



SPIROMETRY FOR HEALTH CARE PROVIDERS

Global Initiative for Chronic Obstructive Lung Disease (GOLD)

CONTENTS

I. INTRODUCTION

II. BACKGROUND INFORMATION

- A. What Is Spirometry?
- B. Why Perform Spirometry?
- C. Spirometry in Primary Care
- D. Screening for Airway Obstruction in Primary Care
- E. Recognizing COPD

III. USING SPIROMETRY IN CLINICAL PRACTICE

- A. Types of Spirometers
- B. Information Provided by the Spirometer
- C. Diagnosis of Airway Obstruction

Figure 1. GOLD Spirometric Criteria for COPD Severity

IV. SPIROGRAM INTERPRETATION

- A. Normal Lung Function
- B. Bronchodilator Reversibility Testing in COPD
- C. Patterns of Spirometric Curves

Figure 2. Normal Spirogram: Volume-Time Curve

Figure 3. Volume-Time Curves (before and after bronchodilator)

Figure 4. Features of Ventilatory Abnormality in Spirometry

Figure 5. Patterns of Ventilatory Abnormalities

- D. Flow-Volume Measurement

V. PERFORMING SPIROMETRY

- A. Preparing the Patient

Figure 6A. Normal Flow-Volume Curve

Figures 6B, 6C, 6D. Patterns of Flow-Volume Curves Showing Ventilatory Abnormalities

- B. Measuring FEV₁, FVC, and Flow-Volume Curves
- C. Differential Diagnosis

VI. TROUBLESHOOTING

- A. Accuracy and Quality of Readings
 - Figure 7. Examples: Poorly Performed Curves*
- B. Equipment Maintenance and Calibration
- C. Infection Control
- D. When to Refer for Further Respiratory Function Testing

REFERENCES

I. INTRODUCTION

Chronic Obstructive Pulmonary disease (COPD) is a clinical diagnosis that should be based on carefully history taking, the presence of symptoms and assessment of airway obstruction (also called airflow limitation). The GOLD international COPD guidelines¹, as well as national guidelines², advise spirometry as the gold standard for accurate and repeatable measurement of lung function. Evidence is emerging that when spirometry confirms a COPD diagnosis, doctors initiate more appropriate treatment. Spirometry is also helpful in making a diagnosis in patients with breathlessness and other respiratory symptoms and for screening in occupational environments.

Although the use of spirometers in primary care is increasing, in some countries uptake is still low. In those countries where spirometry is in more common usage, there are major concerns regarding the technical ability of operators to perform the test and interpret its results. Many primary care physicians, nurses, and other health care providers have had little formal training in spirometry. More accredited courses are appearing but these are often time consuming and fairly expensive. Many clinicians feel apprehensive about purchasing a spirometer because of uncertainties about performing and interpreting spirometry. Epidemiologic studies confirm that both late diagnosis and under-diagnosis of COPD are common—problems that wider use of spirometry could help to address.

There is therefore a considerable need to:

- Encourage the use of spirometers in primary care
- Explain the importance of spirometry in the management of COPD
- Provide information on how to perform spirometry correctly
- Explain interpretation of spirometry results

Most guidelines recommend the use of spirometers that provide a real-time trace to help assess the quality and repeatability of blows. Such spirometers tend to be quite expensive and expectations that these could be used widely in poorer countries are unrealistic. Cheaper substitutes are available at relatively low cost; these can provide the basic indices accurately but give little indication as to how well patients perform the test.

II. BACKGROUND INFORMATION

A. What Is Spirometry?

Spirometry is a method of assessing lung function by measuring the volume of air that the patient can expel from the lungs after a maximal inspiration.

The indices derived from this forced exhaled maneuver have become the most accurate and reliable way of supporting a diagnosis of COPD. When these values are compared with predicted normal values determined on the basis of age, height, sex, and ethnicity, a measure of the severity of airway obstruction can be determined. It is on these values that COPD guidelines around the world base the assessment of mild, moderate, and severe disease levels.

Spirometry is however only one way of interpreting COPD disease severity. Other measures, such as the MRC dyspnea scale for measuring breathlessness, exacerbation frequency, body mass index, quality of life assessment, and exercise capacity all help to build a more complete picture².

B. Why Perform Spirometry?

Spirometry is the best way of detecting the presence of airway obstruction and making a definitive diagnosis of asthma and COPD. Its major uses in COPD are to:

- Confirm the presence of airway obstruction
- Confirm an FEV₁/FVC ratio < 0.7 after bronchodilator
- Provide an index of disease severity
- Help differentiate asthma from COPD
- Detect COPD in subjects exposed to risk factors, predominantly tobacco smoke, independently of the presence of respiratory symptoms
- Enable monitoring of disease progression
- Help assess response to therapy
- Aid in predicting prognosis and long-term survival
- Exclude COPD and prevent inappropriate treatment if spirometry is normal

Spirometry has many other applications in assessing and managing respiratory disease. These include measuring the presence and severity of restrictive lung defects, screening of the workforce in hazardous occupational environments, pre-employment screening for certain occupations, and assessing fitness to dive. Some believe it may be useful as a motivating tool to help smokers to quit, but solid scientific evidence on this point is lacking at present, and research findings have been equivocal.

C. Spirometry in Primary Care

The development of COPD is slow and insidious and symptoms tend to be noted by patients only after there has been a significant loss of lung function, often to 50-60% of predicted value. People with COPD often present far too late to their doctor because they accept cough or mild breathlessness as a “normal” result of years of smoking or because they do not wish to be told that they have to stop smoking. However, stopping smoking is key. It is the most important way of slowing disease progression, and it is most beneficial in the early stages of COPD.

COPD is markedly under-diagnosed, with recent estimates of between 25 and 50% of patients with clinically important disease being undetected or misdiagnosed. Although awareness has increased in the last 10 years, the management and diagnosis of COPD in primary care is still poor. The wrong diagnosis is common—some patients who have a clinical diagnosis of COPD are found to have normal lung function, many patients with COPD are undiagnosed, and there is much confusion regarding labeling patients with COPD or asthma.

Primary care physicians are in an ideal position to be able to detect COPD in its early stages and perform spirometry to confirm the diagnosis^{3,4}. Management of COPD is largely carried out in primary care and much can now be done to improve symptoms and quality of life, and to reduce the frequency and impact of exacerbations. Such information is clearly set out in most national and international guidelines.

D. Screening for Airway Obstruction in Primary Care

The role of screening at-risk populations in primary care is more controversial. When assessing the efficacy of screening programs, a number of important factors need to be considered. These include the criteria for the population to be screened, the percentage of positive results, and the cost effectiveness of screening. It is crucial to assess the clinical outcomes of screening. Although we

have some answers to these questions, the main issue of whether detecting early disease in relatively asymptomatic smokers significantly increases quit rates has still to be resolved.

The most cost-effective method would appear to be a case-finding technique, performing spirometry in those at-risk of COPD. In a Dutch study⁵, 27% of smokers or ex-smokers over 35 years of age who also had a persistent cough were found to have airway obstruction.

E. Recognizing COPD

The GOLD guidelines¹ define COPD as “*A preventable and treatable disease with some significant extrapulmonary effects that may contribute to the severity in the individual patient. Its pulmonary component is characterized by airflow limitation that is not fully reversible. The airflow limitation is usually progressive and associated with an abnormal inflammatory response of the lung to noxious particles or gases.*”

The main clinical features of COPD are:

- Chronic cough, which may be daily and productive, but can also be intermittent and unproductive
- Breathlessness on exertion, initially intermittent and becoming persistent
- Sputum production: any pattern of sputum production may indicate COPD
- Frequent exacerbations of bronchitis
- A history of exposure to risk factors, especially tobacco smoke, occupational dusts, home cooking and biomass fuels.

The GOLD guidelines recommend that clinicians should suspect COPD and perform spirometry whenever any of these indicators are present in an individual aged over 40 years. When these features are present it is crucial to ask, COULD IT BE COPD?

III. USING SPIROMTERY IN CLINICAL PRACTICE

A. Types of Spirometers

There are many different types of spirometer with costs varying from 100–3,000 Euros/50–2,000 USD.

- **Bellows or rolling seal spirometers** are large and not very portable, and are used predominantly in lung function laboratories. They require regular calibration with a 3-liter syringe and are very accurate.
- **Electronic desktop spirometers** are compact, portable, and usually quick and easy to use. They have a real-time visual display and paper or computer printout. Some require calibration with the 3-liter syringe; others can be checked for accuracy with the syringe but require any changes to be performed by the manufacturer. Generally they need little attention other than cleaning. They maintain accuracy over years and are ideal for primary care.
- Small, inexpensive **hand-held spirometers** provide a numerical record of blows but no printout. It may be necessary to look up predicted values in tables, but some include these in their built-in software. Recent models allow pre-programming of patient details so that the spirometer also gives percent predicted values. These are good for simple screening and are accurate for diagnosis if the more expensive desktop form is impractical or too expensive.

Many spirometers provide two forms of traces. One is the standard plot of volume exhaled against time. The other is a plot of flow (L/sec) on the vertical axis versus volume expired (L) on the horizontal axis. This is a flow–volume trace and is most helpful in diagnosing airway obstruction.

In some countries a printed record of spirometry is essential for claiming insurance/practitioner reimbursement. The type of spirometer to be used may need to be considered in the light of this, as some automatically produce a printout, others can store data to be printed later from a PC, and others do not have printing capacity at all.

B. Information Provided by the Spirometer

The standard spirometry maneuver is a maximal forced exhalation (greatest effort possible) after a maximum deep inspiration (completely full lungs). Several indices can be derived from this blow.

- **FVC** – Forced Vital Capacity – the total volume of air that the patient can forcibly exhale in one breath.
- **FEV₁** – Forced Expiratory Volume in One Second – the volume of air that the patient is able to exhale in the first second of forced expiration.
- **FEV₁/FVC** – the ratio of FEV₁ to FVC expressed as a fraction (previously this was expressed as a percentage).

Values of FEV₁ and FVC are measured in liters and are also expressed as a percentage of the predicted values for that individual.

The ratio of FEV₁/FVC is normally between 0.7 and 0.8. Values below 0.7 are a marker of airway obstruction, except in older adults where values 0.65–0.7 may be normal. Caution particularly needs to be taken in patients over 70 years, where the use of predicted values extrapolated from the younger population may result in over-diagnosing COPD. In people over 70 years old, the FEV₁/FVC ratio may need to be lowered to 0.65 as a lower limit of normal. Conversely, in people under 45, using a ratio of 0.7 may result in under-diagnosis of airway obstruction. To avoid both of these problems, many experts recommend use of the lower limit of normal for each population.

Predicted values are calculated from thousands of normal people and vary with sex, height, age and ethnicity. The standard predicted values in most of Europe are those established by the European Respiratory Society or the European Community Health and Respiratory Survey (ECHRS), but other values may be used in different countries. Those values most appropriate for the local population should be used.

Flow–Volume Measurement - Many electronic desktop spirometers and spirometers used in lung function laboratories utilize a pneumotachograph measuring gauge, which measures airflow and integrates the signal to derive volume. This allows the spirometer to plot traces of flow rate against the volume of air exhaled, producing a flow–volume curve. On many spirometers such curves provide the main initial visual real–time display when patients are performing their blows.

FEV₆ - This is a more recently derived value which measures the volume of air that can forcibly be expired in 6 seconds. It approximates the FVC and in normal people the two values would be identical. Using FEV₆ instead of FVC may be helpful in patients with more severe airflow obstruction who make take up to 15 seconds to fully exhale. As they find this difficult and often stop

before full exhalation, the FVC, and hence the severity of airway obstruction, may be underestimated. Some new hand-held spirometers from Vitalograph use the FEV₆ instead of FVC and have predicted tables to match. The FEV₁/FEV₆ is well validated and is an acceptable alternative to FEV₁/FVC^{6,7}.

Slow VC – Slow Vital Capacity – the patient takes a full breath in as before but exhales slowly in their own time. In patients with COPD with more marked airway obstruction and dynamic compression, the slow vital capacity may exceed the FVC by > 0.5 liters. This index is not used routinely in primary care. However, ATS /ERS guidelines are increasingly suggesting FEV₁/ Slow VC as the preferred ratio⁶.

C. Diagnosis of Airway Obstruction

The spirometric criterion required for a diagnosis of COPD is an **FEV₁/FVC ratio below 0.7 after bronchodilator**.

Figure 1. GOLD SPIROMETRIC CRITERIA FOR COPD SEVERITY¹

I: Mild COPD	<ul style="list-style-type: none"> • FEV₁/FVC < 0.7 • FEV₁ ≥ 80% predicted 	At this stage, the patient may not be aware that their lung function is abnormal.
II: Moderate COPD	<ul style="list-style-type: none"> • FEV₁/FVC < 0.7 • 50% ≤ FEV₁ < 80% predicted 	Symptoms usually progress at this stage, with shortness of breath typically developing on exertion.
III: Severe COPD	<ul style="list-style-type: none"> • FEV₁/FVC < 0.7 • 30% ≤ FEV₁ < 50% predicted 	Shortness of breath typically worsens at this stage and often limits patients' daily activities. Exacerbations are especially seen beginning at this stage.
IV: Very Severe COPD	<ul style="list-style-type: none"> • FEV₁/FVC < 0.7 • FEV₁ < 30% predicted <i>or</i> FEV₁ < 50% predicted plus chronic respiratory failure 	At this stage, quality of life is very appreciably impaired and exacerbations may be life-threatening.

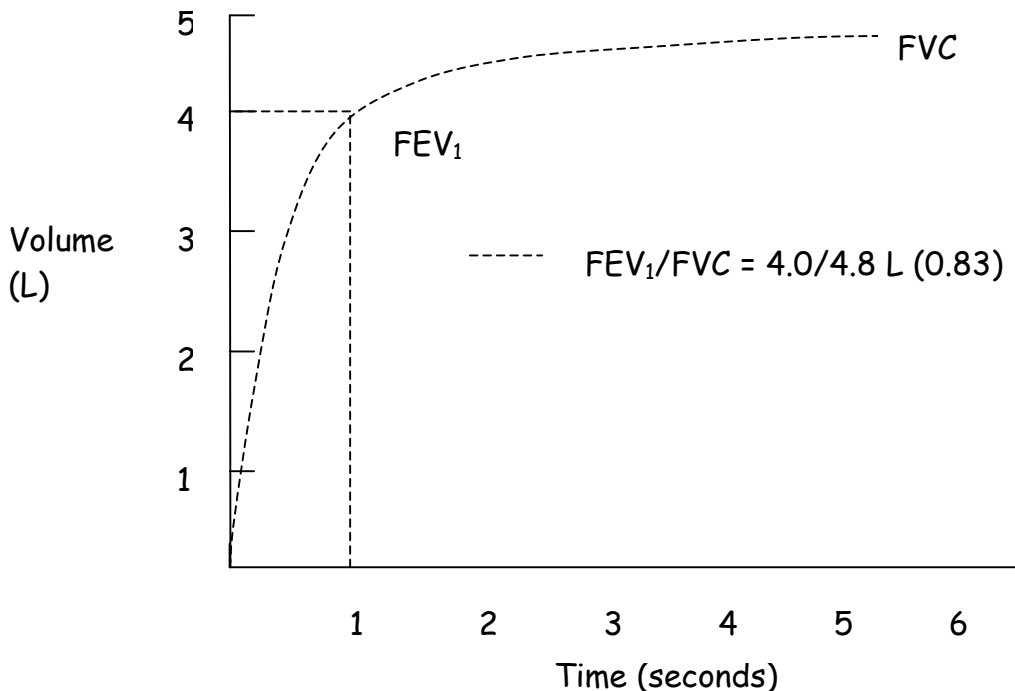
IV. SPIROGRAM INTERPRETATION

A. Normal Lung Function

Interpretation of spirometry involves looking at the absolute values of FEV₁, FVC, and FEV₁/FVC, comparing them with predicted values, and examining the shape of the spirometers. Patients should complete three blows that are consistent and within 5% of each other—many electronic spirometers automatically provide this information.

In a patient with normal lung function, the **volume–time** curve should rise **rapidly and smoothly** and plateau within 3-4 seconds. With increasing degrees of airway obstruction it takes longer to blow out the air—up to 15 seconds—and the upward slope of the spirogram is much less steep.

Figure 2. NORMAL SPIROGRAM: VOLUME-TIME CURVE



B. Bronchodilator Reversibility Testing in COPD

Assessing bronchodilator reversibility is important to determine whether fixed airway narrowing is present⁸. In patients with COPD, **post-bronchodilator FEV₁/FVC remains < 0.7**. However, the FEV₁ may improve significantly after bronchodilator, and a change of > 12% AND > 200 mL in FEV₁ can occur in COPD¹. In addition, the degree of bronchodilator reversibility can vary from day to day. Larger changes in FEV₁ do not negate a diagnosis of COPD, although the greater these changes are the greater the likelihood that the patient has asthma, either instead of or in addition to COPD.

Bronchodilator reversibility testing is best done as a planned procedure, as it is time consuming. If the patient is undiagnosed and on no therapy, acute reversibility can be assessed on the first visit. Short-acting bronchodilators need to be withheld for at least 4 hours prior to testing, and long-acting bronchodilators for 12 hours. Recent treatment with inhaled glucocorticosteroids can also reduce

bronchodilator reversibility because the pre-bronchodilator FEV₁ may improve significantly with inhaled glucocorticosteroid therapy, especially if asthma is present.

Reversibility testing needs to be interpreted in the light of the patient's clinical history and examination. Some patients with COPD can have greater reversibility and some, especially those with late-onset or longstanding asthma, demonstrate very little FEV₁ change in response to bronchodilators.

- Spirometry should be undertaken when the patient is clinically stable and free from a respiratory tract infection.
- Short-acting bronchodilators should be withheld for the previous 6 hours, long-acting bronchodilators for 12 hours, and sustained release theophylline for 24 hours.
- FEV₁/FVC should be measured **before and 15-20 minutes after** bronchodilator is given.
- The bronchodilator should be given by metered dose inhaler, ideally through a spacer. A nebulizer may be used but generally larger doses are delivered by this route.
- The dose administered should be high on the dose-response curve.
- Possible dose protocols include 400 µg salbutamol, up to 160 µg ipratropium, or the two combined.

Calculating bronchodilator reversibility:

$$\% \text{ FEV}_1 \text{ Reversibility} = \frac{\text{Post-bronchodilator FEV}_1 - \text{Pre bronchodilator FEV}_1}{\text{Pre-bronchodilator FEV}_1} \times 100$$

In the example shown in Figure 3: $\% \text{ FEV}_1 \text{ reversibility} = \frac{2.2 - 2.0}{2.0} \times 100 = 10\%$

As a general rule spirometry that becomes normal after bronchodilator is not COPD!

C. Patterns of Spirometric Curves

There are 3 basic patterns to recognize:

NORMAL: FEV₁ and FVC above 80% predicted
FEV₁/FVC ratio above 0.7

OBSTRUCTIVE: FEV₁ below 80% predicted
FVC can be normal or reduced – usually to a lesser degree than FEV₁
FEV₁/FVC ratio below 0.7

RESTRICTIVE: FEV₁ normal or mildly reduced
FVC below 80% predicted
FEV₁/FVC ratio normal - above 0.7.

Spirometry may show a restrictive pattern, suggesting the patient's dyspnea is due to a restrictive lung disease, and not COPD. In this case, the patient should be referred for further lung function testing and investigations.

FIGURE 3. VOLUME-TIME CURVES (before and after bronchodilator)

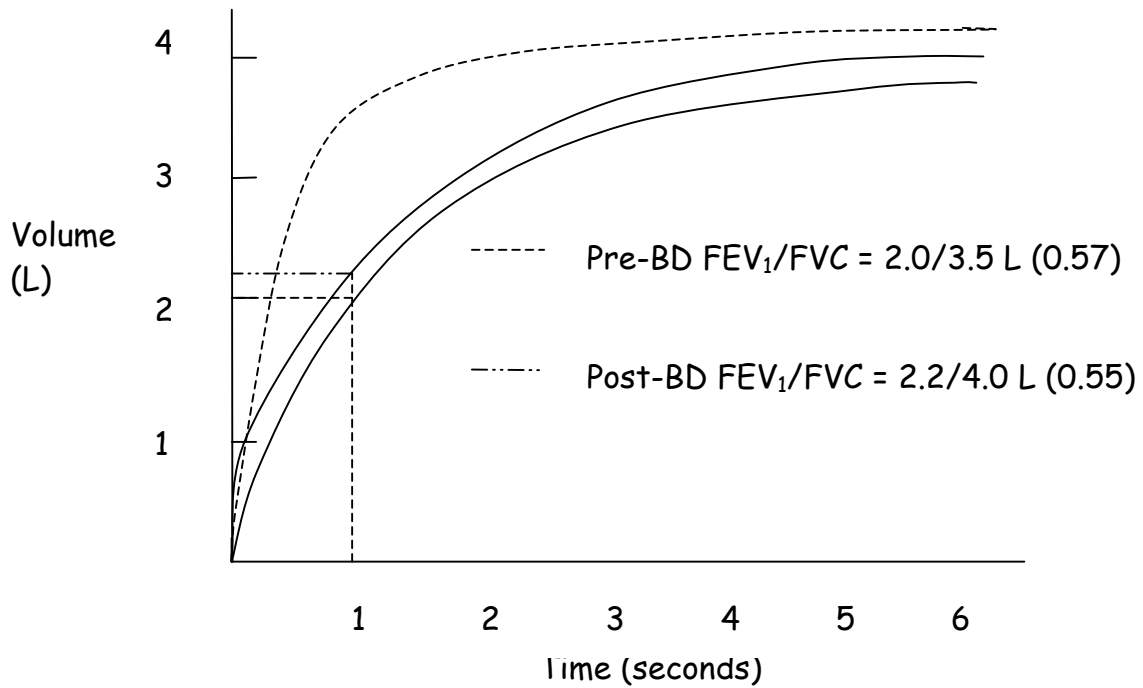
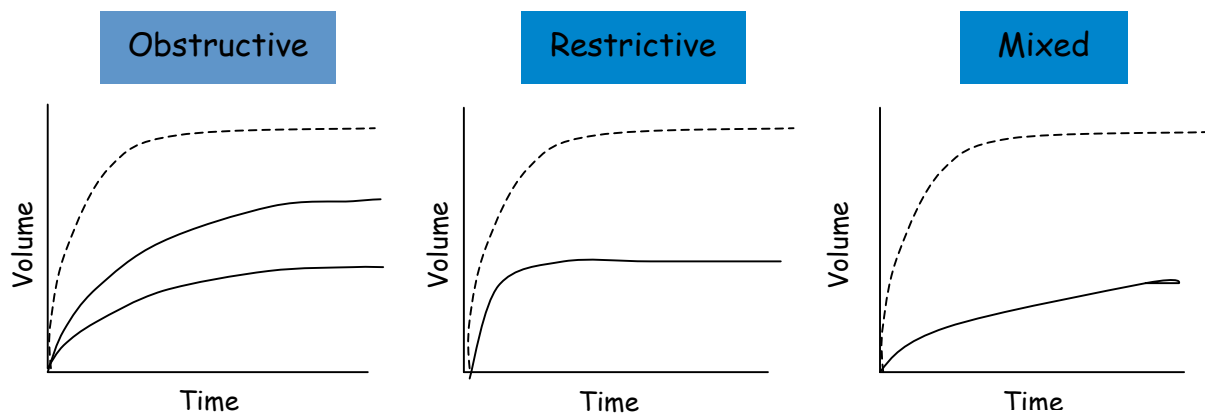


FIGURE 4. FEATURES OF VENTILATORY ABNORMALITY IN SPIROMETRY

	OBSTRUCTIVE	RESTRICTIVE	MIXED
FEV₁	REDUCED	REDUCED OR NORMAL	REDUCED
FVC	REDUCED OR NORMAL	REDUCED	REDUCED
FEV₁/FVC	REDUCED	NORMAL OR INCREASED	REDUCED

FIGURE 5. PATTERNS OF VENTILATORY ABNORMALITIES

(----- normal pattern; _____ abnormal pattern)



D. Flow–Volume Measurement

Many electronic desktop spirometers and spirometers used in lung function laboratories utilize a pneumotachograph measuring gauge, which measures airflow and integrates the signal to derive volume. This allows the spirometer to plot traces of flow rate against the volume of air exhaled, producing a flow–volume curve. On many spirometers such curves provide the main initial visual real–time display when patients are performing their blows.

The interpretation of flow–volume curves is less well understood in primary care as it may not be taught in basic spirometry courses. Nevertheless the curve is a most helpful addition when interpreting lung function results, and provides a quick and simple check on whether or not airway obstruction is present. It is also a tool for identifying the early stages of airway obstruction and provides additional help in the interpretation of a mixed pattern of obstruction and restriction.

In the simplest terms it is adequate to look at the **shape of the curve** and compare it with the shape of the predicted curve—usually a dotted line—constructed by the spirometer.

- A normal trace (*Figure 6A*) will have a rapid rise to maximal expiratory flow and then an almost linear, uniform decline in flow until all the air is expelled—the point of intersection with the x axis is the FVC.
- In airflow obstruction (*Figure 6B*) there is a **concave dip in the second part of the curve** which will become **more marked with increasing obstruction**. This will be seen in COPD and asthma and any other disease causing **airflow obstruction**.
- In more severe emphysema (*Figure 6C*) where loss of airway elasticity causes the airways to collapse when forced exhalation occurs (dynamic compression), there will be a **characteristic sudden fall in flow after maximal expiratory flow is reached—the “steeple” pattern**.
- In restrictive lung abnormalities (*Figure 6D*) the shape of the flow–volume curve is normal but there is a **reduction in lung volume** which moves the **FVC point to the left** compared with the predicted curve.

V. PERFORMING SPIROMETRY

A. Preparing The Patient

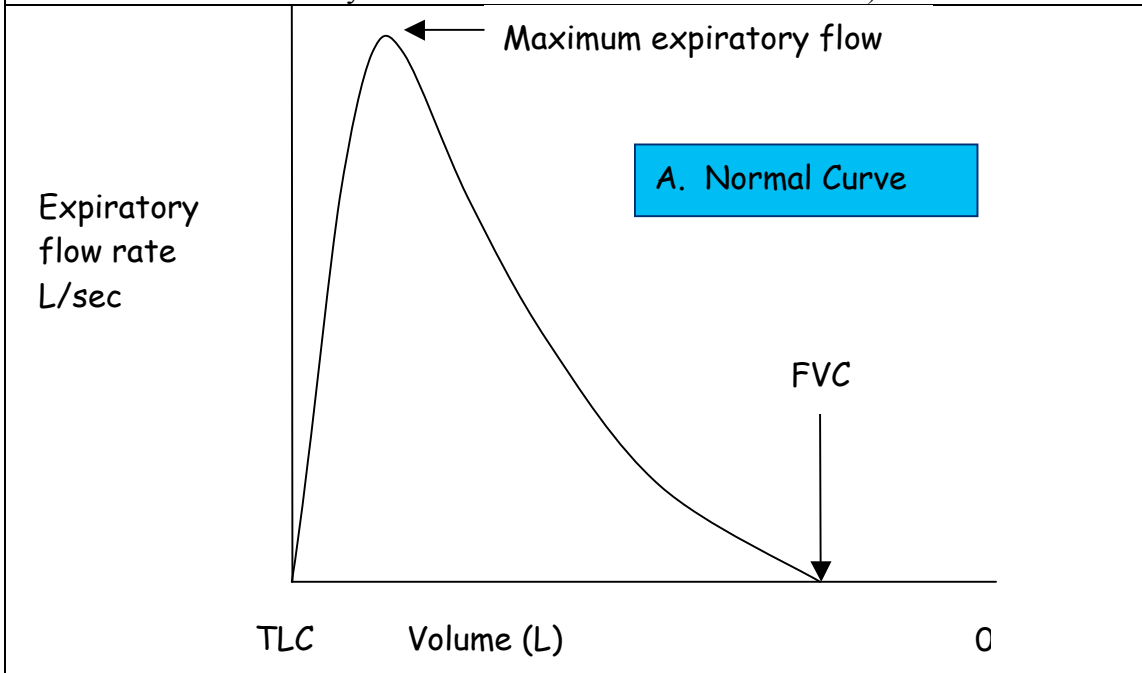
It is important to explain the purpose of the test and describe clearly what the patient will be asked to do. It is often helpful to **demonstrate or mimic the procedure** yourself and emphasize the **importance of taking a full breath and blowing out as fast and hard as possible**.

Before starting the patient’s age, sex, and height need to be recorded and entered into the spirometer so that predicted curves and values can be calculated by the spirometer. If the patient is of Asian or Afro-Caribbean origin you may need to adjust the normal values as these tend to be about 10% less in these groups than in Caucasians. Many spirometers do this adjustment for you.

Inquire and record the time of last bronchodilator inhaler use, particularly if performing a reversibility test. The patient should be comfortable and preferably have recently emptied their bladder – the procedure can cause urinary incontinence. Ideally, they should be **seated for the procedure** as there is a small risk of syncope, which is greater if standing.

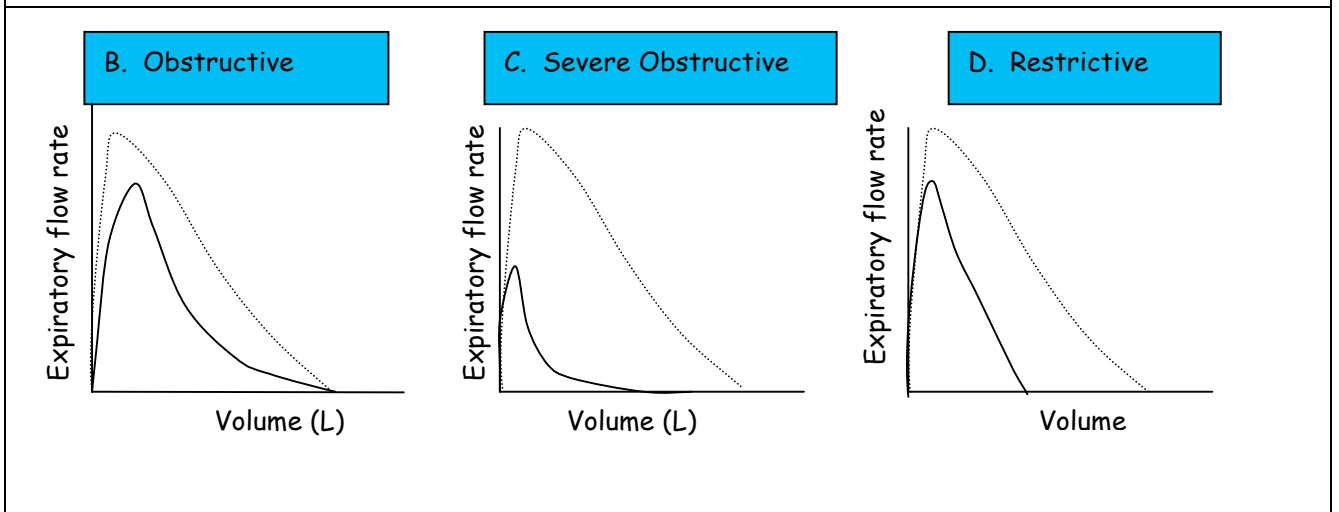
FIGURE 6A. NORMAL FLOW–VOLUME CURVE

(On exhalation there is a rapid rise to the maximal expiratory flow followed by a steady uniform decline until all air is exhaled.)



FIGURES 6B, C, D: PATTERNS OF FLOW-VOLUME CURVES SHOWING VENTILATORY ABNORMALITIES

(----- normal pattern; _____ abnormal pattern)



B. Measuring FEV₁, FVC, and Flow–Volume Curves

- Attach a clean, disposable, one-way mouthpiece to the spirometer.
- Instruct the patient to **breathe in fully** until the lungs feel full.
- The patient should hold their breath long enough to **seal their lips tightly around the mouthpiece**.
- **Blast the air out as forcibly and fast as possible** until there is no more air left to expel. The

operator should verbally encourage the patient to keep blowing and keep blowing during this phase. Watch the patient to make sure a good mouth seal around the mouthpiece is achieved.

- Check that an adequate **trace** has been achieved. Sometimes with electronic spirometers the patient may leak a small volume of air into the mouthpiece while sealing the lips which will register as the blow.
- **Repeat the procedure at least twice** until three acceptable and repeatable blows are obtained. Maximum of 8 efforts.
- There should be three readings, of which the best two are within 150 mL or 5% of each other and best.
- Depending on the model of spirometer, the numbers appear as a table of actual and predicted figures together with volume–time and flow–volume traces. The best readings of FEV₁ and FVC are usually recorded.

The use of a nose clip is uncommon in primary care but it can be helpful; alternatively, ask the patient to pinch their nose if they are having difficulties with blowing correctly.

Spirometers with real-time traces and printouts are preferred as they provide helpful information about the quality and acceptability of the blows.

C. Differential Diagnosis

If spirometry confirms airway obstruction, the main differential diagnoses are COPD and asthma. These two conditions can often be differentiated through a careful clinical history and smoking or other exposure patterns. However, at times certainty is not possible. Although FEV₁ reversibility of more than 12% favors a diagnosis of asthma, reversibility of this magnitude and higher is seen in COPD, even if less frequently.

A history of childhood wheezing, atopic symptoms, and diurnal variation in peak flow > 20% (as established by monitoring at home twice daily for 2 weeks) may all favor a diagnosis of asthma. Similarly, a therapeutic trial of prednisolone 30 mg daily for 2 weeks, or of inhaled corticosteroids for 2-4 weeks, that leads to marked improvement in FEV₁ may help to identify asthma as the more likely diagnosis. The British NICE COPD Guidelines² suggest a greater than 400 mL increase in FEV₁ after treatment trial indicates asthma. A reduced diffusing capacity in addition to airflow limitation is characteristic of emphysema.

VI. TROUBLESHOOTING

A. Accuracy and Quality of Readings

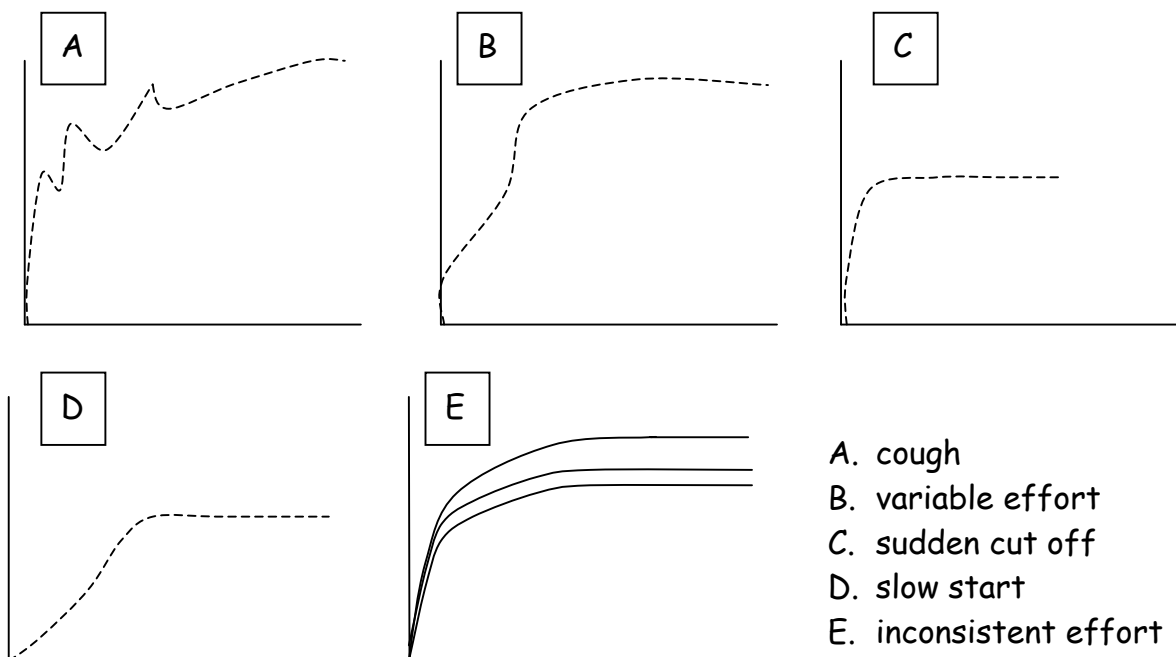
The most common reason for inconsistent readings is patient technique. Errors may be detected by observing the patient throughout the maneuver and by examining the resultant traces.

Spirometry becomes much easier to perform and interpret with practice. Despite this, some patients find it a difficult test, and will not be able to perform repeatable curves. Do not be discouraged – this can occur even for professionals in respiratory function laboratories. However, familiarity with the spirometer is important, and adopting the same careful approach each time will help you gain confidence. Common problems are shown below but do not be discouraged by the long list –it is simply to alert you to points you need to watch closely.

Common problems (and examples of traces where appropriate) include:

- Inadequate or incomplete inhalation (*Figure 7C, 7E*)
- Lack of blast effort during exhalation – sub-maximal effort (*Figure 7E*)
- Delayed onset of maximal effort – under-estimates FEV₁ (*Figure 7D*)
- Incomplete emptying of lungs – common in COPD where this can take up to 15 seconds, and in more elderly and infirm patients (*Figure 7E*)
- Additional breath during maneuver
- Lips not tight around mouthpiece (leaks under-estimate FEV₁ and FVC)
- A slow start to the blow - under-estimates FEV₁ (*Figure 7D*)
- Exhaling in part through the nose
- Coughing (*Figure 7A*)
- Glottic closure
- Obstruction of mouthpiece by teeth or tongue
- Poor posture–e.g., leaning forward or slouching
- Poor operator knowledge and training
- Poorly maintained and calibrated spirometer

Figure 7. EXAMPLES: POORLY PERFORMED CURVES



B. Equipment Maintenance and Calibration

In order to provide accurate and repeatable results, spirometers must be regularly cleaned and maintained **as directed in the manufacturer's instructions**. The correct functioning must be frequently checked with some form of calibration.

Ideally, calibration should be performed with a 3-liter syringe which will allow validation of spirometer accuracy. Some electronic spirometers can be recalibrated by the user but others only by returning them to the manufacturer. Most modern electronic spirometers, however, drift very little

from the set calibration levels so use of the 3-liter syringe helps to check that levels are unchanged.

An alternative is to assess overall performance of the spirometer by regularly testing of a healthy individual every week—a “biological control.” Generally a variation of more than 5% in FEV₁ or FVC should alert you to a problem which may necessitate further testing and possible return to the manufacturer.

C. Infection Control

Precautions must be taken to minimize any cross infection via the spirometer. The use of low-resistance barrier filters and disposable mouthpieces significantly reduces the risk of infection and also helps to protect the equipment from exhaled secretions. A new filter must be used for each patient.

D. When To Refer For Further Respiratory Function Testing

Many physicians do not have the time to perform their own spirometry, and their practice nurse or assistant physician may undertake spirometry. Some studies suggest that superior results (reliability and validity) are obtained this way. When spirometry is abnormal but not diagnostic, or if the test cannot be performed reproducibly, it is preferable for patients to be referred to a lung function laboratory or a specialist, for optimal performance and interpretation of spirometry. In addition, further lung function testing that includes more comprehensive tests will assist in making a definitive diagnosis. These tests may include full lung volumes, diffusing capacity, bronchial provocation testing, skin-prick testing, exhaled breath testing, and arterial blood gas measurements. A restrictive or mixed obstructive-restrictive spirometric pattern almost always requires more complete lung function testing before a final diagnosis can be made.

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