SPIROMETRY

Performance and Interpretation for Healthcare Professionals

Faculty of Respiratory Physiology IICMS

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Background

Faculty of Respiratory Physiology of Irish Institute of Clinical Measurement Science, with the endorsement of the Irish Thoracic Society (ITS), perform spirometry to the ATS/ERS task force (2005 update): Standardisation of Spirometry, guidelines[1].
This document is based on these guidelines and will supersede the previous ITS document on Spirometry performance and interpretation[2].

What is Spirometry?

Spirometry is a physiological test that measures how an individual inhales or exhales volumes of air as a function of time. The primary signal measured in spirometry may be volume or flow.

Spirometry is invaluable as a screening test of general respiratory health in the same way that blood pressure provides important information about general cardiovascular health. However, on its own, spirometry does not lead clinicians directly to an aetiological diagnosis.

Spirometry can be undertaken with many different types of equipment, and requires cooperation between the subject and the examiner, and the results obtained will depend on technical as well as personal factors. If the variability of the results can be diminished and the measurement accuracy can be improved, the range of normal values for populations can be narrowed and abnormalities more easily detected[3].

Definitions

FVC (Forced vital capacity) is the maximal volume of air exhaled with maximally forced effort from a maximal inspiration, i.e. vital capacity performed with a maximally forced expiratory effort, expressed in litres at body temperature and ambient pressure saturated with water vapour (BTPS).

FEV1 (Forced Expired Volume in one second): volume expired in the first second of maximal expiration after a maximal inspiration.

FEV1/FVC: FEV1 expressed as a percentage of the FVC, gives a clinically useful index of airflow limitation.

The ratio FEV1/FVC is between 70% and 80% in normal adults; a value less than 70% suggests airflow limitation.

Who should get a Spirometry test?

Table 1. Indications for Spirometry

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 injurious 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

Who performs Spirometry?

The majority of spirometry testing is performed by qualified Respiratory Physiologists in the acute hospital setting.

However, with adequate training, accurate and reproducible spirometry may be performed by General Practitioners, Respiratory Nurses, Practice Nurses, Physiotherapists and other Healthcare Professionals. An accredited spirometry training programme is now available. The CPD Certificate in Spirometry for Healthcare Professionals (www.iars.ie) is provided by the Irish Association of Respiratory Scientists (now the Faculty of Respiratory Physiology IICMS) in conjunction with Dublin Institute of Technology, Kevin Street. It is strongly recommended that any healthcare professional taking up spirometry testing obtain this qualification thus confirming their competency to perform quality spirometry on patients.

Quality Spirometry

In order to ensure accurate and reproducible data, Spirometry must be considered under the following headings.

- Equipment performance criteria
- Equipment Validation
- Quality Control
- Subject/patient manoeuvre
- Measurement Procedure
- Acceptability
- Repeatability
- Reference Value/Interpretation
- Clinical Assessment
- Quality Assurance
- Feedback to Clinical Measurement Scientist

Equipment Performance Criteria

While manufacturers are responsible for demonstrating the accuracy and reliability of the spirometers they sell, it is the user who is responsible for ensuring that the equipment's measurements remain accurate.

The spirometer must be capable of accumulating volume for 15 seconds (longer times are recommended) and measuring volumes of ≥8 L (BTPS) with an accuracy of at least ±3% of reading or ±0.050 L, whichever is greater, with flows between 0 and 14 L/s^{-1}.
The total resistance to airflow at 14.0 L/s^{-1} must be <1.5 $cmH2O.L^{-1}.s^{-1}$ (0.15 $kPa.L^{-1}.s^{-1}$) the total resistance must be measured with any tubing, valves, pre-filter, etc. included that may be inserted between the subject and the spirometer.

Spirometer Display

For optimal quality control, both flow–volume and volume–time displays are useful, and test operators should visually inspect the performance of each manoeuvre for quality assurance before proceeding with another manoeuvre. This inspection requires tracings to meet the minimum size and resolution requirements set forth in this standard.

Quality control including Calibration and Verification

Calibration is the procedure for establishing the relationship between sensor-determined values of flow or volume and the actual flow or volume. Most portable spirometers are calibrated by the manufacturer on an annual basis. Certificates of calibration should be obtained.

A verification check is different from calibration and is the procedure used to validate that the device is within calibration limits, e.g. ±3% of true value. If a device fails its calibration check, then new calibration procedure or equipment maintenance is required. Calibration checks must be undertaken daily, or more frequently if there is a change in temperature of ≥5 degrees or if the equipment is constantly being moved.

The syringe used to check the volume calibration of spirometers must have an accuracy of ±15 ml or ±0.5% of the full scale (15 ml for a 3-L syringe), and the manufacturer must provide recommendations concerning appropriate intervals between syringe calibration checks. Users should be aware that a syringe with an adjustable or variable stop may be out of calibration if the stop is reset or accidentally moved. Calibration syringes should be periodically (e.g. monthly) leak tested at more than one volume up to their maximum; this can be done by attempting to empty them with the outlet corked. A dropped or damaged syringe should be considered out of calibration until it is checked.

The calibration syringe should be stored and used in such a way as to maintain the same temperature and humidity of the testing site. This is best accomplished by keeping the syringe in close proximity to the spirometer, but out of direct sunlight and away from heat sources.

Attention to equipment quality control and calibration is an important part of good spirometry practice. At a minimum, the requirements are as follows:

1. A log of calibration results is maintained

2. The documentation of repairs or other alterations which return the equipment to acceptable operation

3. The dates of computer software and hardware updates or changes

4. If equipment is changed or relocated (e.g. industrial surveys), calibration checks and quality-control procedures must be repeated before further testing begins.

Key aspects of equipment quality control are summarised in Table 2.

TABLE 2 Summary of equipment quality control

Test	Minimum interval	Action
Volume	Daily	Calibration check with a 3-L syringe
Leak	Daily	3 cmH2O (0.3 kPa) constant pressure for 1 min
Volume linearity	Quarterly	1-L increments with a calibrating syringe measured over entire volume range
Flow linearity	Weekly	Test at least three different flow ranges
Time	Quarterly	Mechanical recorder check with stopwatch
Software	New versions	Log installation date and perform test using ‘‘known’’ subject

Measurement procedure

Pre Test preparation

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

Smoking within 1 hour
Consuming alcohol within 4 hours
Performing vigorous exercise within 30 minutes
Wearing tight fitting clothing
Eating a large meal within 2 hours

The decision to avoid long and short acting bronchodilators is clinical and depends on the question being asked (see section on reversibility testing).
If the test is being performed for the first time it is best to withhold medication.

Contraindications

The updated (2005) ATS/ERS task force on Standarisation of Spirometry[1] states:

- 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

Spirometry test - patient steps

There are three distinct phases to the FVC manoeuvre, as follows:

1. maximal inspiration
2. a ‘‘blast’’ of exhalation
3. continued complete exhalation to the end of test (EOT)

The trained operator should demonstrate the appropriate technique and follow the procedure described in Table 3.

The subject holds the mouthpiece between lips and teeth.
The subject should inhale rapidly and completely from functional residual capacity (FRC), making sure the lips are sealed around the mouthpiece and that the tongue does not occlude it, and then the FVC manoeuvre should begin with minimal hesitation.

Reductions in PEF and FEV1 have been shown when inspiration is slow and/or there is a 4–6 s pause at total lung capacity (TLC) before beginning exhalation.[3] It is, therefore, important that the preceding inspiration is fast and any pause at full inspiration be minimal (i.e. only for 1–2 s).

The spirometry test assumes a full inhalation before beginning the forced exhalation, and it is imperative that the subject takes a complete inhalation before beginning the manoeuvre.

The subject should be prompted to ‘‘blast,’’ not just ‘‘blow,’’ the air from their lungs, and then he/she should be encouraged to fully exhale.

Throughout the manoeuvre, enthusiastic coaching of the subject using appropriate body language and phrases, such as ‘‘keep going’’, is required.

With appropriate coaching, children as young as 5 yrs of age are often able to perform acceptable spirometry[5]. The persons involved in the pulmonary function testing of children should be specifically trained to deal with such a situation.

TABLE 3 Procedures for Recording Forced Vital Capacity

Perform spirometer calibration/verification, only test on patient if calibration/verification is passed

Wash hands before greeting the patient, get patient to wash their hands with bacterial gel

Prepare the subject

Ask about smoking history, recent illness, medication use in particular inhaled medications, etc.
Check for contraindications
Measure weight and height without shoes
Enter patient demographics accurately, age, gender, height, weight, and race

Explain the test

Instruct and demonstrate the test to the subject, to include:

Correct posture with head slightly elevated
Inhale rapidly and completely
Position of the mouthpiece (open circuit)
Exhale with maximal force

Perform manoeuvre (closed circuit method), in seated upright position

Have subject assume the correct posture, feet on floor, legs & arms uncrossed, comfortable clothing
Attach nose clip, place mouthpiece in mouth and close lips around the mouthpiece
Inhale completely and rapidly with a pause of <1 s at TLC (total lung capacity)
Exhale maximally (blast out) until no more air can be expelled while maintaining an upright posture
Repeat instructions as necessary, coaching vigorously
Repeat for a minimum of three manoeuvres; no more than eight are usually required
Check test repeatability and perform more manoeuvres as necessary

Perform manoeuvre (open circuit method), in seated upright position

Have subject assume the correct posture, feet on floor, legs & arms uncrossed, comfortable clothing
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Summary of within and between manoeuvre acceptability criteria for spirometry test

The acceptability criteria of a spirometry trial are a satisfactory start of test and a satisfactory end of test, i.e. a plateau in the volume–time curve. In addition, the person should observe that the subject understood the instructions and performed the manoeuvre with a maximum inspiration, a good start, a smooth continuous exhalation and maximal effort.

Within manoeuvre criteria

Individual spirograpms are “acceptable” if

1. They are free from the following:
    - Cough during the first second of exhalation
    - Glottis closure that influences the measurement
    - Early termination or cut off
    - Effort that is not maximal throughout
    - Leak
    - Obstructed mouthpiece (e.g. obstruction due to the tongue being placed in front of the mouthpiece, or teeth in front of the mouthpiece)
    - An extra breath being taken during the manoeuvre

2. They have a good start
    - Extrapolated volume <5% of FVC or 0.15L whichever is greater

3. They show satisfactory exhalation/EOT
    - Duration of ≥ 6 s (3s for children) or a plateau in the volume-time curve or if the subject cannot or should not continue to exhale.

Between manoeuvre criteria

After three acceptable spirograms have been obtained ensure the following:
The two largest values of FVC must be within 0.150L or each other
The two largest values of FEV1 must be within 0.150 L of each other
If both of these criteria are met, the test session may be concluded.

If both of these criteria are not met continue testing until;

- both of the criteria are met, or
- a total of eight tests have been performed, or
- the patient/subject cannot or should not continue

Spirometry Graphs and Tracings

Examination of the graphical representation of a spirometry test is invaluable for both identifying patient errors and in aiding the interpretation of spirometric results. Two graphs are produced in a spirometry test; a flow/volume loop and a volume time curve. It is recommended that both types of graph are produced on the final report. The flow volume loop is very helpful at showing the start of the test whilst the volume time graph confirms if end of test (EOT) criteria have been met. Figures 1 and 2 show examples of common errors found on spirometry trials. The flow volume loop is also useful in determining the pattern of abnormality in the patient's lung function and it is important that the graph is reviewed as part of the interpretation process. Figures 3 and 4 show spirometry patterns in different types of disease

Figure 1. Volume Time examples of good and poor effort

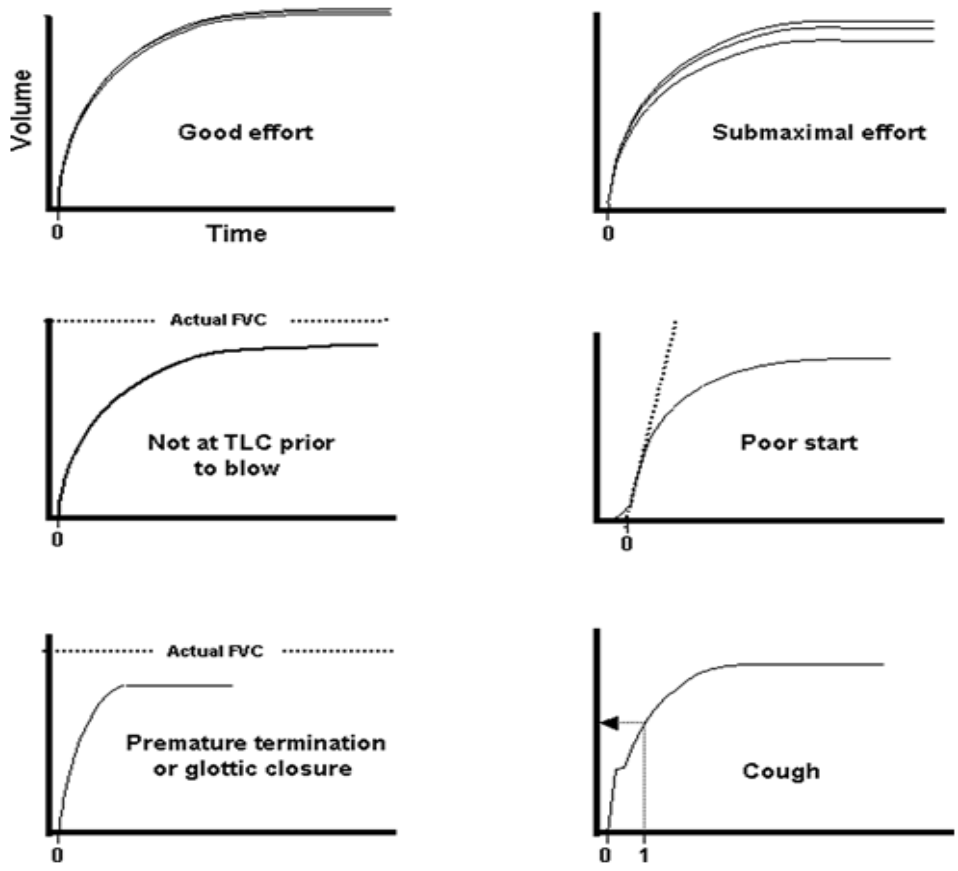


Figure 2. Flow Volumes Curve examples of good and poor effort

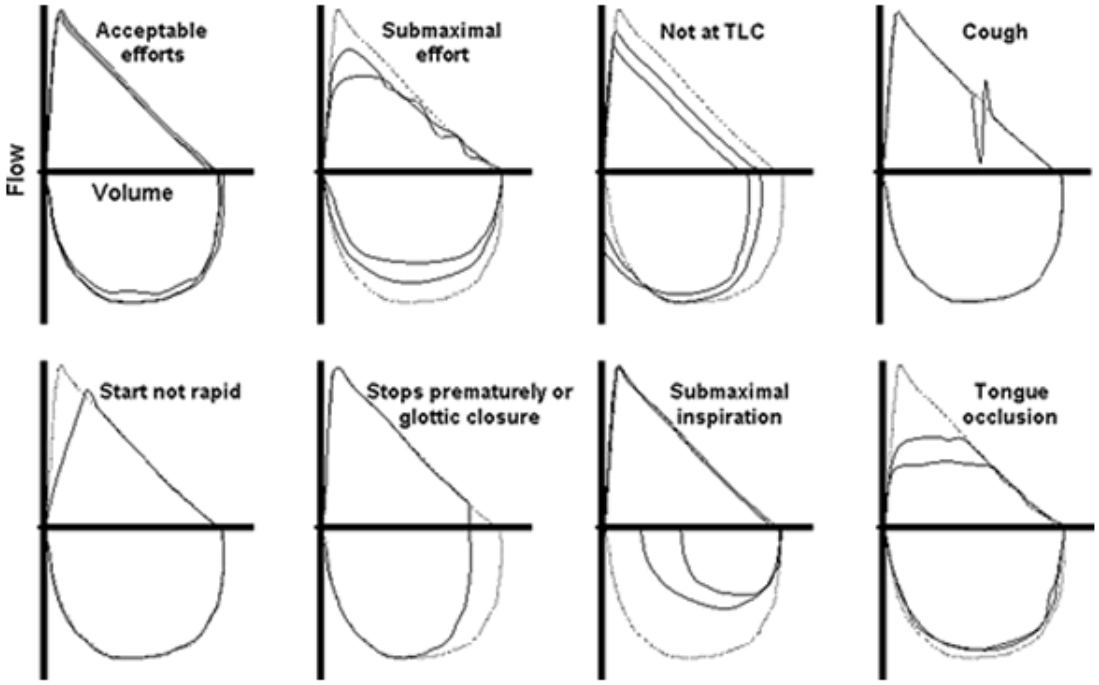
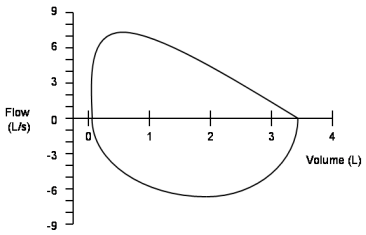
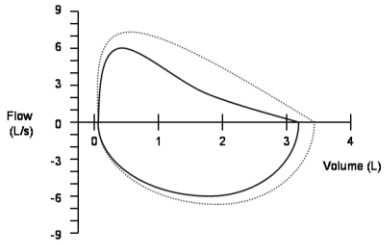


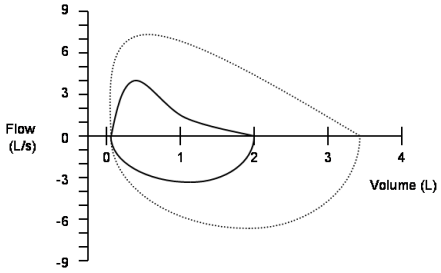
Figure 3. Airways obstruction –Flow Volume Loop patterns



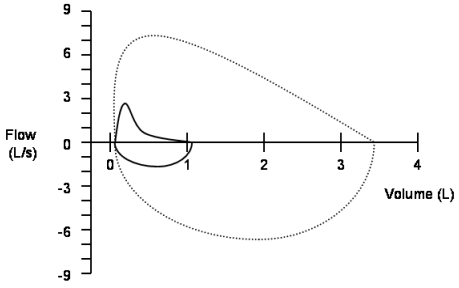
Normal – no airflow obstruction



Mild Airflow Obstruction

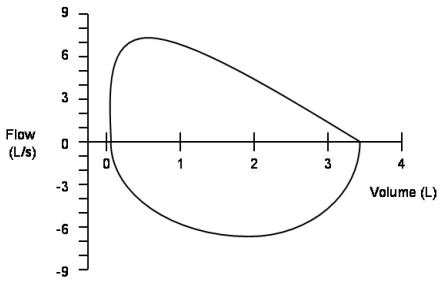


Moderate Airflow Obstruction

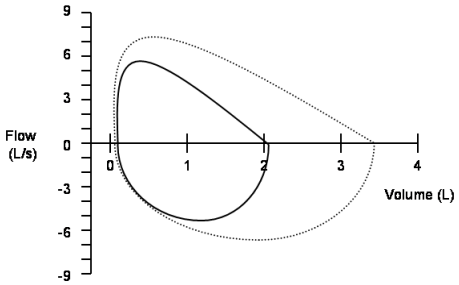


Severe Airflow Obstruction

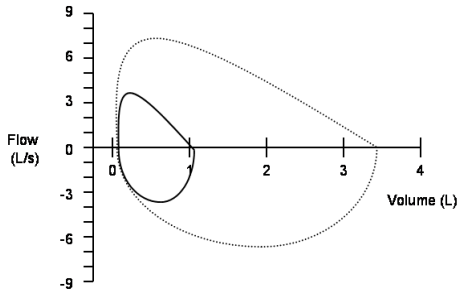
Figure 4. Restrictive Disorders – Flow volume loop patterns



Normal – no restriction



Moderate Restrictive Defect



Severe Restrictive Defect

Reversibility Testing

Reversibility testing can be undertaken for two reasons:

1. To determine if airflow limitation can be reversed with drug administration
2. To determine whether the patients lung function can be improved with therapy, in addition to their regular treatment.

In the latter case the subject may take their prescribed medication prior to the test. However, in the first case the subject should undergo baseline function testing when not taking any drugs prior to the test.

Short-acting inhaled drugs (e.g. the ß-agonist albuterol/salbutamol or the anticholinergic agent ipratropium bromide) should not be used within 4 hours of testing.

Long-acting ß -agonist bronchodilators (e.g. salmetorol or formoterol) and oral therapy with aminophylline or slow release ß -agonist should be stopped for 12 h prior to the test.

Reversibility test procedure

The subject has three acceptable and repeatable tests of FEV1, FVC and PEF recorded as described previously.

According to the ATS/ERS guidelines[1], after a gentle and incomplete expiration, a dose of 100 mg of albuterol/salbutamol is inhaled in one breath to TLC from a valved spacer device.

The breath is then held for 5–10 s before the subject exhales.

Four separate doses (total dose 400 mcg) are delivered at, 30 s intervals.

This dose ensures that the response is high on the albuterol dose–response curve. A lower dose can be used if there is concern about any effect on the patient's heart rate or tremor.

Other drugs can also be used.

For the anticholinergic agent ipratropium bromide, the total dose is 160 µg (8 puffs delivered).

Three additional acceptable and repeatable spirometry trials are recorded 15 min later for short-acting ß2-agonists and 30 min later for short-acting anticholinergic agents.

Interpretation

Interpretation begins with a review of the flow volume graph and technical comments on test quality. Tests that are less than optimal may still contain useful information but interpreters should identify the problems and the direction and magnitude of the potential errors. Omitting the quality review and relying only on numerical results for clinical decision making is a common mistake, which is more easily made by those who are dependent upon computer interpretations.

Reference Equations

Interpretation of spirometry is usually based on comparison of data measured in an individual patient or subjects with reference (predicted) values based on

healthy subjects with the same sex, age, height and weight and where relevant, ethnic characteristics of the patient being tested.

Height and weight should be measured, without shoes, for each patient at the time of testing; a trained operator should not rely on stated height or weight. When height cannot be measured the height can be estimated from using arm span[6].

GOLD Guidelines[7]

The 2014 updated GOLD guidelines have proposed four different stages of COPD based largely on post bronchodilator FEV1 measures (Table 4).

GOLD guidelines recommend that a diagnosis of COPD should be considered and spirometry performed for any patient who has cough, sputum production, or dyspnoea, and/or a history of exposure to risk factors for the disease[7].

This includes all current and former smokers, and any adult with a history of exposure to tobacco smoke, occupational dusts and chemicals, or smoke from home cooking and heating fuels.

Table 4 Classification of Severity of Airflow Limitation in COPD (Based on Post-Bronchodilator FEV_1)

	Inpatients with FEV1/FVC < 0.70:	
GOLD I:	Mild	$FEV_1 \geq 80\%$ predicted
GOLD 2:	Moderate	$50\% \leq FEV_1 < 80\%$ predicted
GOLD 3:	Severe	$30\% \leq FEV_1 < 50\%$ predicted
GOLD 4:	Very Severe	$FEV_1 < 30\%$ predicted

Differential diagnosis of COPD vs. Asthma

COPD
Usually onset in mid-life.
Symptoms slowly progressive.
Often history of tobacco smoking.
Dyspnoea during exercise.
Largely irreversible airflow limitation.

Asthma
Onset early in life (often childhood).

Symptoms vary from day to day.
Symptoms at night/early morning.
Allergy, rhinitis, and/or eczema may also present.
Family history of asthma.
Largely reversible airflow limitation.

Guide to Interpreting the results[7]

When the diagnosis is not confirmed it is recommended to apply the ATS/ERS 2005 interpretation guidelines to the spirometry results[8]. The ITS diagnostic flow chart on page 18 can also be helpful in analysing the results. The following steps are the recommended approach to spirometry interpretation as per the accredited spirometry programme run by the IARS/DIT group.

1. Review the technical quality comment, sub optimal results need to be interpreted with caution

2. Inspect the flow volume graph to confirm good technique and to confirm the presence or absence of airflow obstruction (scooping out on the expiratory portion). Figures 1 and 2, page 11

3. Start with the FEV_1/FVC ratio

4. **In airflow obstruction**, patients cannot exhale the air in their lungs quickly. Therefore, the FEV_1 tends to fall, while the FVC remains relatively preserved (falling only in more severe airflow obstruction). **The FEV_1/FVC ratio is reduced below 70%.** If this is the case, **the patient may have asthma, COPD or another cause of airflow obstruction** – proceed to point 5

5. If the **FEV_1/FVC ratio is greater than 70%,** this usually represents **normal pulmonary function** but can occasionally represent **restrictive disease**. If the absolute values of FEV_1 and FVC are normal, then the test is normal. If the FEV_1 and FVC values are proportionately reduced, then the patient may have restrictive pulmonary disease.

6. The commonest cause of apparent restrictive disease is poor technique, where the apparent reduction in FEV_1 and FVC are due to poor patient effort rather than a true reduction in their value – this underscores the importance of observation of patient effort during the procedure.

7. The degree of airflow obstruction allows a classification of disease severity using the GINA[9] (asthma) or GOLD[7] (COPD) guidelines, and appropriate choice of therapy or action, but only patients with these diagnoses can be stratified using these specific guidelines.

8. Assess the flow-volume curve to confirm your impression of the diagnosis (Figures 3 and 4, page 12).

9. In a patient with respiratory symptoms, airway obstruction where the FEV_1 and/or FVC increases by ≥12% and 200mls following bronchodilator therapy, is suggestive of asthma.

10. In a patient with intermittent respiratory symptoms, the lack of airway obstruction, or the lack of a bronchodilator response do not rule out asthma. Similarly, a bronchodilator response with normal spirometry does not always indicate asthma.

11. Airway obstruction in an adult smoker is usually (but not always) due to COPD.

12. After spirometry, if you remain uncertain of the diagnosis, consider referral to a hospital pulmonary function laboratory for lung volumes and a diffusing capacity estimation (to assess for evidence of emphysema or interstitial lung disease) or appropriate bronchial challenge provocation test.

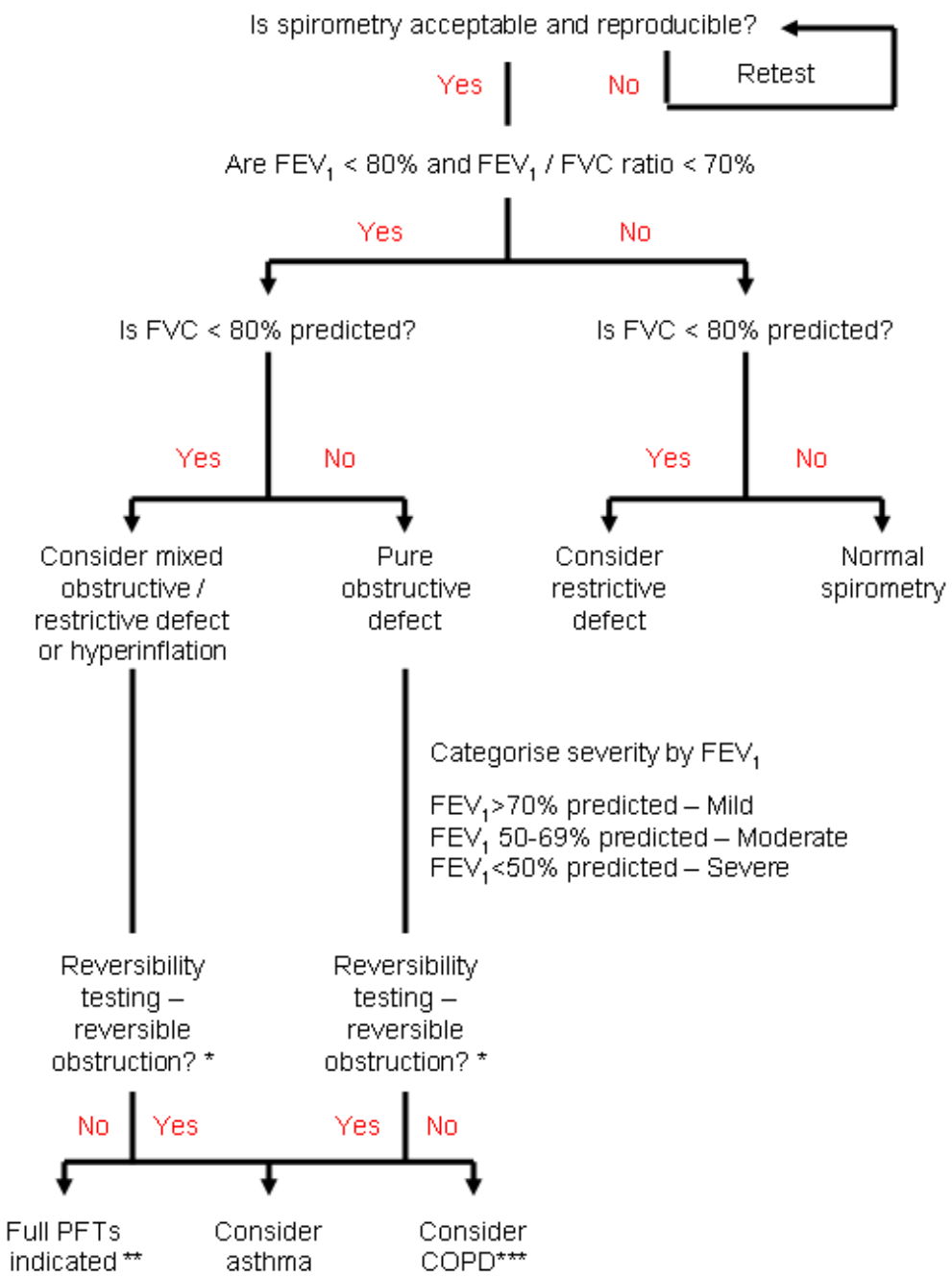
Table 5 Summary of Abnormal Spirometry Results

	Obstructive	Restrictive	Combined
FEV_1/FVC%	↓↓	N or ↑	↓
FVC	N or ↓	↓↓	↓
FEV_1	↓↓	N or ↓	↓

N – Normal ↑ - Increased compared to predicted value

↓ - Decreased compared to predicted value

Figure 5. Spirometry Diagnostic Flowchart[2]



* **Reversibility testing** with ß-agonist indicates an improvement of >12% and >200ml in FEV_1 and/or FVC approximately 15 mins after inhalation.
** **Full PFT's** refers to the measurement of diffusing capacity DL_{co} and Lung volumes using dilution or plethysmography in a computerized hospital based respiratory function laboratory to determine the severity of the defect.
*** Some subjects with chronic asthma may not respond at all to a ß-agonist. Some COPD patients may show improvement post ß-agonist.

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