain disease pattern. Here are examples of some of the more common curves achieved on routine spirometry:

Figure 1
A normal (red) flow–volume curve sees a sharp rise in flow at the start of the test, and a flow graph that closely follows the predicted line (blue). The flow drops off in a uniform fashion down to the x-axis, with no abrupt stop or cessation of flow.

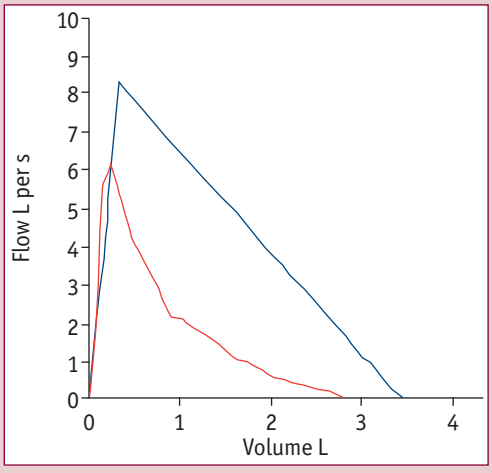


Figure 2
As mild obstructive lung disease (red) develops, the flow rate drops below the predicted line on the flow–volume graph. The initial rise in flow is maintained, but to a lesser extent than 'normal', and there is a steady drop off as the obstruction causes closure of the airways on forced expiration. The FVC is still within normal limits (measured on x-axis). Predicted: blue.

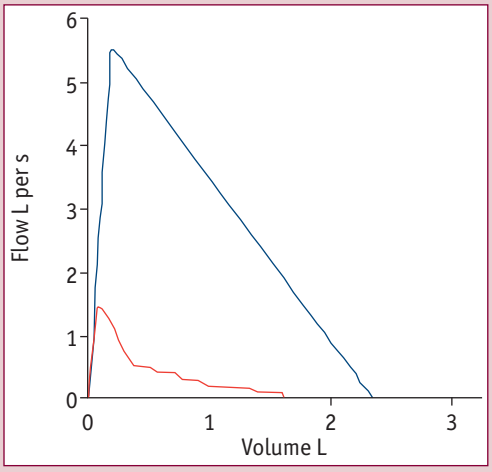


Figure 4
In severe obstructive disease (red), e.g. emphysema, there is significant flattening of the expiratory curve. There is evidence of initial effort (peak flow), but the curve quickly flattens out due to closure of the airways because of damage to the walls and subsequent collapse on forced expiratory effort. The flow rates are low and greatly below the predicted (blue). FVC will probably be reduced at this stage.

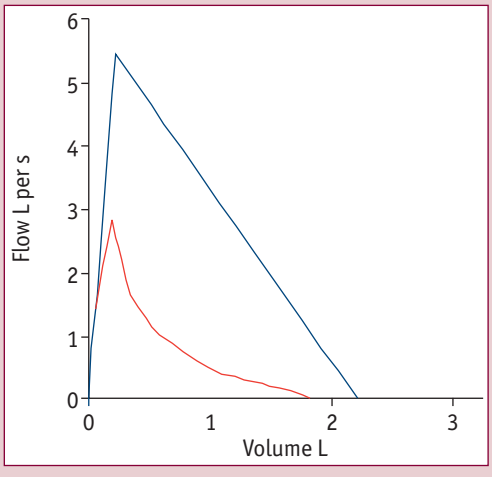


Figure 3
In moderate obstructive disease (red), the flow–volume curve becomes more 'scooped-out', and further away from the predicted line (blue). Mid-flow rates are reduced and FEV1 is also significantly reduced.

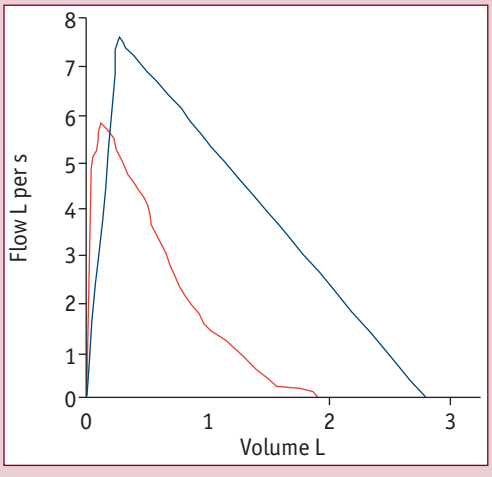


Figure 5
In a restricted patient (red), the shape of the expiratory curve is similar to that of a normal subject but smaller. You can see that the volume is significantly less than the predicted (blue), while the flow reduces from peak flow at the start of the manoeuvre to residual volume in a normal fashion (without flattening or 'scooping out').

Further reading

Miller MR, Hankinson J, Brusasco V, *et al*. Standardisation of spirometry. *Eur Respir J* 2005; 26: 319–338.

Miller MR, Crapo R, Hankinson J, *et al*. General considerations for lung function testing. *Eur Respir J* 2005; 26: 153–161.

For more information regarding the use of spirometry and on the abbreviations used please read:

Hughes JMB. Interpreting pulmonary function tests. *Breathe* 2009; 6: 103–110.

Quanjer H, Tammeling GJ, Cotes JE, *et al*. 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. *Eur Respir J* 1993; 6 Suppl. 16, 5-40.

Standardisation of Spirometry 1994 update. American Thoracic Society. *Am J Respir Crit Care Med* 1995; 152: 1107–1136.

Pulmonary function laboratory management and procedure manual. 2nd Edn. New York, American Thoracic Society, 2005.

Standard operating procedure: spirometry

Process

Spirometry is a physiological test that measures how an individual inhales/exhales volumes of air as a function of time. It is an objective assessment of lung function and can be used as a screening test of general respiratory health.

Indications

Diagnostic

- To evaluate symptoms, signs or abnormal laboratory tests
- To measure the effect of disease on pulmonary function
- To screen individuals at risk of having pulmonary disease
- To assess pre-operative risk
- To assess prognosis
- To assess health status before beginning strenuous physical activity programmes

Monitoring

- To assess therapeutic intervention
- To describe the course of diseases that affect lung function
- To monitor people exposed to harmful agents
- To monitor for adverse reactions to drugs with known pulmonary toxicity

Disability/impairment evaluations

- To assess patients as part of a rehabilitation programme
- To assess risks as part of an insurance evaluation
- To assess individuals for legal reasons

Public health

- Epidemiological surveys
- Derivation of reference equations
- Clinical research

Contraindications

- Recent myocardial infarction – patients should not be tested within 1 month
- Patients with the following are unlikely to achieve optimal or reproducible results:
  - Chest or abdominal pain of any cause
  - Oral or facial pain exacerbated by a mouthpiece
  - Stress incontinence
  - Dementia or confused state

Patient preparation

Patients should be advised to avoid the following prior to testing:

- Smoking within 1 h
- Consuming alcohol within 4 h
- Performing vigorous exercise within 30 min
- Wearing tight-fitting clothing
- Eating a large meal within 2 h

The decision to avoid long- and short-acting bronchodilators is clinical, and depends on the question being asked. If the test is being carried out to diagnose a particular condition it is useful to withhold medication.

Testing may be performed in the sitting or standing position, which should be noted on the report. Sitting is preferable for safety reasons in order to avoid falling due to syncope. The chair should have armrests and be without wheels. If a wheelchair is used, the brake should be applied during the test. If the patient is tested in the standing position a chair should be placed behind them so that they can be moved into a sitting position should they become dizzy or light-headed during the test. Obese patients will often attain a deeper inspiration in the standing position – consequently forced expiratory volumes and flows may improve in the standing position in these individuals.

Dentures should be left in place; however, if they are loose and interfering with the test performance, they should be removed.

Equipment/supplies used

- Spirometer
- Single-use, biological filter
- Rubber mouthpiece/cardboard mouthpiece with filter
- Noseclip
- Height and weight scale
- A sink for staff hand-washing between patients and after handling mouthpieces or used equipment
- Sterilising supplies for equipment (refer to equipment manual for preferred process)

Filters should always be used. As a minimum, the standard cardboard mouthpiece with plastic filter will prevent patients inhaling bacteria/viruses from the equipment, but will demand a high level of equipment sterilisation. The biological, single-use filters offer better protection to patients because they prevent bacteria/viruses entering into the equipment. Equipment will need to be sterilised in both circumstances, and a regular programme of sterilisation should be in place in all departments carrying out lung function tests. Always check independent validation of filter performance when purchasing filters.

Calibration and quality control

- Refer to the equipment manual for calibration requirements
- Calibration checks should be performed daily using a 3-L calibration syringe. A log of these checks and any other software or hardware changes should be kept in the department for future reference
- Biological testing figures should also be recorded and logged
- Problems and repairs to equipment should be recorded for future reference
- The equipment file or folder for all the above records should be kept close by the machine for easy reference by whoever is operating the equipment at any given time

Test procedure

- Check for a completed requisition form and identify the patient
- Measure patient's height in cm while standing erect and in bare feet. For patients with spinal deformity, arm-span measurement can be substituted as estimate for standing height. Have the patient stand against a wall and spread their arms out straight to their side and measure from fingertip to fingertip of the middle fingers
- Measure patient's weight in indoor clothes without shoes
- Date of birth should be recorded on day of test. Check date in equipment software to ensure accurate correlation (age, height and sex are used to determine predicted values)
- Explain the test and demonstrate with a spare mouthpiece and noseclip where necessary

Relaxed VC measurement

- Activate spirometer using keyboard, mouse or special key
- Patient inhales maximally to total lung capacity, places mouthpiece in mouth and seals lips around it
- Patient exhales gently into machine to residual volume
- Terminate manoeuvre using keyboard or mouse

FVC measurement

- Activate spirometer using keyboard, mouse or special key
- Patient inhales maximally to total lung capacity places mouthpiece in mouth and seals lips around it, noseclip in place
- Patient blasts air out as fast as they can until no air remains in lungs. Exhalation time should be ≥6 s in adults or ≥3 s in children <10 yrs
- Patients inhales maximally back to total lung capacity for a flow–volume loop following step 3

Acceptability and reproducibility

- Start of test must be without hesitation (satisfactory start – rapid rise in flow)
- No cough during the first second
- No early termination of exhalation
- No glottis closure
- No leak at the mouthpiece
- No obstruction of mouthpiece
- No extra breath during manoeuvre

Results are deemed 'usable' or 'acceptable':

- for a 'usable' curve, it must meet the first two criteria
- for an 'acceptable' curve, it must meet all seven criteria

There must be three acceptable manoeuvres (the difference between the largest and the next largest FVC and FEV_1 should be ≤0.15 L). For those with an FVC of ≤1.0 L, both these values are 0.10 L. If this cannot be met in three manoeuvres, then additional trials should be attempted, but no more than eight.

Reporting

- All volumes and flows are reported at body temperature and ambient pressure conditions
- The largest SVC from at least three acceptable manoeuvres is reported
- The largest FVC and largest FEV_1 from acceptable manoeuvres are reported, even though the values may not come from the same manoeuvre
- The largest peak expiratory flow is reported
- All other flows are reported from the 'best' test. The 'best' test is defined as the manoeuvre with the largest sum of FVC and FEV_1
- All inspiratory measurements are reported from the largest values obtained
- The final print out contains a graphical representation of spirometry, *e.g.* volume–time and flow–volume curve (these are useful to ensure good technical quality of manoeuvre: flow–volume curve for start of test criteria, and volume–time curve for end of test criteria)
- The technician's comments and/or grading regarding the acceptability and reproducibility of the data should be noted on the printout
- Software version and reference set used should be reported on the printout