# Joint Indian Chest Society – National College of Chest Physicians (India) Guidelines for Spirometry

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## Executive Summary

Spirometry is the one of the commonest and most widely used lung function test, but remains underutilised in India. The current document provides evidence-based guidelines that can help physicians at all levels of healthcare in performing and interpreting spirometry in a scientific manner.

## Methodology

The process of development of guidelines was undertaken as a joint exercise of the two National Respiratory Associations (Indian Chest Society and National College of Chest Physicians [India]), by the Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh. The committee constituted for this purpose included representatives from the two associations, as well as experts from other institutes and medical colleges. An extensive initial desk review was followed by a joint workshop. The review of literature was done by searching the electronic databases (PubMed, EmBase, and Cochrane). Besides a systematic review of the literature, the Indian studies were specifically analysed to arrive at simple and practical recommendations. Major guidelines from American Thoracic Society (ATS), British Thoracic Society (BTS), European Respiratory Society (ERS), and other international professional bodies were also reviewed in detail.[1-8]

The search was conducted under four subgroups: (a) spirometry equipment, technical details, quality control and infection control; (b) indications and contraindications, conducting the test, and quality assurance of maneuvers; (c) generating/standardising numerical and graphical data, interpretative algorithms, and test reporting; and (d) miscellaneous and special issues, such as peak expiratory flow (PEF), bronchodilator reversibility (BDR), training, reference equations and others. Important questions were framed based on issues pertinent to the Indian context. The available evidence as well as the questions were circulated to all the group members before the joint workshop. Discussions for grading the evidence and formulating recommendations were held independently in four parallel group sessions coordinated by the Group Chairs and recorded by a rapporteur. Thereafter, in the joint meeting of all the groups, final decisions were taken based on a consensus approach. The final document was also reviewed by all the participating experts.

The modified GRADE system was used for classifying the quality of evidence as 1, 2, 3 or usual practice point (UPP) (Table 1).[9] The strength of recommendation was graded as A or B depending upon the level of evidence (Table 1). Grade A recommendations in the guidelines should be interpreted as "recommended" and the grade B recommendations as "suggested". While making a recommendation, the issues of practicality, costs, and feasibility in the country at different levels of healthcare were also taken into consideration.[10]

## Standardisation of spirometry

- The spirometer must be capable of continuously accumulating volume for at least 15 seconds, accommodate a total volume of at least 8 L, with flows between 0 and 14 $L.s^{-1}$. (2A)
- The spirometer should have an accuracy of at least ± 3% or ± 50 mL (whichever is greater). (3A)
- The total resistance of circuit, including any object which may be inserted between the subject and the spirometer (*e.g.*, mouth-piece, tubing, valves or filters), should be less than 1.5 $cmH_2O.L^{-1}.s^{-1}$ at an airflow of 14 $L.s^{-1}$. (3A)
- The on-screen display and the hardcopy output of the spirometry equipment should meet the specifications recommended by the American Thoracic Society (ATS)/European Respiratory Society (ERS) task force (*see above*). (UPP)
- All spirometry values should be reported after suitable BTPS (Body temperature, ambient pressure, satureated with water vapour) correction. The BTPS correction appropriate for each spirometer should be specified by its manufacturer after considering the various factors which may influence it. (UPP)
- Measured height rather than the stated height should be recorded before spirometry. (1A)
- Completed age in years should be recorded in adults aged ≥18 years. (1A)
- When height needs to be estimated from arm span, it should be done using regression equations (preferred option), or the fixed ratio method (less preferred option), rather than directly substituting the arm span for height. (1A)
- The routine use of nose clip during spirometry is not necessary. (2A)

## How is quality control established in a spirometry laboratory?

- Quality control measures, including volume validation, linearity testing, and leak testing should be routinely performed as instructed by the manufacturer. In the absence of such specific instructions from the manufacturer or when the manufacturer's recommendations lack sufficient evidence, recommendations outlines in this document can be followed. (UPP)

- The calibration syringe should have an accuracy of ± 15 mL or ± 0.5% of the full scale. The calibration syringe itself must be calibrated at least yearly. It should preferably be stored close to the spirometer to maintain similar temperature and humidity. (UPP)
- It is desirable to use a biological control even when a proper protocol for device validation is in place. (2A)

## How should infection control be optimised in a spirometry laboratory?

- Standard precautions for airborne infection control should be applied while performing spirometry. (UPP)
- Volume-sensing devices
  - Use of a disposable mouthpiece is recommended. If a reusable mouthpiece is used, it should be appropriately disinfected before using it for another patient. (UPP)
  - An inline filter should be used in all patients. (2A)
  - If use of inline filters is not feasible the following may be done: (a) interval of at least five minutes between each patient (3A); and (b) flushing the spirometer with room air (five times) after each patient. (UPP)
- Flow-sensing devices
  - Use of a disposable mouthpiece is recommended. If a reusable mouthpiece is used, it should be appropriately disinfected before using it for another patient. (UPP)
  - An inline filter (placed between the mouth and the sensor) should be used in all patients. (2A)
  - Wherever feasible, disposable sensors may be preferred. (UPP)

## What are the standards for office spirometry?

- Office spirometers should conform to the same standards as laboratory spirometers. (UPP)

## What are the general indications of spirometry for diagnosis, screening, prognostication and monitoring?

- Spirometry is useful for the diagnosis of obstructive and restrictive lung diseases. (1A)
- Risk assessment of patients undergoing cardiothoracic surgeries should be done by spirometry. (2A)
- For patients undergoing non-cardiothoracic surgery, spirometry should be done for patients suspected to have chronic obstructive pulmonary disease (COPD) (2A) and other chronic lung diseases. (UPP)
- Spirometry is useful for prognostication in several conditions, like COPD, asthma, bronchiectasis, interstitial lung disease (ILD), and neuro-muscular diseases. (1A)
- Periodic spirometry should be performed to monitor disease progression in ILD. (1A) Periodic spirometry is also useful in other conditions, like COPD, asthma, and bronchiectasis. (2A)
- Routine use of screening spirometry is not recommended for the diagnosis of COPD (2A) or occupational asthma. (3A)

## What are the minimum numbers of maneuvers to be performed during spirometry?

- At least three acceptable spirograms should be obtained during a spirometry session.

## How to standardise display of numerical/ graphical data?

- Flow-volume loop and volume-time graph should be obtained and reported as per the standard ATS/ERS guidelines (2005). (UPP)
- Forced expiratory volume in one second ($FEV_1$) and forced vital capacity (FVC) should be reported in liters, to two decimal places. (UPP)
- All flows should be reported in liters per second, to two decimal places. (UPP)

## Which variables should be used for spirometry interpretation?

- The primary variables for reporting spirometry should include $FEV_1$ (in liters), vital capacity (VC) (FVC or slow vital capacity [SVC]) (in liters), $FEV_1$/VC (%), and peak expiratory flow (PEF) (L/s). (UPP)
- SVC may be additionally performed and reported if airflow limitation is suspected. (3A)
- If vital capacity is determined by both slow as well as forced maneuvers, the larger of the two should be reported. (2A)
- A flow-volume loop and volume-time graph should be included in the report. (UPP)
- Reporting of additional variables (*e.g.*, $FEF_{25-75\%}$ or $FEF_{75\%}$) is not recommended. (2A)

## How should spirometry data be interpreted?

- A spirometric variable is to be reported as abnormal when the values obtained are less

than what is generally expected in apparently healthy individuals of similar age, gender, body habitus and ethnicity. (UPP)

- Statistically derived lower limits of normal (LLN) should be used in preference to fixed cut-offs for identifying abnormal values. (1A)
- $FEV_1$/VC less than the LLN should be interpreted as diagnostic of obstructive ventilatory defect. (1A)
- VC below the LLN, with normal or increased $FEV_1$/VC, may suggest a restrictive defect. (3B)
- VC greater than the LLN usually rules out the presence of a true restrictive defect. (2A)
- Diagnosis of true restriction cannot be made using spirometry alone, and requires a measurement of the total lung capacity (TLC). (1A)
- Reduction of both VC and $FEV_1$/VC below LLN may suggest either obstructive or mixed defect and estimation of TLC may be necessary to differentiate between these two patterns. (2A)

## Should a fixed ratio or lower limit of normal be used during interpretation?

- Statistically derived LLN should be used in preference to fixed cut-off for identifying abnormal values. (1A)

## How to categorise the severity of an abnormal spirometry report?

- Severity assessment of both restrictive and obstructive defects on spirometry should be based on $FEV_1$ values. (UPP)
- Impairment of pulmonary function (obstructive or restrictive) can be categorised as mild, moderate and severe when $FEV_1$ is $\geq$ 70%, 50-69%, and <50% predicted, respectively. (UPP)

## What is the place of $FEV_6$ in spirometry interpretation?

- $FEV_6$ may be a reasonable surrogate of FVC. (1B)
- Obstructive defect may be diagnosed using $FEV_1/FEV_6$ < LLN (as an acceptable alternative to $FEV_1$/FVC < LLN) when FVC is not obtainable. (2B)
- $FEV_6$ is equivalent to FVC in predicting the presence of a restrictive ventilatory defect. (2A)
- Use of $FEV_6$ is not recommended until reference equations for $FEV_6$ are available. (UPP)

## Is spirometry helpful in detecting central/ upper airway obstruction?

- Presence of a typical abnormal flow-volume loop may suggest presence of central airway obstruction. However, this needs to be confirmed with further evaluation. (3B)
- Normal spirometry does not rule out central airway obstruction and further investigation is essential, if there is a strong clinical suspicion. (3A)

## What is the role of additional parameters in interpreting spirometry?

- The measurement of additional spirometric values, $FEF_{25-75\%}$ and $FEF_{75\%}$ do not have an additional advantage to the routinely measured parameters, namely, $FEV_1$, VC, and $FEV_1$/VC. These can be misleading and are not recommended for the interpretation of spirometry. (2A)

## What equipment and procedure is necessary for peak expiratory flow determination?

- Hand-held PEF meters are more convenient and may be preferred to measure PEF. (UPP)
- PEF measurements obtained from different equipments may not be considered as interchangeable. (1A)
- PEF meters should use non-linear scales, like the ATS or EU scale in preference to the conventional Wright scale. (2A)
- PEF meters should be calibrated annually wherever feasible. (2A) When this is not possible, at least periodic inspection of the equipment should be done to detect any obvious defects. (UPP)
- PEF measurements obtained using FVC maneuvers cannot be considered equivalent to PEF measurements obtained using PEF maneuvers. (2A)

## What is the role of peak expiratory flow in diagnosis and monitoring of various respiratory disorders?

- There is no role of PEF in the diagnosis or monitoring of COPD. (2A)
- PEF monitoring is a useful adjunct to establish a diagnosis of asthma in patients with symptoms suggestive of asthma. (2A)
- PEF monitoring is useful in the diagnosis of occupational asthma. (1A)
- PEF monitoring should be used as a part of written asthma action plans to guide self-management of asthma. (1A)
- The personal best value established after optimum therapy (rather than percent predicted PEF) should be used as the standard for comparison of serial values. (1A)

## What is bronchodilator reversibility test and how is it performed?

- Bronchodilator reversibility (BDR) testing should be performed at baseline in all individuals suspected or found to have airflow obstruction. (1A) However, in subsequent serial testing in such individuals, BDR test is usually not required. (UPP)
- BDR test should be performed between 15 and 20 minutes after administering salbutamol (four puffs of 100 μg) or equivalent doses of levosalbutamol (4 puffs of 50 μg). (1A)
- If use of salbutamol is contraindicated, ipratropium (8 puffs of 20 μg) may be used as an alternative with spirometry performed after 30 minutes. (2B)
- The bronchodilator should be delivered with an metered dose inhaler (MDI) device, ideally with a spacer, using correct technique. (1A)
- Alternative preparations, such as nebulisation or dry powder inhaler may be used in patients who are unable to take MDIs. (2B)

## What criteria should be used to define bronchodilator reversibility?

- An increase in $FEV_1$ and/or FVC of 200 mL and 12% of the baseline should be used as the criterion for defining BDR. (UPP)

## Is there a role of bronchodilator reversibility in differentiating asthma from COPD?

- Bronchodilator reversibility test, as a single test should not be used to differentiate between asthma and COPD. (1A)
- **Bronchodilator reversibility** may be used to corroborate a diagnosis of asthma while recognising its limitations. (UPP)

## What is the role of bronchoprovocative tests?

- Because of their inherent risk for precipitating an acute attack of bronchospasm tests for bronchial hyperresponsiveness should be performed in specialised centers with facilities for resuscitation. (UPP)
- Lack of $PC_{20}$ response at 16 mg/mL concentration should be considered as a negative response during methacholine challenge testing. (2A)

## What basic skills are expected from spirometry technicians?

- Formal training of the personnel (physician and technician) conducting spirometry is strongly recommended. (2A)

# Guidelines for Spirometry

## Introduction

Spirometry is the one of the commonest and most widely used lung function test, with utility comparable to blood pressure measurement or electrocardiography. However, one needs to pay careful attention to follow standard procedures while performing and interpreting the test. The available international guidelines clearly stress the importance of performing pulmonary function tests in a standardised fashion. Despite being available for several years, spirometry remains under-utilised in India. The non-availability of good equipment, paucity of trained technicians, lack of time, inability to interpret computerised output, and poor adaptability of international standards to Indian patients are some of the common reasons cited for not performing spirometry routinely. Several of these issues are either incorrect, or can be easily sorted out. In this regard, there is a need to develop guidelines on spirometry tailored to the Indian scenario. The two foremost societies of Respiratory Medicine in India, namely the Indian Chest Society and the National College of Chest Physicians (India) have collaborated to develop evidence-based guidelines with an aim to assist physicians at all levels of healthcare in performing and interpreting spirometry in a scientific manner. The consensus statement was aimed at covering all important domains relevant to clinicians working under diverse settings in India.

## Methodology

The process of development of guidelines was undertaken as a joint exercise the two National Respiratory Associations (Indian Chest Society and National College of Chest Physicians [India]), by the Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh. The committee constituted for this purpose included representatives from the two associations, as well as experts from other institutes and medical colleges. An extensive initial desk review was followed by a joint workshop. The review of literature was done by searching the electronic databases (PubMed, EmBase, and Cochrane). Besides a systematic review of the literature, the Indian studies were specifically analysed to arrive at simple and practical recommendations. Major guidelines from American Thoracic Society (ATS), British Thoracic Society (BTS), European Respiratory Society (ERS), and other international professional bodies were also reviewed in detail.[1-8]

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## Spirometry Equipment, Technical Details, Quality Control and Infection Control

### What are the technical considerations for spirometric equipment?

#### Spirometers and their types

Spirometers measure the air inhaled or exhaled by an individual. There are three measurement parameters — volume, flow, and time. Historically, change in lung volume was measured by change in volume of a connected container, via a closed circuit (volume-sensing spirometers). The rate of change of volume with time was used to calculate flow. Since the capacity of the container had to be larger than the respired volumes of the patient, such devices were bulky. Subsequent generations of spirometers measured flow and calculated volume as the integral of flow over time, overcoming this limitation (flow-sensing spirometers). A comparison of these two types of spirometers is shown in table 2. Since the residual volume in lungs cannot be exhaled, spirometric measurements are limited to the vital capacity (VC) and its sub-divisions (Figure 1).

**Table 1. Classification of level of evidence and grading of recommendation based on the quality of evidence supporting the recommendation**

| | |
|---|---|
| **Classification of level of evidence** | |
| Level 1 | High-quality evidence backed by consistent results from well-performed randomised controlled trials, or overwhelming evidence from well-executed observational studies with strong effects |
| Level 2 | Moderate-quality evidence from randomised trials (that suffer from flaws in conduct, inconsistency, indirectness, imprecise estimates, reporting bias, or other limitations) |
| Level 3 | Low-quality evidence from observational evidence or from controlled trials with several serious limitations |
| Useful practice point | Not backed by sufficient evidence; however, a consensus reached by working group, based on clinical experience and expertise |
| **Grading of recommendation based on the quality of evidence** | |
| Grade A | Strong recommendation to do (or not to do) where the benefits clearly outweigh the risk (or *vice versa*) for most, if not all patients |
| Grade B | Weaker recommendation where benefits and risk are more closely balanced or are more uncertain |

**Table 2. Comparison of volume-sensing and flow-sensing spirometers**

| | Volume-sensing Spirometers | Flow-sensing Spirometers |
|---|---|---|
| Size | Bulky | Relatively more compact |
| Robustness | Sturdy | Comparatively fragile |
| Cost | Generally cheaper | Generally expensive |
| Influence of test results by water vapour in exhaled air | Not affected | Affected |
| Calibration | Hold calibration for months to years | Need more frequent calibration (except in ultrasonic devices) |
| Disinfection | Difficult and time consuming | Relatively easy, especially when disposable sensors are used |

Volume-sensing devices may be further classified as wet or dry depending on whether these use liquid or other material to separate the static and moving parts of the equipment. The ***water-seal spirometer*** (*e.g.*, the Benedict-Roth apparatus) is a wet spirometer which consists of a large bell suspended in a container of water with the open end of the bell submerged

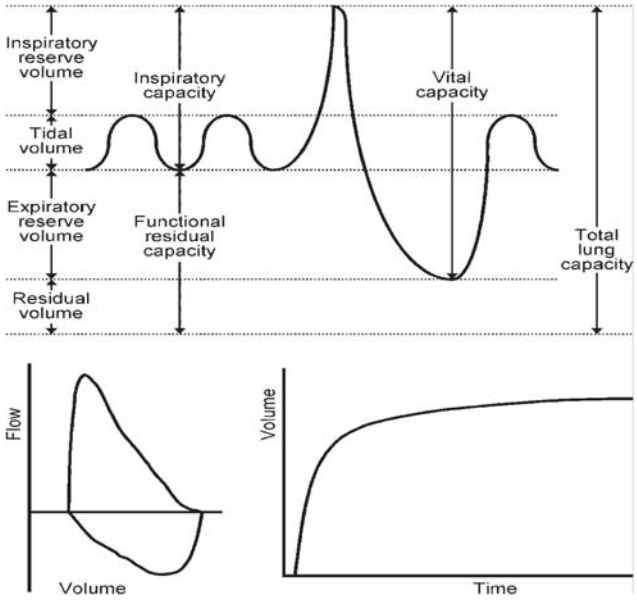


**Figure 1. The top panel shows various lung volumes and capacities in relation to the spirometry tracing. Note that spirometry can determine vital capacity and its subdivisions but not the residual volume. The bottom panel shows standard normal flow-volume loop and volume-time curve tracings.**

below the water surface. As the subject breathes, the bell moves, and this movement is recorded on a rotating drum. Dry spirometers include the rolling seal and the bellows type devices. The ***rolling-seal spirometer*** consists of a light weight piston mounted horizontally within a cylinder. The piston is attached to the cylinder by a flexible seal which rolls on itself (rather than sliding within the cylinder), as the piston moves with the individual's respiration. The ***bellows-type spirometer*** uses collapsible bellows that fold or expand in response to the individual's breathing movements.

The majority of the contemporary spirometers are flow-sensing devices, with a sensor (or flow meter) to produce signal in proportion to either the volumetric flow rate itself, or the air-flow velocity that is converted to a volumetric flow rate, by accounting for the geometric cross-sectional area. These devices contain no moving parts, are simple to automate, and possess good frequency characteristics. However, these may be difficult to calibrate as volume is calculated indirectly by time integration. ***Thermal flow meters or hot-wire anemometers*** measure airflow velocity based on the cooling of a heated wire placed in the air stream. ***Turbine flow meters*** measure volumetric flow by using a system of vanes, the rotations of which are measured by an infrared beam. Such devices are often used for office spirometry. ***Pneumotachographs*** utilise the Venturi principle, and measure drop in pressure associated with volumetric air flow across a resistive element. The resistive element may be a fine mesh

(*Screentype or Lilly type*), a series of parallel capillaries (*Capillarytype or Fleisch type*), ceramic channels (*Ceramic type*), or a flexible plastic sheet with an orifice closed by a movable flap (*Variable orifice type*). The mesh is often heated to prevent condensation of moist air. ***Vortex flow meters*** work by generating vortices by directing the airflow against a resistive element called bluff body. The number of vortices generated are evaluated using piezoelectric crystals or thermistors. ***Ultrasonic flow meters*** use the Doppler effect to measure airflow velocity. The flow-sensing principle of a spirometer is important to know because some types, such as pneumotachographs, may require more frequent calibration than others. However, with correct use, as described subsequently, all types of flow-sensing spirometers perform adequately.

**Standardisation of spirometry**

Efforts to standardise the procedure of spirometry have been ongoing since its formal description in the medical literature.[11] The European Community for Coal and Steel (ECCS) first issued its recommendations in 1960,[12] which were later updated in 1983.[2] In 1993 these recommendations were updated and adopted by the ERS.[5] Similarly, efforts to standardise spirometry were undertaken by the ATS in 1979,[13] and the recommendations were further updated in 1987,[3] and 1994.[7] In an attempt to standardise the procedures further, the ATS and the ERS issued a joint statement in 2005.[14] This is the last major international update on standardisation of spirometry.

**Spirometry device and display specifications**

The minimum recommendations for a spirometer were first detailed in an ATS statement in 1979.[1] Based on spirometric information from 9347 coal miners, it was concluded that a spirometer accommodating a volume of at least 8 liters for at least 15 seconds with flow between 0 and 14 $L.s^{-1}$can cater to the majority of the population.[15] In a single centre experience from nearly one lakh tests performed over more than a decade, these volume and flow specifications were adequate for more than 99.9 % of patients (*unpublished data from the Department of Pulmonary Medicine, PGIMER, Chandigarh*). Subsequent guidelines continue to follow these recommendations as minimum standards.[3,7,14] The readings from the spirometer should not vary from the actual measurement by an amount more than the normally observed variation. The normal intra-individual variability of spirometry values obtained over a period (within a day or up to an interval for 2 years) is about 3%.[15-19] Hence, spirometers should have an accuracy of at least ±3% of the reading or ±50 mL, whichever is greater. The total resistance of the circuit, including any object, which may be inserted between the subject and the spirometer (*e.g.*, mouthpiece, tubing, valves or filters), should be less than 1.5 $cmH_2O.L^{-1}.s^{-1}$ at an airflow of 14 $L.s^{-1}$.[20] These specifications should be considered as minimum acceptable standards, and manufactures should preferably try and exceed these specifications.

Spirometry curves need to be viewed in real time for quality control. The ATS/ERS task force on standardisation of spirometry has recommended a minimum set of requirements for flow, volume, and time for the instrument display screen and hard copy output.[14] In the absence of any studies on the minimum set of scale and resolution required, the group endorsed these recommendations (Table 3).

**Table 3. Minimum recommended scale factors for volume, flow, and time on graphical output**

| | Instrument Display | | Hardcopy Output | |
|---|---|---|---|---|
| | Resolution | Scale factor | Resolution | Scale factor |
| Volume# | 0.050L | $5mm.L^{-1}$ | 0.025L | $10mm.L^{-1}$ |
| Flow# | $0.200L.s^{-1}$ | $2.5mm.L^{-1}.s^{-1}$ | $0.100L.s^{-1}$ | $5mm.L^{-1}.s^{-1}$ |
| Time | 0.2s | $10mm.s^{-1}$ | 0.2s | $20mm.s^{-1}$ |

#=The correct aspect ratio for a flow *versus* volume display is two flow units per volume unit

*Recommendations*

- **The spirometer must be capable of continuously accumulating volume for at least 15 seconds, accommodate a total volume of at least 8 L, with flows between 0 and 14 $L.s^{-1}$. (2A)**
- **The spirometer should have an accuracy of at least ± 3% or ± 50 mL (whichever is greater). (3A)**
- **The total resistance of circuit, including any object which may be inserted between the subject and the spirometer (*e.g.*, mouthpiece, tubing, valves or filters), should be less than 1.5 $cmH_2O.L^{-1}.s^{-1}$ at an airflow of 14 $L.s^{-1}$. (3A)**
- **The on-screen display and the hard copy output of the spirometry equipment should meet the specifications recommended by the ATS/ERS task force (*see above*). (UPP)**

**Volume corrections**

The volume of a gas is influenced by the ambient temperature and pressure. Hence, the observed values of various parameters measured by the spirometer under ambient conditions need to be standardised to conditions within the human body (body temperature, ambient pressure, saturated with water vapor [BTPS]). The BTPS correction factor may be calculated as follows:

$$[(P_B - P_{H2O}) \div (P_B - 47)] \times [(273 + 37) \div (273 + T)],$$

where, $P_B$ = barometric pressure in mmHg, $P_{H2O}$ = ambient pressure of water vapor in mmHg, and T = ambient temperature in Celsius.[21] In the past, nomograms were used for doing BTPS correction.[22,23]

However, most contemporary spirometers make this correction automatically.

It is advisable to measure and use the temperature inside or at the surface of the spirometer while doing the BTPS correction.[24] Temperature should be recorded for each spirometry procedure, if wide diurnal fluctuations are anticipated.[25] Daily measurement of barometric pressure is not required in most situations, unless the region is known to have significant daily barometric pressure fluctuations.[26] In general, BTPS correction is more important for volume-sensing devices than flow-sensing devices.[21,27] However, readings from flow sensors may also be influenced by water vapour in exhaled air (Table 2). Considering the multitude of factors involved, it is essential that the spirometer manufacturer specifies the BTPS correction suitable for their device and incorporate the same in the device software.

*Recommendation*

- **All spirometry values should be reported after suitable BTPS correction. The BTPS correction appropriate for each spirometer should be specified by its manufacturer after considering the various factors which may influence it. (UPP)**

**Recording age and anthropometric data**

Age and height are two parameters which appear consistently in all adult spirometry reference equations, and hence, these needs to be accurately recorded.[28] Age is usually rounded off to the nearest integer and not recorded in decimals. A one-year age bias due to truncating age to the last birthday can lead to a bias in predicted forced expiratory volume in one second ($FEV_1$) or forced vital capacity (FVC) values of up to 8.5% in children.[29] However, such errors are minimal (<2%) in adults. Thus, the use of decimal age enhances the accuracy of spirometry measurements in children; however, substituting it with truncated age will not introduce major errors in the adults.

Use of stated, rather than actual height for predicting normal values can also result in significant errors. Hence, it is recommended to always measure the height.[30] A bias of only 1% in height can introduce 1%–40% change in $FEV_1$ and/or FVC.[29] Height should ideally be measured with a calibrated stadiometer, with the subject standing with heels together, keeping the heels, calves, buttocks, and back touching the stadiometer and the head positioned such that the lower orbital level and the external auditory meatus are at the same level (Frankfurt plane). It is advisable to measure height to the nearest 1mm.[29] In the absence of a stadiometer, a wall-mounted measuring tape may be used.

The arm span is the distance between the tips of the middle fingers measured with the arms stretched sideways with the palms facing the investigator. In patients who are unable to stand erect due to physical disability, arm span can be used to predict pulmonary function parameters. This can be done in two ways. If reference equations incorporating arm span values are available, these can be directly used to predict pulmonary function. When such equations are not available, height is first estimated from arm span, and then this estimated height is used in standard prediction equations. However, which of these two methods is better is controversial.[31,32] Height can be estimated from arm span by multiplying the arm span with the mean height to arm-span ratio of the population (fixed ratio method) or using regression equations.[33] Studies have found that the arm span-to-height ratio changes non-linearly with age, and differs between men and women, as well as between ethnic groups; hence regression equations are the better approach to calculate height from arm span.[32-36] Although the use of height estimated from arm span employing the fixed ratio method may not be as accurate as regression equations, it is still more accurate than direct substitution of arm span for height.[35,36]

*Recommendations*

- **Measured height rather than the stated height should be recorded before spirometry. (1A)**
- **Completed age in years should be recorded in adults aged ≥18 years. (1A)**
- **When height needs to be estimated from arm span, it should be done using regression equations (preferred option), or the fixed ratio method (less preferred option), rather than directly substituting the arm span for height. (1A)**

**Nose clip**

The use of the nose clip during spirometry is recommended by most guidelines.[14,37,38] However, several studies have shown, that the use of nose clip during spirometry, in addition to being uncomfortable to most patients, has no demonstrable benefit.[39-44] The use of nose clips should be limited to individuals in whom nasal leak is suspected, rather than routinely using it for all.

*Recommendation*

- **The routine use of nose clip during spirometry is not necessary. (2A)**

## How is quality control established in a spirometry laboratory?

Quality control is the practice of ensuring reliability of spirometry measurements by maintaining sufficient standards of the equipment and the staff performing spirometry through periodic scrutiny. Quality control of spirometry technicians is described separately under the section 'Training in spirometry'. Quality control of spirometry equipment is ensured by regular performance of validation, calibration, linearity check, and leak testing on the spirometer.

While performing calibration, the spirometer should be in the calibration mode so that BTPS corrections are not applied.

**Calibration and validation**

Calibration is a process that ensures the accuracy of the spirometer by adjusting the device based on the measurement of a known standard. Validation (or calibration check) is a similar process in which a known standard is measured to verify the accuracy of the spirometer, without making any adjustment of the device. If a spirometer fails validation, it will require calibration.

**Calibration syringe**

The performance of volume validation and linearity check requires a calibration syringe with a volume of 3 L or more. The calibration syringe must have an accuracy of ±15 mL or ±0.5% of the full scale (15 mL for a 3 L syringe). Calibration syringes must be stored such that these are in an environment with temperature and humidity like that of the spirometer. Calibration syringes usually have a stable stroke volume even after years of use and storage. However, it is preferable to validate the calibration syringes at least annually.[45] A syringe which has been dropped on the floor or damaged should be considered to be unsuitable for validation until it itself is validated again.

**Volume validation**

In volume-sensing devices, volume validation is performed by injecting a known volume of air into the spirometer with the calibration syringe. The volume measured by the spirometer should be within 3.5% of the volume injected by the syringe. In flow-sensing devices, the calibration syringe should be sequentially emptied at least three times, each time at a different flow rate. Every time, the measured volume should be within 3.5% of the injected volume.

**Linearity check**

Linearity testing is required to establish the proportionality of the output to the input. In volume-sensing devices, it can be done by two methods. In the first method, a volume validation is performed as described above, making note of the starting volume of the spirometer before beginning the procedure. If successful, the procedure is repeated over the entire volume range of the spirometer, sequentially increasing the spirometer starting volume each time. For example, if the initial procedure was done with an empty spirometer, the procedure is repeated after increasing the spirometer starting volume to 1 L, then again at 2 L, and so on. In the second method, a known volume of air is injected repeatedly into an empty spirometer with a calibration syringe until the maximum capacity of the spirometer is reached. Then, the cumulative volume injected by the syringe is compared with the corresponding accumulated volume measured by the spirometer. In flow-sensing devices, linearity testing is performed similar to the volume validation procedure. However, at each of the three flow levels, the procedure is repeated thrice.

**Leak testing**

Volume-sensing devices and calibration syringes must be checked periodically for any leaks. This is done by applying a constant pressure to the spirometer (occluded at its mouth piece) for a period of at least one minute and checking for any evidence of air leak.

**Test signals for spirometer testing**

Before using a spirometer in clinical practice, it is essential to make sure that the spirometer can measure the various FVC curves encountered in various respiratory diseases. This is done by testing the spirometer with various standard FVC curves designed to mimic various clinical conditions. However, reproducing these standard FVC curves requires sophisticated computer driven syringes. Hence, this procedure is not done routinely in spirometry laboratories, and is primarily used by spirometry manufacturers and researchers. Standard curves for use as test signals have been developed by Hankinson and Gardner,[46] and the ATS.[7] However, recent studies have questioned the adequacy of these standard curves.[47,48]

**Validation thresholds**

Most spirometry guidelines have suggested an arbitrary threshold of ±3.5% variation as acceptable limits during validation. This includes the 3% accuracy limit for spirometry measurements and the 0.5% accuracy limit of the calibration syringe. McCormack *et al*[49] visually inspected plots of validation data obtained from seven volume-sensing spirometers over several years to identify sub-optimal spirometers with systematic sources of error, drift, and bias. They found that a cut-off of value of ±2% could identify these faulty spirometers which were missed by using a cut-off value of ±3.5%. They also found that sub-optimal spirometers could also be identified when four consecutive validations exceed 1% deviation.[49] Although this small study may not be a sufficient impetus for most laboratories to revise the existing cut-off of 3.5%, it highlights the importance of maintaining and reviewing a log of all validation and calibration data by the spirometry laboratories.

**Frequency of quality control measures**

There is limited evidence on the optimal frequency of calibration in lab spirometers. Different guidelines recommend different validation frequency of volume and flow measuring devices. For volume validation, most guidelines recommend a daily or weekly schedule for volume-sensing devices, while they uniformly recommend daily calibration for flow-sensing devices.[14,37,38,50] Linearity check (which is more

important for flow-sensing devices) is recommended quarterly for volume-sensing devices and weekly for flow-sensing devices.[14,37] However, studies have shown that certain ultrasonic and turbine spirometers may reliably hold calibration for long periods (6 months to 4 years).[51-54] For such instruments, where the manufacturer's calibration recommendations are substantiated with sufficient data, a less frequent calibration schedule can be followed. In the absence of specific recommendations for quality control by the manufacturer, we recommend the schedule as outlined in table 4. The device should also be validated after any relocation or dismantling.

**Table 4. Recommended frequency of performance of quality control measures on spirometry equipment (and their acceptable limits)**

| | Volume-sensing devices | Flow-sensing devices |
|---|---|---|
| Volume validation | Daily (± 3.5%) | Daily (± 3.5%) |
| Linearity check | Quarterly (± 3.5%) | Weekly (± 3.5%) |
| Leak testing | Daily (≤30 mL after 1 min) | Not applicable |

### Use of biological controls

Volume validation with a 3 L syringe alone may be misleading, hence it is preferable to check validation additionally with healthy individuals.[55] Healthy adults with no respiratory symptoms between 18 to 65 years of age with no past history of lung disease can serve as biological controls. The spirometric measurements obtained from a biological control should be within his or her acceptable range (established by prior testing). If not, a calibration of the spirometer should be performed. To establish the acceptable range for a biological control, the person is asked to perform spirometry at the same time of the day on 10 different days. The mean of these spirometric measurements are calculated from these values. An acceptable range for each measurement is calculated as ±5% from the mean value. It has been suggested that mechanical syringes which can simulate breathing maneuvers can serve as a replacement for biological controls.[56]

*Recommendations*

- **Quality control measures which include volume validation, linearity testing, and leak testing should be routinely performed as instructed by the manufacturer. In the absence of such specific instructions from the manufacturer or when the manufacturer's recommendations lack sufficient evidence, recommendations from Table 4 can be followed. (UPP)**
- **The calibration syringe should have an accuracy of ±15 mL or ±0.5% of the full scale. The calibration syringe itself must be calibrated at least yearly. It should preferably be stored close to the spirometer to maintain similar temperature and humidity. (UPP)**
- **It is desirable to use a biological control even when a proper protocol for device validation is in place. (2A)**

## How should infection control be optimised in a spirometry laboratory?

Infection control measures aim to prevent transmission of infection from the patient performing spirometry to other patients and staff. Transmission of infection during spirometry can occur either by direct contact (through saliva and respiratory secretions from contaminated spirometer parts) or indirectly (through aerosol droplets). The mouth-piece and the adjoining surfaces of valves or tubing come in direct contact with respiratory secretions and may transmit these infections. Several studies have documented colonisation of spirometer with various bacteria, mycobacteria and fungi.[57-59] However, evidence regarding cross-infection with these micro-organisms is sparse.[60,61] Water-seal spirometers are more likely to be colonised with micro-organisms than heated pneumotachographs.[58]

The level of disinfection required, ease of disinfection, compatibility with the equipment, and cost are the major factors determining the method employed for the prevention of the infection. Recommendations based on limited evidence may be controversial and impractical. For example, an analysis done in a busy laboratory showed that using a barrier filter was approximately five times cheaper than implementing guidelines which required equipment cleaning and disinfection between patient use.[62]

### General considerations

Standard precautions for airborne infection control are also applicable to the spirometry laboratory.[63] These include hand hygiene, proper cough etiquette, selection of personal protective equipment based on the assessment of risk, and cleaning and disinfection of patient care environment and equipment.

Hand hygiene is the single most important step in preventing nosocomial infection. Skin contact has been shown to transmit respiratory viruses and bacteria.[64,65]Hand washing with plain soap and water significantly reduces contamination of the skin with bacteria and viruses.[66-68] Laboratory staff should wash their hands with soap and water (when visibly dirty) or alcohol based hand rubs, before and after assisting patients with spirometry.

Work surfaces and floors should be cleaned daily with detergent. Comprehensive cleaning disrupts the chain of infection between organisms and patients.[69]

Cleaning and mopping should be done before arrival of the patients, as it is has been shown that the bacterial burden in the air increases immediately after mopping.[70]

A simulation model has shown that significant transfer of aerosolised organisms does not occur during routine pulmonary function testing if an interval of five minutes or more is allowed between the tests.[71] Hence, wherever feasible, a time interval of at least five minutes should be maintained between spirometry procedures. If spirometry needs to be performed on patients with active respiratory infections (especially pulmonary tuberculosis), they should preferably be scheduled at the end of testing session, or a separate machine (if available) may be used.

**Patient-specific considerations**

The referring clinician should provide details regarding the infective potential and susceptibility to infection of the patient while filling the request form. Any patient with signs and symptoms suggestive of pulmonary tuberculosis must be first evaluated for tuberculosis.[72] In a patient who is known to be infective, spirometry need not be performed. Whenever feasible, potentially infective patients may be tested in their own rooms, or in the laboratory using barrier filters in an instrument that can be easily disinfected after the procedure. Immunosuppressed patients can be tested at the start of the day, before performing spirometry in other patients.

**Equipment-specific considerations**

In general, the manufacturer's instructions for cleaning and disinfecting the equipment should be followed. User manuals should clearly describe acceptable methods for disinfection, including recommended chemicals and their concentrations, as well as safety precautions. Hospital infection control protocols regarding disinfection can replace those of the manufacturer's, provided these do not harm the equipment.

Mouth-piece is the most contaminated part of the spirometry equipment and ideally should not be shared between the patients.[73] If a re-usable mouth-piece is used, it should be appropriately cleaned and disinfected before its re-use.

It is practically difficult to disinfect the entire spirometry equipment in between the two tests, especially in busy laboratories. Modifying the spirometer components with disposable parts to perform bag-in-the-box measurements has been demonstrated,[74,75] but this may not be always feasible. Placing a bacterial filter between the patient's mouth and the spirometer seems to be the most practical option for infection control. Instrument contamination (during expiration) and subsequent bacterial mobilisation (*i.e.*, detachment and aerosolisation of bacteria from the spirometer during inspiration) have been shown to be significantly reduced when spirometry is performed with in-line filters.[76,77] An ideal filter should have a bacterial and viral removal efficiency of more than 99.9%, add little to the resistance and the dead space of the circuit, and be economical to use. Though most manufactures claim bacterial removal efficiency to the tune of 99.9% for these filters, results of clinical studies have been contradictory.[78-80] Moreover, the efficacy of filters in filtering viruses is largely unknown. The use of microbial filters in spirometry circuits have been shown to significantly increase the airway resistance (Raw), resulting in reduction of the measured $FEV_1$, FVC, and peak expiratory flow (PEF). However, these changes are usually clinically insignificant.[81,82]

*Recommendations*

- **Standard precautions for airborne infection control should be applied while performing spirometry. (UPP)**
- **Volume-sensing devices**
  - **Use of a disposable mouth-piece is recommended. If a re-usable mouth-piece is used, it should be appropriately disinfected before using it for another patient. (UPP)**
  - **An inline filter should be used in all patients. (2A)**
  - **If use of inline filters is not feasible, the following may be done: (a) interval of at least five minutes between each patient (3A); and (b) flushing the spirometer with room air (five times) after each patient. (UPP)**
- **Flow-sensing devices**
  - **Use of a disposable mouth-piece is recommended. If a re-usable mouth-piece is used, it should be appropriately disinfected before using it for another patient. (UPP)**
  - **An inline filter (placed between the mouth and the sensor) should be used in all patients. (2A)**
  - **Wherever feasible, disposable sensors may be preferred. (UPP)**

## What are the standards for office spirometry?

Office spirometers or desktop spirometers are compact devices as compared to the bulky laboratory spirometers. These are used principally in the primary care setting.[83,84] Office spirometers, in general, are reliable, although some models may have issues with precision and accuracy.[48,85] Accuracy implies closeness of a measured value to a standard or known value, while precision refers to the closeness of two

or more measurements to each other on successive recordings. The specifications of the devices used for office spirometry should conform to the same standards as laboratory spirometers. The device should preferably be able to measure ambient temperature and pressure and perform BTPS correction automatically. These devices usually do not need frequent calibration.[51-54] However, it is a good practice to perform regular quality control measures.

Handheld or pocket devices are slightly different from office spirometers. These are ultra-compact, portable, user-friendly devices, best suited for home monitoring of pulmonary functions by the patients themselves.[86-89] Handheld devices may not meet the stringent standards of conventional spirometers. Moreover, despite having adequate precision, these may not be as accurate as laboratory spirometers.[90-93] Hence, at present, most handheld devices cannot be considered as replacement for the conventional spirometers.

*Recommendation*

**Office spirometers should conform to the same standards as laboratory spirometers. (UPP)**

## Indications and Contraindications, Conducting the Test, and Quality Assurance of Maneuvers

### What are the general indications of spirometry for diagnostic purposes?

Spirometry is indicated for the detection of pulmonary disease in patients presenting with respiratory symptoms, like breathlessness, wheezing, cough, or chest tightness. Spirometry may also be useful in distinguishing respiratory from cardiac disease.

**Chronic Obstructive Pulmonary Disease**

Chronic obstructive pulmonary disease should be suspected in any patient with breathlessness, chronic cough, or sputum production. Demonstration of airflow obstruction in spirometry is essential for the diagnosis of COPD,[94,95] as history and physical examination have a sensitivity only about 67% for its diagnosis.[96-98]

**Asthma**

Although an initial diagnosis of asthma is largely clinical, spirometry should be used to confirm the clinical diagnosis of asthma.[99] In one study,[100] asthma was under-diagnosed in 21% of the subjects who sought medical attention when spirometry was not done. However, normal spirometry does not exclude a diagnosis of asthma.

**Interstitial lung disease**

Interstitial lung diseases (ILDs) usually have a restrictive pattern on spirometry. But, a restrictive pattern on spirometry is not specific for ILD.[101,102] On the other hand, the negative predictive value of a normal spirometry is quite high. Only 2.4% of 1361 patients with a normal vital capacity (VC) on spirometry had a restrictive defect by the measurement of total lung capacity (TLC).[103] However, when compared with more sensitive measures of ILD like high resolution computed tomography (HRCT) of the thorax, spirometry has a relatively poor sensitivity.[104]

### What are the general indications of spirometry for prognostication and monitoring?

In several respiratory diseases, spirometry has shown good correlation with clinical outcomes and serial spirometry measurements have been shown to be beneficial.

**COPD**

In COPD, worsening airflow limitation is associated with increasing mortality, risk of exacerbations, and hospitalisation.[95,105-107] However, it should be noted that airflow limitation alone may not adequately predict disease progression in COPD due to the existence of several COPD phenotypes. In a multi-centre prospective study of COPD patients (ECLIPSE [evaluation of COPD longitudinally to identify predictive surrogate end-points] study), annual forced expiratory volume in one second ($FEV_1$) decline over a 3-year period was highly variable with between-patient standard deviation for the annual rate of $FEV_1$ decline of 59 mL.[108] This finding was confirmed by another recent study,[109] which found the multi-dimensional BODE (body-mass index, airflow obstruction, dyspnoea and exercise) index to be a better measure of disease progression in COPD compared to $FEV_1$.

**Asthma**

In asthma, disease control is usually assessed using symptoms rather than with serial spirometry measurements. This is because $FEV_1$ is a highly variable parameter with daily, weekly, and annual variations of $\geq$5%, $\geq$12% and $\geq$15%, respectively, even in healthy individuals.[110] However, assessment of $FEV_1$ may be useful in certain situations. Some asthmatics (poor perceivers like elderly, patients with long-standing asthma or severe disease) may complain of less symptoms despite significant reduction in $FEV_1$.[111,112] Assessment of $FEV_1$ in these subjects may allow better optimisation of therapy. $FEV_1$ can also be used to assess prognosis in asthma. In some follow-up studies, low $FEV_1$ has been significantly associated with a risk of asthma attacks that may require hospitalisation.[113,114]

**Bronchiectasis**

Spirometry in patients with bronchiectasis can be obstructive, restrictive, or normal.[115]An obstructive pattern in spirometry has been shown to be associated with higher risk of *Pseudomonas* colonisation of the airway, whereas both obstructive and restrictive

patterns have been associated with more severe disease and increased risk of hospitalisation.[115] Several studies have correlated low pulmonary function test results with more severe disease, higher risk of exacerbations requiring hospitalisation, and mortality.[116,117] Additionally, a rapid decline in lung function has been associated with an increased mortality in bronchiectasis.[118]

**Interstitial lung disease**

Serial measurement of forced vital capacity (FVC) is one of the most useful parameters for the assessment of the disease progression in idiopathic pulmonary fibrosis (IPF). A decline in FVC by 10% over 6 to 12 months has been reliably associated with decreased survival in IPF.[119-121] Antifibrotic agents which decrease the rate of decline in FVC may be associated with a reduction in mortality in IPF.[122]

**Neuromuscular disorders**

Spirometry may also be useful in prognosticating patients with neuromuscular disorders. A low FVC in patients with amyotrophic lateral sclerosis (ALS) has been associated with more rapid progression and lower median survival.[123]

## What are the general indications of pre-operative spirometry for risk assessment for post-operative pulmonary complications?

The severity of airway obstruction has been shown to be a significant predictor of morbidity and mortality in patients undergoing thoracic surgeries. In a study evaluating patients who underwent coronary artery bypass graft (CABG), progressively worsening airway obstruction was clearly associated with increasing morbidity and mortality.[124] Subsequent studies have confirmed this association of airflow obstruction with post-operative morbidity, but not with mortality.[125,126]

The importance of airway obstruction may be even more pronounced in patients who undergo lung resection. Bugge *et al* found that severe COPD ($FEV_1$<50%) was associated with a 69% increased risk of mortality (adjusted hazard ratio, 1.69; 95% CI [Confidence interval], 1.12 to 2.55) after lung resection.[127]In the National Emphysema Treatment Trial (NETT), which evaluated lung volume reduction surgery (LVRS) for emphysema, patients with $FEV_1$≤20% along with homogeneous distribution of emphysema on computed tomography (CT) or a diffusion capacity of the lung for carbon monoxide (DLCO) ≤20% had a 30-day mortality of 16% as compared to 0 in medically treated patients.[128]A diagnosis of COPD has been associated with post-operative pulmonary complications after both thoracic and non-thoracic surgery.[126,129,130] On the other hand, mere reduction in spirometry parameters have not been independently associated with an increased risk of post-operative pulmonary complications after non-thoracic surgery.[131,132]

## What are the general indications of spirometry for disease screening?

In several population-based studies involving current or former smokers (with or without respiratory symptoms), spirometry has been able to demonstrate airflow limitation in a significant proportion of the subjects.[133,134] However, the health benefits of subsequent intervention in the subjects diagnosed with airflow limitation by screening spirometry has not been demonstrated thus far.[84] Many subjects diagnosed with airflow limitation by screening spirometry are likely to be asymptomatic and may not need any intervention. Moreover, several randomised controlled trials have shown that adding spirometry to the available interventions for smoking cessation does not increase the rate of smoking cessation.[84,135-138] Thus, screening asymptomatic subjects for COPD is not recommended.[95,139,140]

Screening spirometry is often advocated as a part of medical surveillance for occupational asthma. However, screening spirometry has been shown to add little benefit to surveillance programmes employing validated questionnaire.[141-144] However, in selected high-risk settings, spirometry can be used as a part of comprehensive screening programme.[145,146]

*Recommendations*

- **Spirometry is useful for the diagnosis of obstructive and restrictive lung diseases. (1A)**
- **Risk assessment of patients undergoing cardio-thoracic surgeries should be done by spirometry. (2A)**
- **For patients undergoing non-cardio-thoracic surgery, spirometry should be done for patients suspected to have COPD (2A) and other chronic lung diseases (UPP).**
- **Spirometry is useful for prognostication in several conditions, like COPD, asthma, bronchiectasis, ILD, and neuromuscular diseases. (1A)**
- **Periodic spirometry should be performed to monitor disease progression in ILD. (1A) Periodic spirometry is also useful in other conditions, like COPD, asthma, and bronchiectasis. (2A)**
- **Routine use of screening spirometry is not recommended for the diagnosis of COPD (2A) or occupational asthma (3A).**

## What are the contraindications for spirometry?

Different exclusion criteria have been followed in large epidemiological studies in which spirometry was performed.[147,148] Some of the conditions which may preclude spirometry are listed in table 5.

**Table 5. Contraindications for spirometry**

| |
|---|
| Unstable cardiovascular status, such as myocardial infarction within previous one month |
| Recent thoracic or abdominal surgery (within previous 6 weeks) |
| Recent eye or ear surgery (within previous 6 weeks) |
| Proven or suspected active pulmonary tuberculosis |
| Thoracic, abdominal, or cerebral aneurysm |
| Oral or facial pain exacerbated by mouth-piece |
| Active haemoptysis |
| Uncontrolled blood pressure |
| Acute illnesses that may interfere with performance of the procedure, such as acute respiratory tract infection, nausea, vomiting, chest pain, or abdominal pain |
| Last trimester of pregnancy |

## What are the minimum pre-checks for spirometry?

Several drugs and patient activities can alter results from spirometry testing. In general, patients should avoid oral bronchodilators and long-acting inhaled bronchodilators for at least 24 hours, and short-acting inhaled bronchodilators for at least six hours, prior to the procedure. Oral/inhaled steroids need not be discontinued. Patients should avoid intake of caffeine containing products (tea, coffee, cola) for at least six hours, and alcohol for at least four hours, prior to the test. They should not eat a large meal for at least two hours before spirometry and avoid smoking for at least one hour. Vigorous exercise should be avoided for at least 30 minutes before the procedure. They should wear comfortable clothes that allow full expansion of chest and abdomen.

## What are the minimum numbers of maneuvers to be performed during spirometry?

In a study evaluating the utility of performing multiple maneuvers for spirometry, the $FEV_1$ and FVC values were obtained in the following situations: average of the best two spirograms of five acceptable spirograms, average of the best two spirograms of first three acceptable spirograms; and single best spirogram of first three acceptable spirograms. The study showed that all the values were nearly similar and correlated with each other with a correlation coefficient >0.99.[1] Hence, it appears reasonable to obtain at least three acceptable spirograms during spirometry.

*Recommendation*

- **At least three acceptable spirograms should be obtained during a spirometry session.**

## How should the vital capacity maneuver be performed?

### Definitions

Vital capacity (VC) is the volume change occurring in the lung between full inspiration and maximum expiration. It may be measured by a full inspiration after complete expiration (inspiratory capacity) or a full expiration after a complete inspiration (expiratory capacity). The maneuver during VC measurement can be forced or slow depending on whether a maximal forced effort was involved or not during the maneuver, respectively. The expiratory VC from a forced maneuver is referred to as forced vital capacity. The slow expiratory VC and slow inspiratory VC are respectively referred to as slow VC (SVC), or just vital capacity, and inspiratory VC (IVC), respectively. Inspiratory capacity is the volume change occurring in the lung while taking a slow full inspiration from a position of passive end-tidal expiration.

### Factors influencing spirometry

Spirometry can be performed with the subject either sitting or standing. FVC and $FEV_1$ obtained in the sitting posture were slightly better than those in stting position in one study on patients with normal to severe ventilatory impairment.[149] However, other researchers have found marginally better or similar results with standing posture as compared to the sitting posture.[150-152] Since spirometry performed in the sitting posture is generally more comfortable and safe, we endorse performance of the procedure in sitting posture. Flexion of the neck should be avoided during spirometry as it can significantly increase airway resistance compared to the neutral position (gaze parallel to the floor).[153]

A study on edentulous subjects showed that spirometry with or without dentures did not result in significant differences in FVC or $FEV_1$. However, spirometry with dentures resulted in slightly better flows in healthy subjects and patients with ILD (but not COPD).[154] However, another recent study[155] observed that FVC, $FEV_1$, and PEF values obtained with dentures were slightly better than those obtained without dentures. However, as the difference is small and clinically insignificant, we suggest that edentulous subjects wearing comfortable, well-fitting dentures need not remove them while performing the spirometry.

### Procedure

Forced expiratory maneuver can be done by either closed- or open-circuit method. During a closed-

circuit procedure, the subjects inhales and exhales exclusively through the mouth-piece of the spirometer with no communication with ambient air. In open circuit technique, the subject takes a maximal inspiration from the room, inserts the mouth-piece into the mouth, and then blows out either slowly (SVC) or rapidly (FVC) until the end-of-test criterion is met. Unlike the closed-circuit method, there is no display of inspiration during the open-circuit method and subject can lose volume at TLC without the knowledge of spirometry technician. Moreover, inserting mouth-piece after full inspiration is cumbersome and may contribute to leak. However, since the subject does not inspire air from/through the spirometer, chances of acquiring infections transmitted via aerosols is minimal with the open-circuit method. Both open-circuit and closed-circuit methods are acceptable for clinical use. It should be noted that to achieve best results during the FVC maneuver, forced expiration should be performed after a rapid maximal inspiration without any end inspiratory pause (Table 6).[156,157]

**Table 6. Expiratory maneuver for measuring vital capacity**

| |
|---|
| Place the mouth-piece in mouth and close lips around the mouth-piece. |
| Inhale completely and rapidly to reach the total lung capacity |
| Start exhalation without pausing at the total lung capacity |
| For forced vital capacity, exhale as fast, as hard, and as completely as possible until no more air can be expelled while maintaining an upright posture |
| For slow vital capacity, the exhalation is relatively relaxed and at a nearly constant flow, except near end-inspiration and end-expiration |
| At least three maneuvers should be performed; no more than eight maneuvers are usually required |
| Check for repeatability after three acceptable maneuvers. If repeatability criteria are not met, more maneuvers should be performed as neeeded (not more than a total of 8 maneuvers) |

It is extremely important that the technician supervising the test constantly encourages the patient throughout this procedure, to generate the best possible effort. Failing this, not only will the test remain poor quality, but the end-result may also be a falsely abnormal spirometry report.

**What are the within-maneuver acceptability criteria for FVC maneuver?**

Before embarking on interpretation of the spirometry data, it is essential to confirm that the test is indeed of "good" quality". As with any other clinical investigation, the utility of a spirometry report is only as good as the quality of the data on which this report is based. The within-maneuver and between-maneuver acceptability criteria for spirograms can be broadly divided as visual criteria and numerical (computer-calculated) criteria. On visual inspection, the volume-time and flow-volume curves show a quick and smooth start, maximal effort throughout the blow, and a smooth progression (Figure 1). Coughing during exhalation produces spikes or fluctuations in the tracings. Any cough occurring within the first second, or that which interferes with accurate measurements in the technician's judgement, makes that maneuver unacceptable. Variable or sub-maximal, effort results in an undulating or wavy pattern in the curves. Abrupt cessation of flow towards the end of exhalation (commonly from closure of glottis) manifests as an abrupt decrease in volume and flow in the terminal portion of the curves. There should also be no evidence of blockade of mouth-piece or an extra breath during the whole maneuver. Identification of some of these problems is illustrated in figure 2. In a study involving 3113 subjects, it was found that nearly one-third of the visually unacceptable spirograms met all three numerical criteria and could have been erroneously concluded as acceptable if these had not been visually inspected.[158] Hence, only visually acceptable spirograms should be considered for numerical acceptability. Individual spirograms can be considered as acceptable when the within-maneuver acceptability criteria are met (Table 7).[14]

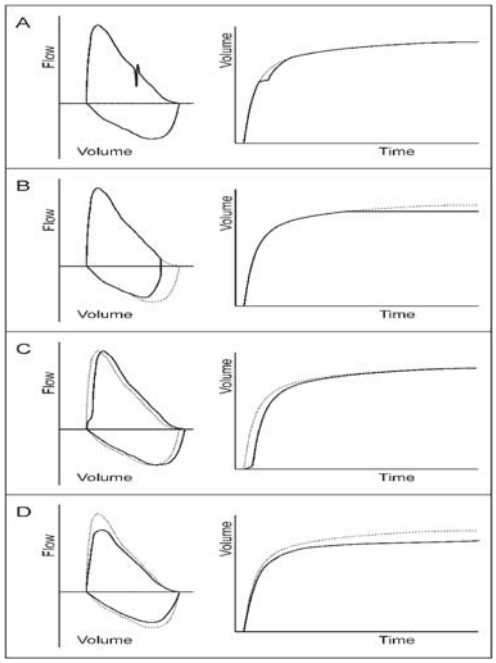


**Figure 2. Abnormalities seen on flow-volume loops and volume-time curves in relation to (A) coughing, (B) early glottic closure, (C) hesitant start and (D) submaximal effort.**

The start of expiration is usually defined by back-extrapolation of the steepest portion of the volume-time curve to zero volume (Figure 3). To achieve an accurate time zero and ensure that the $FEV_1$ comes from

**Table 7. Maintaining quality of spirometric and peak expiratory flow maneuvers**

| |
|---|
| **Within-maneuver acceptability criteria for spirometry** |
| An acceptable spirogram should be free from the following visual artefacts: |
| Cough during the first second of exhalation |
| Effort that is not maximal throughout |
| Obstructed mouth-piece |
| Early termination or cut-off |
| Glottis closure that influences the measurement |
| Leak |
| Start-of-test criteria: extrapolated volume <5% of FVC or <150 mL, whichever is greater |
| End-of-test criteria: |
| The volume-time curve shows no change in volume (<25 mL) for at least 1 second, and the subject has tried to exhale for at least 6 seconds, OR |
| The subject cannot or should not continue further exhalation |
| **Between-maneuver repeatability criteria for spirometry** |
| After three acceptable spirograms are obtained, the following criteria should be applied: |
| The two largest values of FVC must be within 150 mL of each other* |
| The two largest values of $FEV_1$ must be within 150 mL of each other* |
| If both of these criteria are met, the test session may be concluded |
| If both of these criteria are not met, testing should be continued until: |
| Both of the criteria are met in the subsequent acceptable spirograms OR |
| A total of eight tests have been performed (optional) OR |
| The subject can not or should not continue further |
| **Within-maneuver acceptability criteria for peak expiratory flow maneuver** |
| No hesitation |
| No cough |
| No leak at mouth |
| **Between-maneuver repeatability criteria for peak expiratory flow maneuver** |
| At least three maneuvers should be performed |
| Largest two of three acceptable maneuvers must be within 0.67 L/s (40 L/min) |
| If the above criterion is not met, up to two additional maneuvers can be performed |

*=For subjects with FVC≤1L, the two largest values must be within 100 mL of each other.

*Definition of abbreviations:* $FEV_1$=Forced expiratory volume in one second, FVC=Forced vital capacity

a maximal effort curve, the extrapolated volume (EV) must be <5% of FVC or 150 mL, whichever is greater. A higher value suggests a hesitant start. Evaluation of the flow-volume curve may be an added measure to assess a satisfactory start of the test. The initial expiratory portion of the flow-volume curve should demonstrate a steep and early (typically less than 120 m) rise to peak expiratory flow.

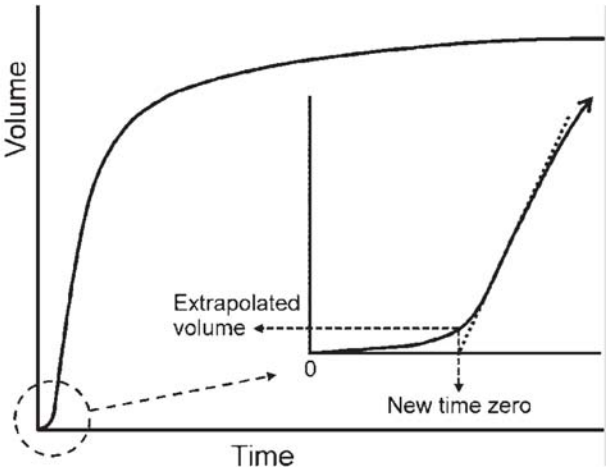


**Figure 3. A typical volume-time trace from spirometry. Note the smooth and rapid rise in expired volume, and a volume plateau towards the end of exhalation. The graphical method to calculate time of start of test, as well as extrapolated volume, from the early portion of the curve is also illustrated.**

The end of expiration is reached when the expired volume is less than 25 mL in one second (the plateau criterion) or the subject cannot continue exhaling further. Normally, expiratory time should exceed six seconds for the maneuver to be termed satisfactory. One can also terminate the effort after 15 seconds of exhalation to avoid syncope. However, subjects can conclude the maneuver at any time if they experience discomfort. Although an exhalation time exceeding six seconds is desirable, early termination is not enough reason to exclude the maneuver from further analysis. In situations where forced expiratory volume in six seconds ($FEV_6$) is used as a surrogate of FVC, a forced exhalation time of six seconds alone may be used as the end-of-test criterion.

There are certain other surrogate criteria, which can be of use in subjects who fail to achieve a plateau during expiration. In a study involving nearly 25,000 spirograms, it was found that $EV/FEV_6$ ≥5.25% and $EV/ FEV_3$ (forced expiratory volume at three seconds) ≥5.59 seconds corresponded to EV/FVC ≥5%.[159] Additionally, $EV/FEV_3$ may serve as an early warning signal for hesitant start and may avoid unnecessary continuation of the FVC maneuver to completion.

**What are the between-maneuver reproducibility criteria for spirometry?**

Reproducibility assesses how well the results of individual "acceptable" maneuvers in any spirometry session match with each other. Acceptable repeatability is said to be present between maneuvers when the largest FVC and $FEV_1$ values are within 150 mL of the next largest FVC and $FEV_1$ values (or within 100 mL of the next largest FVC and $FEV_1$ values in case VC is below 1 L) (Table 7).[14] The earlier spirometry guidelines had stated that the largest two readings should not vary by >5% or 100 mL, whichever was

greater.[1,3] However, it was found that the use of this criterion resulted in classification of the spirograms of a large number of subjects with short stature as not acceptable.[160] Hence, a fixed volume criterion of 200 mL was used in subsequent guidelines.[7] A fixed volume criterion of 150 mL appears sufficient for most subjects as about 95% and 92% of the subjects will be able to reproduce their FVC and $FEV_1$, respectively within this limit.[161]In a study involving 123 subjects, 98% of the subjects were able to achieve at least three acceptable tracings in ≤8 attempts.[162] Each spirometry session should have at least three acceptable maneuvers from which reproducibility can be assessed. If three maneuvers do not meet reproducibility criteria then testing can be continued till these criteria are met. Normally, no more than eight maneuvers are recommended, as patients get fatigued beyond that. If reproducibility criteria are not met even after eight attempts, testing should be concluded and interpretation performed from three best tests, making a note of this fact in the final report.

## Generating/Standardising Numerical and Graphical Data, Interpretative Algorithms and Test Reporting

### How to standardise display of numerical/ graphical data?

For a meaningful interpretation, a spirometry report should meet certain minimum standards. The standards proposed by the ERS/ATS (2005) that have been adopted by various other national and international organisations, would be followed to maintain uniformity.[163] All flows should be reported in liters per second at BTPS conditions. $FEV_1$ and VC should be reported in liters. Volume-time graph and flow-volume loop should be reported and displayed as per standard recommendations (Table 3).[163] Flow-volume loops are essential as these provide an idea on the quality of the spirometry. Additionally, these may yield valuable clues to the presence of obstructive airway disease (Figure 4). A small and concave or scooped curve suggests obstructive disorder. A small curve with steep slope suggests restriction. A small and flat curve suggests central airway obstruction. In disorders with variable intrathoracic obstruction, only the expiratory component of the loop is flat, whereas in disorders with variable extrathoracic obstruction, only the inspiratory component is flat. Both components are flat in lesions causing fixed airway obstruction.

*Recommendations*

- **Flow-volume loop and volume-time graph should be obtained and reported as per the standard ATS/ERS guidelines (2005). (UPP)**
- **$FEV_1$ and FVC should be reported in liters, upto two decimal places. (UPP)**
- **All flows should be reported in liters per second, upto two decimal places. (UPP)**

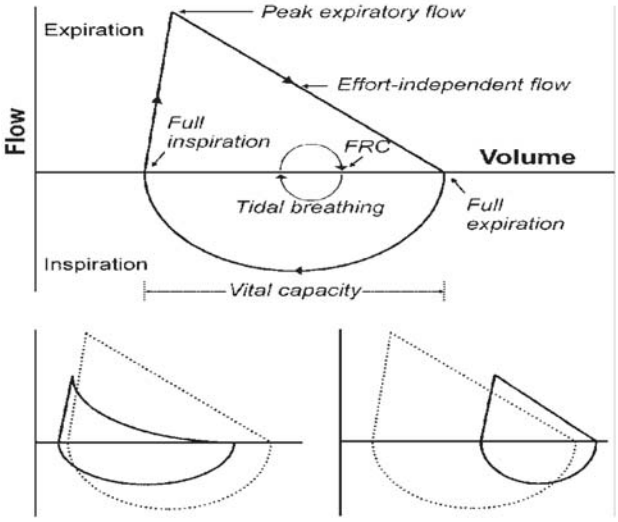


**Figure 4. Flow-volume loops. The upper panel shows a typical flow-volume loop and the various subdivisions of lung volume. The bottom panel shows changes in the shape of flow volume loop in obstructive (right) and restrictive (left) defects, with the dotted line representing the normal loop.**

**FRC=Functional residual capacity**

### Which variables should be used for spirometry interpretation?

Commercially available spirometers provide output on several variables, most of which are not essential for interpreting spirometry. The available spirometry variables include (but are not limited to) FVC, SVC or VC, forced inspiratory vital capacity (FIVC), IVC, maximal voluntary ventilation (MVV), $FEV_1$, $FEV_6$, $FEV_1$/FVC ratio, $FEV_1/FEV_6$ ratio, instantaneous expiratory flows at 25%, 50%, and 75% of the FVC ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$), maximum mid expiratory flow (MMEF) or flow measured between 25% and 75% of the FVC maneuver ($FEF_{25-75\%}$or MMEF), peak expiratory flow (PEF), forced expiratory time (FET), peak inspiratory flow (PIF), expiratory reserve volume (ERV), inspiratory reserve volume (IRV). Amongst these $FEV_1$, VC, and $FEV_1$/VC % are the most important parameters in interpretation of the spirometry.

Forced vital capacity is dependent on flow and volume histories. The velocity at which residual volume is reached from a state of maximal inspiration also determines the VC;[156] this difference has been demonstrated in individuals with asthma and COPD.[164] Thoracic gas compression artifact, where the flow-derived volume measured at the mouth under-estimates the actual change in thoracic volume, is a major contributor.[165] Elimination of this artifact requires seating of the patient inside a body plethysmograph and is impractical. Thus, in usual practice, IVC and SVC may be significantly larger

than the FVC in persons with airway obstruction, with the difference increasing with worsening severity of obstruction.[166] Understandably, the ratio of $FEV_1$/VC would typically be lower when the denominator is SVC or IVC rather than FVC. Hence, the sensitivity to diagnose an obstructive defect may be better when SVC is used. In another study, prevalence of COPD increased significantly (by >6%) when VC (largest of either SVC or FVC) was used instead of FVC.[167] On the other hand, both SVC and FVC were found to be equivalent in predicting a low TLC, and either may be used when restrictive defect is suspected.[168] Using the better of the two VCs (SVC and FVC) is definitely advantageous in diagnosing suspected obstructive defects than using FVC alone. Recent international guidelines also recommend using the larger of the two VCs (FVC and SVC).[110] The largest observed values of $FEV_1$ and VC available from among at least three acceptable and reproducible tests should be used as the key parameters for interpretation, even if these individual observations are derived from different test maneuvers. If both FVC and SVC maneuvers have been performed, the larger value of VC amongst the FVC and SVC measurements should be used for interpretation. However, the lack of appropriate reference equations for SVC and the requirement of two separate maneuvers for every patient should be borne in mind.

The conventional spirometric indices are known to have poor sensitivity in certain situations, especially when the diseases are mild or in their early stages. Researchers had tried the utility of various additional spirometric parameters in identifying such early abnormalities. Of note, $FEF_{25-75\%}$, $FEF_{25\%}$, $FEF_{50\%}$, and $FEF_{75\%}$ have been studied for this purpose. Generally, $FEV_1$ correlates well with $FEF_{25-75\%}$, however, some studies have noted that, in mild diseases, especially in children, $FEF_{25-75\%}$ may be abnormal even when $FEV_1$ is normal.[169] It was also suggested that using more than one flow-volume expiratory variable may lead to better sensitivity. However, subsequently, larger, and more recent studies have shown that the additional advantage of using these indices was low. For example, only 3% had an abnormal $FEF_{25-75\%}$ in the presence of a normal $FEV_1$/FVC.[170]Also, due to higher thoracic gas compression artifact, as mentioned earlier, this phase of the forced expiration shows poorer reproducibility.

The large number of other variables, often available from computerised spirometer outputs, usually provide no additional information, and are best excluded from a standard interpretative algorithm. Even though a small number of cases could be additionally picked up, the false positives associated preclude their routine use. In a study of 251 apparently healthy individuals, it was noted that when a battery of 14 tests were performed, abnormalities were detected in 24% as opposed to 10% detected by the routine spirometric indices ($FEV_1$, $FEV_1$/FVC, and FVC). More importantly, the false positive rate increased by 5% for each additional parameter employed.

Interpreting spirometric data is not just about reviewing numerical values generated by the equipment. Both the volume-time curve and the flow-volume loop must be assessed with reference to their technical quality, size and shape, and various components, before arriving at a final interpretation. Often, such graphical analysis provides vital supplementary information not obtainable from numerical data alone. Therefore, it is recommended that the spirometry report should include $FEV_1$, VC (FVC or SVC), $FEV_1$/VC, PEF, flow volume loop, and the volume-time graph. Reporting of additional variables (*e.g.*, $FEF_{25-75\%}$ or $FEF_{75\%}$) is not recommended.

*Recommendations*

- **The primary variables for reporting spirometry should include $FEV_1$ (in liters), VC (FVC or SVC) (in liters), $FEV_1$/VC (%), and PEF (L/s). (UPP)**
- **SVC may be additionally performed and reported, if airflow limitation is suspected. (3A)**
- **If VC is determined by both slow as well as forced maneuvers, the larger of the two should be reported. (2A)**
- **A flow-volume loop and volume-time graphs should be included in the report. (UPP)**
- **Reporting of additional variables (*e.g.*, $FEF_{25-75\%}$ or $FEF_{75\%}$) is not recommended. (2A)**

## How should spirometric variables be classified as normal or abnormal?

The aim of performing a spirometry is to identify individuals with abnormal lung function. To identify what is abnormal, one should define what constitutes a normal spirometry. The predicted normal values for any given individual can be obtained using reference equations developed from healthy individuals of that population (see below). A caveat here is that highly prevalent sub-clinical disease burden in a population could lead to less stringent reference normal values, due to inclusion of apparently healthy subjects with sub-clinical disease. However, large unexplained inter-ethnic variations in lung function necessitate the population-specific approach.

Values less than the predicted value do not necessarily imply that the spirometry is abnormal, since the "normal" value is generally a range rather than a fixed point. The lower limit of normal (LLN) and upper limit of normal (ULN) are the limits of this 'normal range', beyond which the measured values would be abnormal. In clinical practice, spirometric

values which are lower than normal are more commonly encountered than values which are higher than normal. Hence, the LLN is more commonly utilised than the ULN.

Various methods are available to identify the LLN. The simplest and most widely used method employs a fixed percentage of the predicted value to differentiate normal from abnormal. For instance, it is a common practice to use 80% of the predicted value of a spirometric parameter as the cut-off below which the measured value would be considered as abnormal. This cut-off is arbitrary and there is little statistical or scientific evidence favouring such a practice. In children, using a fixed cut-off may be acceptable, but in adults it may lead to erroneous interpretation.[4] A more valid approach, which takes into account the age, anthropometry, and gender related changes in lung function, is to identify and use the fifth percentile of the values measured in the reference population as the LLN below which measured parameters can be considered abnormal. The fifth percentile (lower 95% confidence limits of the predicted value) can be estimated as: predicted value - (1.645 × SEE), where SEE is the standard error of estimate of the prediction equation.[4] Another statistically appropriate way of defining LLN is the use of lambda-mu-sigma method (LMS) wherein the results are reported using the "Z-score". The Z-score can be calculated as (x-μ)/ó, where, x is the value obtained, μ is the population mean, and ó is the standard deviation. This method is usually employed in pediatric growth charts, and has also been studied in defining LLN for spirometric indices. However, it needs further validation.[171,172]

In practice, observed spirometric values below the predicted LLN should be reported as abnormal. The practice of using a fixed ratio ($FEV_1$/VC <0.7) or a fixed percentage of the predicted value (80% of the predicted value of $FEV_1$ or FVC, or 60% of the predicted value of $FEF_{25-75\%}$) to differentiate normal from abnormal is discouraged and statistically derived LLN should be used.[173]

## How should spirometry data be interpreted?

The primary step in interpretation is confirmation that the test is of good quality (as discussed above). In general, the interpretation of spirometric data revolves around numerical values for only three variables: $FEV_1$, VC and $FEV_1$/VC. Values clearly above or clearly below their respective LLNs can be interpreted confidently. Borderline values need interpretation with caution, often supplementing clinical information and/or other test results to make decisions. Only a spirometry record with normal $FEV_1$, VC and $FEV_1$/VC (*i.e.*, all values above their respective predicted LLN values) should be interpreted as being normal.

### Obstructive ventilatory defect

An obstructive ventilatory abnormality is diagnosed when the maximal airflow from the lung is disproportionately reduced, in relation to the maximal volume that can be displaced from the lung. Therefore, any spirometry record with $FEV_1$/VC value below its predicted LLN should be interpreted as having an obstructive abnormality.[110,172] Such a defect is commonly seen in disorders associated with airflow limitation, such as asthma and COPD. It may also be observed in diseases with small airway obstruction (such as bronchiolitis), cystic fibrosis, bronchiectasis, airway tumours and others. Patients with upper airway obstruction can be further characterised based on appearance of the flow volume loops, as described previously.

*Restrictive ventilatory defect*

Restrictive defects are common in conditions with loss of functioning lung parenchyma (*e.g.*, diffuse parenchymal lung diseases, lung collapse/atelectasis, pneumonia, after lung resection). Such defects are also seen in patients with neuromuscular disorders (due to decrease in generation of force necessary for a good spirometric maneuver) and diseases of the chest wall and the pleura (*e.g.*, obesity, kyphoscoliosis, large pleural effusion, pleural fibrosis). The diagnosis of a restrictive ventilatory defect is made when the TLC is reduced. This requires measurement of lung volumes, and hence, restrictive lung defects cannot be diagnosed with the use of spirometry alone. However, a restrictive defect may be suspected on spirometry if the VC is reduced below the LLN, in the presence of normal or increased $FEV_1$/VC ratio (*i.e.*, value above corresponding LLN).[110] The ability of spirometry to suggest a restrictive defect is at best modest. The sensitivity of a reduced VC in predicting a decreased TLC varies from 59% to 88.6% in various studies.[174-176] However, the negative predictive value of a low VC or a reduced VC along with a normal $FEV_1$/VC ratio is generally more than 90%.[174] Hence, the presence of a normal VC may obviate the need for performing lung volume measurements to exclude restrictive lung disease.[177] Notably, while the restrictive pattern is neither sensitive, nor specific for restrictive lung diseases, such as ILD, it seems to be a powerful predictor of premature mortality and cardio-metabolic morbidity, first seen in the Framingham cohort and replicated in multiple studies since then.[178-180] It is also not clear whether the lower VC and higher cardio-metabolic morbidity/mortality seen in low-income countries, including India, is part of this spectrum.[101]

*Mixed ventilatory defect*

Coexistence of a restrictive defect (low TLC) and an obstructive defect ($FEV_1$/VC < LLN) is termed as mixed ventilatory defect. Measurement of lung volume is essential to make this diagnosis. However,

spirometry may suggest such a defect when both VC and $FEV_1$/VC are below the LLN. In the presence of severe obstruction, VC may be decreased due to air trapping (hyperinflation), thereby normalising the $FEV_1$/FVC ratio (mimicking a restrictive defect). The differentiation of this 'pseudo restriction' from true restriction requires measurement of TLC. In one study, 19.6% of the subjects with a low $FEV_1$/FVC ratio and low FVC had decreased TLC, whereas, only 0.8% subjects with low $FEV_1$/FVC and normal FVC had low TLC.[174] Therefore, a normal FVC in the presence of an obstructive ventilatory defect practically rules out superimposed restrictive defect. On the other hand, a low FVC in the presence of an obstructive ventilatory defect is mostly a result of severe obstruction, but measurement of TLC is required to rule out a coexisting restrictive defect.

**Other abnormalities**

A decrease in both $FEV_1$ and VC in the presence of a normal $FEV_1$/VC ratio and a normal TLC is a non-specific pattern.[181] A reduced VC and normal $FEV_1$/VC ratio would suggest restrictive defect, but a normal TLC rules it out. Similarly, a low $FEV_1$ and normal TLC would favour an obstructive defect, but a normal ratio of $FEV_1$/VC goes against it. This is common when the test is not properly performed and the patient fails to inhale or exhale completely. However, the occurrence of such a pattern even after a properly performed maneuver may be seen in various conditions, such as asthma, COPD, bronchiectasis, other causes of hyperresponsive airways, and several other conditions (congestive heart failure, diseases of respiratory muscles, chest wall disorders and others).[181-183] In the absence of lung volume measurement, this pattern cannot be recognised and would be labeled as suggestive of restrictive spirometric defect.

An abnormally low $FEV_1$/FVC in the presence of a normal $FEV_1$ represents obstructive ventilatory defect, but this may represent a physiological variant (especially in adolescents and trained competitive swimmers) or an early indicator of obstructive airway disease.[184,185] Different aspects of lung development take place at different points of time. These factors interplay in such a way that in adolescents, FVC may be disproportionately larger than $FEV_1$ and TLC.[186] Hence, spirometry done at this point of lung growth may be misinterpreted as an obstructive defect. The presence of respiratory symptoms, however, suggests airflow obstruction.[185] In a larger retrospective study of 280 individuals, airway hyperresponsiveness was demonstrated in 28% of patients with $FEV_1$/FVC < LLN and $FEV_1 \geq 90\%$ predicted.[187] Therefore, symptom assessment and additional testing to rule out airway hyperresponsiveness is essential, before labelling this abnormality as a physiological variant. A simple algorithm to diagnose lung function abnormalities based on spirometry is outlined in figure 5.

*Recommendations*

- **A spirometric variable is to be reported as abnormal when the values obtained are less than what is generally expected in apparently healthy individuals of similar age, gender, body habitus, and ethnicity. (UPP)**
- **Statistically derived lower LLN should be used in preference to fixed cut-offs for identifying abnormal values. (1A)**
- **$FEV_1$/VC less than the LLN should be interpreted as diagnostic of obstructive ventilatory defect. (1A)**
- **VC below the LLN, with normal or increased $FEV_1$/VC, may suggest a restrictive defect. (3B)**
- **VC greater than the LLN usually rules out the presence of a true restrictive defect. (2A)**
- **Diagnosis of true restriction cannot be made using spirometry alone, and requires a measurement of the TLC. (1A)**
- **Reduction of both VC and $FEV_1$/VC below LLN may suggest either obstructive or mixed defect and estimation of TLC may be necessary to differentiate between these two patterns. (2A)**

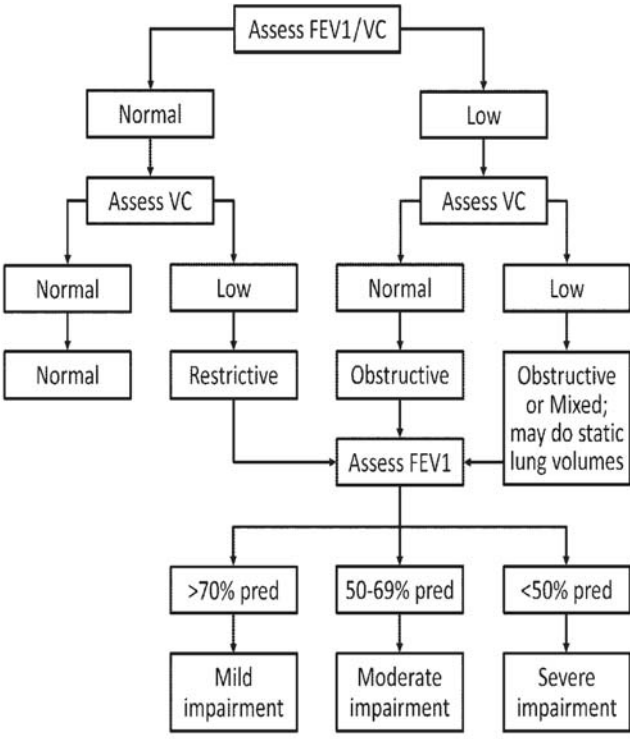


**Figure 5. A basic algorithm for spirometry interpretation.**

**$FEV_1$=Forced expiratory volume in one second, VC=Vital capacity, % pred=Percentage of predicted normal value**

## Should a fixed ratio or lower limit of normal be used during interpretation?

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines for COPD define $FEV_1$/FVC <0.7 (fixed cut-off) as obstructive ventilatory defect. However, use of the GOLD criteria may misclassify of a significant number of subjects as abnormal (restrictive, as well as obstructive).[188] A fixed cut-off for $FEV_1$/VC fails to consider the age, sex, and body habitus of the individual. Moreover, LLN for $FEV_1$/FVC is above this fixed cut-off of 0.7 in many elderly individuals.[189] A statistically derived LLN is, therefore, more reliable and reduces the frequency of mis-classification (especially, in elderly).[190-199] Using this fixed ratio may lead to under-diagnosis of asthma in younger patients. The Global Initiative for Asthma (GINA) guidelines on asthma suggest a $FEV_1$/FVC ratio of >0.75-0.80 as normal for adults. This results in significant under-diagnosis of asthma in younger adults as opposed to the usage of statistically derived LLN.[200] Therefore, most of the international and national guidelines including the ERS/ATS currently recommend a statistically defined LLN instead of using a fixed cut-off.[38,110]

Despite compelling evidence and scientific/ statistical rationale for the LLN, there are researchers who still favour the use of a fixed ratio.[201,202] Individuals identified as normal by the LLN criteria but abnormal by the fixed ratio criterion (the so-called discordant group) have been shown to have increased exacerbations, mortality, and increased chance of requiring long-term oxygen therapy as compared to those who were normal by both the criteria.[203-205] It has also been argued that the GOLD criteria tends to pick up early cases of COPD and has good correlation with respiratory symptoms.[201,206,207] Ultimately, more appropriate reference standards (such as expert panel diagnosis of COPD based on history, examination, spirometry, DLCO, or CT evidence of air trapping), would be required when comparing the diagnostic utility of fixed ratio *versus* LLN criteria rather than using LLN-based criteria as the reference standard.[208-210]

Even though some researchers have provided evidence in favour of the fixed ratio for the diagnosis of COPD, it must be remembered that the utility of spirometry is broader than diagnosing COPD alone. Moreover, employing this criterion (which has little scientific rationale) and its inadvertent extrapolation to several other diseases, like asthma, could lead to significant mis-diagnosis of respiratory diseases. Despite claims that the fixed ratio may identify COPD 'earlier' than the LLN criteria, these early cases have no definite treatment apart from smoking cessation, which is offered even otherwise. An obstructive spirometric defect should preferably be identified when the $FEV_1$/FVC ratio is less than the LLN for the reference population, and a fixed cut-off should not be used.[173,189,199] However, in situations where data on statistically valid LLN figures is not available (or impractical to calculate, as in some field settings), $FEV_1$/ VC ratio less than 70% may be employed to define airway obstruction in a high probability clinical setting.

*Recommendation*

- **Statistically derived lower limits of normal should be used in preference to fixed cut-off for identifying abnormal values. (1A)**

## How to categorise the severity of an abnormal spirometry report?

The severity of impaired lung function in obstructive airway diseases has been traditionally classified based on $FEV_1$ (% predicted) and has been shown to predict mortality from both cardiovascular and respiratory diseases.[178,211] This increase in all-cause mortality has been noted irrespective of the smoking status.[212] Follow-up studies have demonstrated strong correlation between degree of airflow obstruction and COPD-related mortality.[211,213] $FEV_1$ is also useful in predicting long term outcome as well as risk of exacerbation in asthmatics.[113,214] Spirometric indices also correlate well with respiratory symptoms and other aspects of quality of life.[215,216]

The $FEV_1$ is reduced in both obstructive and restrictive lung diseases, and a reduced $FEV_1$ can be considered an indicator for impaired lung function. The $FEV_1$ expressed as a percentage of predicted normal value, can be employed to categorise severity of impairment of lung function (both restrictive and obstructive). Though the correlation of lung function to morbidity and mortality is well established, there is no universally accepted scheme of categorisation of severity of pulmonary function.[110] Severity classification suggested by GOLD (for COPD) and ERS/ ATS (for obstructive airway diseases) includes five categories based on post-bronchodilator $FEV_1$% predicted. VC is reduced in restrictive diseases, including parenchymal lung diseases and neuromuscular diseases. The classification of severity of restrictive defects was traditionally based on VC measurements. However, since the correlation between $FEV_1$ and VC is good when $FEV_1$/FVC is normal, the ATS/ERS endorsed $FEV_1$% to classify restrictive defect as well, thereby making the severity classification uniform (for both obstructive as well as restrictive defects).[110] The correlation between the previous severity classification based on VC and the current $FEV_1$ based classification for restrictive defects is reasonably good. But these cannot be used interchangeably since up to 31.3% were noted to have discordant categorisation.[217]

*Recommendations*

- **Severity assessment of both restrictive and obstructive defects on spirometry should be based on $FEV_1$ values. (UPP)**
- **Impairment of pulmonary function (obstructive or restrictive) can be categorised as mild, moderate and severe when $FEV_1$ is ≥70%, 50-69%, and <50% predicted, respectively. (UPP)**

## What is the place of $FEV_6$ in spirometry interpretation?

Forced expiratory volume in six seconds is the maximal volume of air that is expelled in the first six seconds of a FVC maneuver. 99% individuals can obtain their FVC in 6.64 seconds or less.[218] Measurement of FVC requires patient effort and cooperation, and may not be obtained in all patients, especially in the elderly.[219] In such patients where FVC is unreliable or not feasible, and the obstruction is mild, measuring $FEV_6$ may be useful.[220] In a study on 1531 subjects aged 65-100 years, valid FVC and $FEV_6$ measurements were obtainable in 56.9% and 82.9% subjects, respectively.[219]

The $FEV_1/FEV_6$ ratio has been evaluated as an alternative to $FEV_1$/FVC in interpreting spirometry, and both have been shown to be comparable in diagnosing airway obstruction.[220-228] A meta-analysis of 11 studies involving 31333 participants, of whom 10171 had airway obstruction, $FEV_1/FEV_6$ had an estimated sensitivity of 0.89 (95% CI, 0.83 to 0.93) and specificity of 0.98 (95% CI, 0.95 to 0.99) with an area under the summary receiver operating characterstic (ROC) curve of 0.97.[229] However, similar to $FEV_1$/FVC, employing a fixed cut-off to diagnose obstruction is not preferred and wherever feasible, $FEV_1/FEV_6$ lower than the statistically derived LLN for the reference population is to be used.[230]

The role of $FEV_1/FEV_6$ as an alternative to $FEV_1$/FVC for suspecting restrictive defects has been studied, and both indices are comparable in predicting reduction in TLC.[168,222,224,231-234] Apart from its role in diagnosing obstructive and restrictive defects, $FEV_6$ has also been shown to be equivalent to FVC in the assessment of bronchodilator response.[235] A definite end-of-test criteria, shorter time for completing a test, lesser chances of syncope, lesser exertion, and diagnostic capability comparable to FVC are the potential advantages favouring the use of $FEV_6$.

There is sufficient data suggesting that $FEV_6$ may be a reasonable surrogate for FVC. However, there is little data from India and reference equations need to be generated before the routine use of $FEV_6$.[236]

*Recommendations*

- **$FEV_6$ may be a reasonable surrogate of FVC. (1B)**
- **Obstructive defect may be diagnosed using $FEV_1/FEV_6$ < LLN (as an acceptable alternative to $FEV_1$/FVC < LLN) when FVC is not obtainable. (2B)**
- **$FEV_6$ is equivalent to FVC in predicting the presence of a restrictive ventilatory defect. (2A)**
- **Use of $FEV_6$ is not recommended until reference equations for $FEV_6$ are available. (UPP)**

## Is spirometry helpful in detecting central/upper airway obstruction?

Miller and Hyatt evaluated the utility of flow-volume loops in central/upper airway obstruction and identified four patterns: (a) flattening of inspiratory loop in extrathoracic airway obstruction, (b) flattening of expiratory loop in intrathoracic airway obstruction, (c) flattening of both loops in fixed airway obstruction, and (d) unclassifiable or atypical flow-volume loop.[237] Additional visual criteria which have been proposed to identify upper airway obstruction include the biphasic waveform on flow-volume loop and the presence of flow oscillations (saw-tooth pattern) indicating mechanical instability of the airway wall.[238]

Central/upper airway obstruction is associated with a significantly reduced PEF, but usually $FEV_1$ and VC are unaffected. Hence, $FEV_1$/PEF ratio >8 can suggest central/upper airway obstruction.[239] Since poor patient effort could result in similar findings, it has been suggested that at least three acceptable and evaluable flow-volume loops are essential to assess central/upper airway obstruction by spirometry.[110] $MVV/FEV_1$ <25%, $FEV_1$/PEF >10 mL/L/min, $FEV_1/FEV_{0.5}$ > 1.5, PIF< 100 mL/min, $PEF_{50\%}/PIF_{50\%}$ <0.3 or >1.0 (ratio of the flow at the mid-point of the forced expiratory maneuver to the flow at the mid-point of the forced inspiratory maneuver r <0.3 or >1.0) are few other parameters noted in central airway obstruction.[238,240]

Spirometry is not the preferred test for the diagnosis of central/upper airway obstruction due to its poor diagnostic capability as well as the easy availability of better alternate investigations. For instance, in a study of 475 patients (7.5% with upper airway obstruction) the area under the receiver-operating-curve (AUROC) for any one, or more than one of the above-mentioned spirometric visual or quantitative criteria was only 0.522 and 0.605, respectively.[238] Thus, the presence of these criteria may point towards the presence of central/upper airway obstruction. However, the sensitivity as well as positive predictive value of these criteria, either alone or in combination, is poor. Therefore, an abnormal test requires confirmation by bronchoscopy, laryngoscopy, or relevant imaging. Despite the fact the negative

predictive value of the spirometric parameters approach 90% or more, a normal spirometry does not rule out central/upper airway obstruction. Moreover, a spirogram may fail to show any abnormality till the tracheal lumen narrows to 8 mm or less.[241]

Spirometry is insufficient to rule out central/upper airway obstruction and more definitive tests are required.[238] In the modern era where imaging, bronchoscopy, and laryngoscopy are widely available, the utility of spirometry in the diagnosis of upper airway obstruction is modest at the best.

*Recommendations*

- **Presence of a typical abnormal flow-volume loop may suggest the presence of central airway obstruction. However, this needs to be confirmed with further evaluation. (3B)**
- **Normal spirometry does not rule out central airway obstruction and further investigation is essential if there is a strong clinical suspicion. (3A)**

## What is the role of additional parameters in interpreting spirometry?

The $FEV_1$, FVC and their ratio are the most important parameters in interpreting spirometry. Apart from these, PEF is also routinely measured. Several devices also provide information on additional flow indices, like $FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$, and $FEF_{25-75\%}$. These additional parameters are believed to be more sensitive for small airway function (especially $FEF_{25-75\%}$) than routine spirometry indices. This view is, however, not universally accepted, and there are several studies providing evidence to the contrary.[170] Although these parameters correlate well with $FEV_1$, their use does not provide any additional advantage over $FEV_1$.[242-244] A large study on 22,767 spirometries demonstrated that when the $FEV_1$, FVC, and $FEV_1$/FVC are normal, only 2.8% and 1.3% of the patients had $FEF_{25-75\%}$ and $FEF_{75\%}$, respectively below the LLN.[170] Moreover, the spread of observed values in healthy population is quite wide, and therefore, there is substantial overlap between the normal and the abnormal values. For instance, the statistically derived LLN for $FEF_{25-75\%}$ for children and elderly (>80 years) have been found to be 67% and 35% of the predicted mean, respectively. For $FEF_{75\%}$, these values were found to be 56% and 31% of the predicted mean, respectively.[170] These parameters may, therefore, remain falsely normal even in patients with documented airflow limitation. For instance, in a study done on 3570 current smokers from the Third National Health and Nutrition Examination Survey (NHANES III) database, 64% of patients with a low $FEV_1$/FVC ratio were found to have a normal $FEF_{25-75\%}$.[245] These measurements are less reproducible and also correlate poorly with other markers of small airway disease, such as air trapping or histologic evidence of small airway inflammation.[246] $FEF_{25-75\%}$ is also FVC dependent and changes in FVC are likely to affect the portion of the flow-curve examined.

*Recommendation*

- **The measurement of additional spirometric values, $FEF_{25-75\%}$ and $FEF_{75\%}$ do not have an additional advantage to the routinely measured parameters, namely, $FEV_1$, VC, and $FEV_1$/VC. These can be misleading and are not recommended for the interpretation of the spirometry. (2A)**

# Miscellaneous and Special Issues

## Peak expiratory flow

### What equipment and procedure is necessary for peak expiratory flow determination?

Peak expiratory flow is the maximum flow achieved during a maximum forced expiration starting from the level of maximal lung inflation.

*Equipment for measuring PEF*

Peak expiratory flow can be measured using spirometers or PEF meters. Although PEF meters measure PEF alone (unlike spirometers which measure various other parameters as well), these are cheaper, portable, do not require electricity for their operation, and are easier to use than spirometers. Hence, PEF meters are considered as the instrument of choice for measuring PEF. PEF is expressed at BTPS in L/s when calculated from flow-volume curve data measured during spirometry, while the unit L/min is used when measured with the help of portable PEF meters.

Several hand-held devices have been described for the measurement of PEF. The oldest one that gained prominence was the Wright's peak flow meter.[247] Several devices followed, including the mini-Wright peak flow meter, Vitalograph peak flow meter, Assess peak flow meter, Ferraris pocket peak flow meter, and the VMX Mini-Log. Among these, the most commonly used device is the mini-Wright peak flow meter. The mini-Wright peak flow meter consists of a hollow plastic cylinder, which encloses a disc which slides freely over a central rod. When air is blown into the PEF meter, the disc moves forward. The level at which the disc comes to rest depends on the maximum expiratory flow rate. The movement of the disc displaces an indicator along a graduated, non-linear scale from which PEF is inferred.

Although some researchers have shown that PEF readings obtained from PEF meters may not be significantly different from those obtained using flow-sensing spirometers, others have shown differences up to 20%.[248-250] Several studies have shown

that significant variation exists between PEF measured using the variable types of portable PEF meters.[250-253] Hence, PEF obtained using various devices should not be considered interchangeable. Small, yet significant differences can exist between PEF meters of the same model and make.[254] Hence, when serial measurements are made over time on a single patient, it is preferable to use the same PEF meter. Predicted values based on measurements obtained on spirometers cannot be used for measurements obtained with a hand-held PEF meter.[248,255]

*Scale for PEF meters*

There are three scales commonly used in PEF meters: Wright scale, ATS scale, and European Union (EU) scale. The Wright scale, defined in 1959, was a linear scale developed from airflow measurements from a small group of patients, including patients with lung diseases.[247] Miller *et al*[256] demonstrated that PEF has non-linear characteristics and which to inaccuracies in the PEF meters based on the Wright's scale resulting in a higher reading of up to 80 L/min in the mid-flow range from 300 to 500 L/min. Subsequently, non-linear scales (ATS scale and the EU scale) were developed to overcome this issue.[7,257]

The PEF meters should clearly specify the scale which they are using as the ATS and EU scales are not identical. Pesola *et al*[248] compared mini-Wright PEF meters employing the ATS scale and the EU scale in 57 healthy volunteers and found that the ATS PEF meter readings was 2.8% higher than the EU PEF meter across a range of flows. The magnitude of difference may not be clinically significant. However, when precise measurements are needed as in the research setting, a single type of PEF meter and scale should be used consistently.

For conversion of PEF values measured using the Wright scale to the EU scale, the following correction equation can be used[258]:

Corrected PEF = (0.00090 × Measured PEF$^2$) + (0.373 × Measured PEF) + 47.4

*Equipment specifications for PEF meters*

Resistance of the equipment used to measure PEF will affect the measured PEF values.[259-261] For variable orifice PEF meters, the resistance falls as the flow increases, while the reverse is true for fixed orifice PEF meters.[261] In one study, it was shown that a PEF meter with a resistance of 2.1 $cmH_2O.L^{-1}.s^{-1}$ (at 600 L/min flow) under-read the PEF values by 8% in comparison with a pneumotachometer.[260] Earlier, the recommended resistance limits for spirometers, *i.e* <0.5-1.5 $cmH_2O.L^{-1}.s^{-1}$ used to be extrapolated to PEF meters as well.[3,5] However, it has been shown that the resistance of the available PEF meters usually ranged from 0.5 to 3.5 $cmH_2O.L^{-1}.s^{-1}$ across their flow ranges.[256,261] Hence, existing guidelines recommend that the mean instrument resistance (measured across the range of the instrument) should be <2.5 $cmH_2O.L^{-1}.s^{-1}$.[14]

Recommendations for accuracy and inter-device variability for PEF measurements are less stringent than for other spirometry measurements (±10% for PEF *versus* ±3% for other spirometric measurements) because of inherent higher variability in PEF measurements due to existing equipment limitations.[7,163] However, recommendations for intra-device variability (precision) is lower (<5%) as this is essential in situations where serial measurements are necessary.[7,163]

*Calibration of PEF meters*

Although portable PEF meters aged up to 14 years have been shown to give readings comparable to new PEF meters, there is evidence to suggest that some PEF meters demonstrate significant change in their readings in just one year of use.[254,262] Hence, in situations which demand accurate PEF testing, it would be prudent to calibrate the PEF meters annually by sending them back to the manufacturer. If this is not feasible, at least a simple inspection of the PEF meter should be done periodically.[262] This should include visual inspection of the PEF meter for any cracks or deformity on its body. Additionally, the smooth movement of the pointer over the scale should be verified and the meter should be gently shaken to identify any loose material inside it.

*Test signals for PEF meter testing*

The accuracy and repeatability of PEF meters should be verified by the equipment manufacturer using flow-time waveforms delivered by computerised mechanical syringes. Initially, the same set of 24 flow-time waveforms used for testing spirometers were recommended for testing PEF meters as well by the ATS.[3] However in 1995, Hankinson *et al*[263] published a set of 26 flow-time waveforms developed specifically for the testing of PEF meters. Subsequently, the ATS recommended this set of 26 flow-time waveforms for testing of PEF meters.[7,14] However, these set of waveforms may still be inadequate and may not fully cover the diverse peak flows encountered in the general population.[264,265]

*Procedure for measurement of PEF*

The usual precautions to be taken during spirometry apply to PEF as well. Although both the FVC and PEF maneuvers involve forceful expiration, the PEF maneuver is different from the FVC maneuver in that it consists of a short, sharp exhalation instead of the prolonged, deep expiration during a FVC maneuver. PEF values obtained with the PEF maneuver are significantly higher as compared to those obtained with the FVC maneuver.[249,266]

Peak expiratory flow maneuver is usually performed with the subject sitting comfortably on

a chair. PEF recorded in the supine and prone positions is lower as compared to that recorded in the sitting position.[267,268] However, there is no significant difference between the PEF recorded in the sitting and standing positions or supine and prone positions.[267,268] While performing the PEF maneuver, sufficient care should be exerted to avoid undue flexion/extension of the neck and breath holding at TLC. Flexion at the neck leads to a reduction in the PEF by reducing the longitudinal tracheal tension, and thereby, increasing the tracheal compliance.[269] Extension of neck may lead to an increase in PEF by elongating and stiffening the trachea, but this effect has not been demonstrated consistently.[269,270] If there is a pause between the maximal inspiration and the expiratory maneuver (*i.e.*, a breathhold at TLC), it results in decrease in PEF.[269] This could be attributable to stress relaxation of the airways and the pulmonary parenchyma, resulting in increased compliance of the airways and reduced elastic recoil of the lung.

For comparison between PEF values over an interval, PEF should be measured during the same time of the day as it has diurnal variability. In a study on healthy Indian men, it was found that PEF was lowest at 5 AM, progressively increased to the highest value at 5 PM and then progressively decreased till 5 AM.[271] Daily diurnal variability is calculated from twice (or more) daily PEF records as: (Day's maximum PEF – Day's minimum PEF)/(Mean of day's maximum and minimum PEF), and is usually averaged over a week.

As PEF depends on expiratory muscle strength, adult males generally have higher PEF than females of the same height and age. The decline in expiratory muscle strength and increased lung compliance with ageing leads to a fall in PEF.[272]

**Within- and between-maneuver acceptability for PEF maneuver**

Ninety-five percent of trained healthy subjects can usually reproduce PEF within 30 L/min.[273] In another study, the proportion of untrained healthy subjects who were able to reproduce the PEF within 30 L/min and 40 L/min was 90% and 95% respectively.[260] Hence, it is recommended that the largest two of the acceptable blows should be within 40 L/min of each other (Table 6). If acceptable reproducibility is not achieved within five PEF maneuvers, further testing is unlikely to be helpful, and hence, not recommended.[274]

*Recommendations*

- **Hand-held PEF meters are more convenient and may be preferred to measure PEF. (UPP)**
- **PEF measurements obtained from various different equipment may not be considered as interchangeable. (1A)**
- **PEF meters should use non-linear scales like the ATS or EU scale in preference to the conventional Wright's scale. (2A)**
- **PEF meters should be calibrated annually wherever, feasible. (2A) When this is not possible, at least periodic inspection of the equipment should be done to detect any obvious defects. (UPP)**
- **PEF measurements obtained using FVC maneuvers cannot be considered equivalent to PEF measurements obtained using PEF maneuvers. (2A)**

**What is the role of peak expiratory flow in diagnosis and monitoring of various respiratory disorders?**

The PEF is a non-specific measure of pulmonary function and is reduced in both obstructive and restrictive lung diseases. It is predominantly a measure of large airway function, while $FEV_1$ reflects both large and peripheral airway function. This is because PEF is usually recorded in the first 100 ms of forced expiration, while $FEV_1$ continues to record forced expiration for another 900 ms.[275]

*COPD*

Though there is a steady decline in the expiratory flow in normal individuals after the maximal flow is reached, the flow rate collapses in patients with severe COPD. This sudden decline in the airflow due to the collapsing airways is not captured by the PEF.[275] Thus, PEF cannot act as a surrogate for $FEV_1$ for the diagnosis of airflow obstruction or severity classification of COPD.[276,277] In a study reported from Thailand for screening for COPD in the elderly, even at the best cut-off for accuracy, PEF had a sensitivity of only 72.7% and a specificity of 81.1%.[278] However, there is evidence that adding PEF measurement to a screening questionnaire may be of use, as PEF ≥70% predicted effectively ruled out severe to very severe COPD.[279] PEF is not a good predictor of an exacerbation of COPD. In a prospective longitudinal follow-up study of 101 patients with moderate to severe COPD, it was demonstrated that symptoms, but not lung function worsened significantly before an exacerbation.[280]

*Asthma*

In patients with symptoms suggestive of asthma, PEF variability can be used as an indicator of the variability of expiratory airflow limitation, thereby establishing a diagnosis of asthma. A diurnal variability (over 2 weeks) of more than 10% in adults (13% in children) suggests significant variability of airflow obstruction.[281] A significant increase (>20%) in PEF after four weeks of anti-inflammatory treatment is also a pointer towards variable expiratory airflow limitation.[281] PEF monitoring and subsequent demonstration of variability in PEF may help confirm a diagnosis of asthma in symptomatic patients even in the presence of a normal

spirometry.[282] Serial PEF measurements have also been shown to have good sensitivity and specificity for the diagnosis of occupational asthma.[283]

Excessive variability in PEF suggests poor asthma control and increased risk of exacerbation.[284] Trends in PEF monitored as a part of a written asthma plan may be used to guide self-adjustment of therapy in asthma.[281,285] Global Initiative for Asthma (GINA) recommends a short-course of oral corticosteroids for the patients in whom the PEF deteriorates to <60% of their personal best or predicted value.[281] PEF monitoring may also be helpful in severe asthma and in patients who are poor perceivers of airflow obstruction. During daily PEF monitoring, the patient's 'personal best' PEF rather than the predicted PEF should be used for comparisons because it has been shown that the 'personal best' PEF may vary from the predicted PEF by >±10% in 55% of patients with chronic asthma.[286] Further, it has been demonstrated that action points based on 'personal best' PEF provide greater health benefits, than those based on predicted PEF.[285]

*Restrictive lung diseases*

The PEF is reduced in parenchymal lung diseases.[287-290] However, its sensitivity for this condition is poor as compared to FVC.[289,290] PEF is also reduced in neuromuscular diseases and this reduction may be used as an index of disease severity and progression.[291-293]

*Recommendations*

- **There is no role of PEF in the diagnosis or monitoring of COPD. (2A)**
- **PEF monitoring is a useful adjunct to establish a diagnosis of asthma in subjects with symptoms suggestive of asthma. (2A)**
- **PEF monitoring is useful in the diagnosis of occupational asthma. (1A)**
- **PEF monitoring should be used as a part of written asthma action plans to guide self-management of asthma. (1A)**
- **The personal best value established after optimum therapy (rather than percent predicted PEF) should be used as the standard for comparison of serial values. (1A)**

## What is bronchodilator reversibility test and how is it performed?

Bronchodilator reversibility (BDR) test consists of measuring the lung function before and after administering a fast-acting bronchodilator and measuring the reversibility of airflow limitation. BDR testing should be performed at baseline in all subjects suspected or found to have airflow obstruction. However, in subsequent serial testing in such subjects, BDR test is usually not required.

Preparation for BDR testing should be similar to preparation for spirometry, and contraindications to spirometry apply to BDR testing as well. Moreover, BDR testing may be avoided in patients with cardiac arrhythmias or known hypersensitivity to the agent used for BDR testing.

Several drugs and dosages have been used in previous major studies on BDR; most recent studies have used short-acting beta-agonists (SABA), especially salbutamol. Most commonly, BDR test involves repeating spirometry between 15 and 20 minutes after administering salbutamol (four puffs of 100 μg) or equivalent doses of levosalbutamol (4 puffs of 50 μg). If use of salbutamol is contraindicated, ipratropium (8 puffs of 20 μg) may be used as an alternative with spirometry performed after 30 minutes. The bronchodilator should be delivered with an MDI device, ideally with a spacer, using correct technique. Alternatives such as nebulisation or dry powder inhaler may be used for patients who are unable to take MDIs.

*Recommendations*

- **BDR testing should be performed at baseline in all subjects suspected or found to have airflow obstruction. (1A) However, in subsequent serial testing in such subjects, BDR test is usually not required. (UPP)**
- **BDR test should be performed between 15 and 20 minutes after administering salbutamol (four puffs of 100 μg) or equivalent doses of levosalbutamol (4 puffs of 50 μg). (1A)**
- **If use of salbutamol is contraindicated, ipratropium (8 puffs of 20 μg) may be used as an alternative with spirometry performed after 30 minutes. (2B)**
- **The bronchodilator should be delivered with an MDI device, ideally with a spacer, using correct technique. (1A)**
- **Alternative preparations such as nebulisation or dry powder inhaler may be used in subjects who are unable to take MDIs. (2B)**

**What criteria should be used to define bronchodilator reversibility?**

Bronchodilator reversibility may be expressed as the absolute increment in $FEV_1$ ($\Delta FEV_1$), as a percentage improvement over baseline ($\Delta FEV_1$ % baseline) or predicted $FEV_1$ ($\Delta FEV_1$ % predicted), or as a percentage of maximal achievable reversibility ($\Delta FEV_1$% [Predicted - Baseline]). However, percentage of maximal achievable reversibility is a poor measure of variability because if the baseline $FEV_1$ equals the predicted $FEV_1$, the value becomes infinity.

The different reversibility criteria recommended by various old and current guidelines have been

summarised in table 8.[4,5,110,281,294-299] An ideal reversibility criterion should (a) be able to identify a true bronchodilator response, (b) provide information on the severity of the airway obstruction, (c) correlate well with clinical response, and (d) be independent of the baseline $FEV_1$. However, none of the available criteria meet all the ideal characteristics.

The most widely used BDR criterion, $\Delta FEV_1$ % baseline, is based on expert opinion only. It is influenced by the baseline $FEV_1$ (*i.e.*, subjects with lower baseline $FEV_1$ will be more likely to have a better $\Delta FEV_1$ % baseline, even when $\Delta FEV_1$ is small). This error may be partly nullified by adding an absolute $\Delta FEV_1$ criterion. In a study of 660 subjects with COPD, investigators found that $\Delta FEV_1$ % baseline showed an apparently elevated response when the baseline $FEV_1$ is low and this relationship persisted even when the ATS absolute $\Delta FEV_1$ criterion were applied.[300] The expression of $\Delta FEV_1$ as a percentage of the predicted $FEV_1$ avoids this error, in addition to avoiding bias due to age and sex.[300,301] In a study comparing different reversibility criteria in subjects with asthma, $\Delta FEV_1$ % predicted>9% had a reasonable sensitivity (87%) and a much better specificity (95% *versus* 67%)as compared to $\Delta FEV_1$ % baseline with $\Delta FEV_1$>200 mL as the gold standard.[302] However, since the most widely followed ATS/ERS recommendations endorsed $\Delta FEV_1$ % baseline, we decided to retain $\Delta FEV_1$% baseline for defining BDR until further evidence emerges.

**Table 8. Bronchodilator reversibility criteria used in various guidelines**

| Guideline | Criteria |
|---|---|
| ACCP 1974[294] | $\Delta FEV_1$ >15% of baseline value |
| ATS 1991[4] | $\Delta FEV_1$ or $\Delta FVC$ >12% of baseline value AND >200 mL |
| ERS 1993[5] | $\Delta FEV_1$ >9% of predicted value |
| ERS 1995[295] | $\Delta FEV_1$ ≥10% of predicted value |
| BTS/SIGN 2003 [296] | $\Delta FEV_1$ >15% of baseline value AND >200 mL |
| NICE 2004[297] | $\Delta FEV_1$ >400 mL |
| ATS/ERS 2005[110] | $\Delta FEV_1$ and/or $\Delta FVC$ >12% of baseline value AND >200 mL |
| GOLD 2010[298] | $\Delta FEV_1$ and/or $\Delta FVC$ >12% of baseline value AND >200 mL |
| BTS/SIGN 2016[299] | $\Delta FEV_1$ >12% of baseline value AND >200 mL |
| GINA 2017[281] | $\Delta FEV_1$ >12% of baseline value AND >200 mL |

*Definition of abbreviations:* ACCP=American College of Chest Physcians, ATS=American Thoracic Society, ERS=European Respiratory Society, BTS=British Thoracic Society, SIGN=Scottish Intercollegiate Guidelines Network, NICE=National Institute for Clinical Excellence, GOLD=Global Initiative for Chronic Obstructive Lung Disease, GINA=Global Initiative for Asthma, $\Delta FEV_1$=Post-BDR, $FEV_1$=Forced expiratory volume in one second, FVC=Force vital capacity, BDR=Bronchodilator reversibility

In addition, it is also important to use absolute change in pulmonary function as a criterion while assessing reversibility, to avoid falsely positive results based on relative change alone, as can happen when the baseline pulmonary function is poor. Most contemporary guidelines, therefore, use a combination of absolute and relative improvements in lung volume define BDR (Table 8).

*Recommendation*

- **An increase in $FEV_1$ and/or FVC of 200 mL and 12% of the baseline should be used as the criterion for defining bronchodilator reversibility. (UPP)**

### Is there a role of bronchodilator reversibility in differentiating asthma from COPD?

Chronic obstructive pulmonary disease has traditionally been considered to be a disease with poorly reversible lung function. However, in a recent post-hoc analysis of the Understanding Potential Long-term Impacts on Function with Tiotropium (UPLIFT) trial, 39%–73% of COPD patients exhibited BDR according to various criteria.[303] In another analysis of data from two randomised trials consisting of patients with moderate to severe COPD, large proportions of patients met the ATS BDR criterion for $FEV_1$ (57%–59%) and FVC (57%–67%).[304] Additionally, several patients of asthma may not exhibit BDR at the time of spirometric evaluation. These data highlight the existence of substantial overlap in BDR between asthma and COPD. Therefore, the diagnostic ability of acute BDR in separating asthma from COPD is limited. Moreover, using different expressions or cut-offs of BDR criteria may still not help to differentiate asthma from COPD.[305,306]

*Recommendations*

- **Bronchodilator reversibility test, as a single test should not be used to differentiate between asthma and COPD. (1A)**
- **BDR may be used to corroborate a diagnosis of asthma while recognising its limitations. (UPP)**

## What is the role of bronchoprovocative tests?

Bronchoprovocative or bronchial challenge tests are tests used to demonstrate airway hyperresponsiveness by exposing the subject to an agent or condition which elicits bronchoconstriction. These may be of use in patients in whom asthma is strongly suspected but spirometry results are normal. However, these should not be used routinely for the diagnosis of asthma.[99] Demonstration of non-specific bronchial hyperresponsiveness using bronchoprovocative tests may also be useful in the diagnosis of work-related asthma.[307]

Many clinical conditions, in addition to the general contraindications for spirometry, preclude

performance of bronchoprovocative testing. In patients with uncontrolled hypertension, recent myocardial infarction or cerebrovascular accident, the stress induced by bronchospasm may precipitate cardiovascular events. Existing guidelines suggest that bronchoprovocation tests should not be done in subjects with severe airflow limitation ($FEV_1$<50% predicted or <1L) and be preferably avoided in subjects with moderate airflow limitation ($FEV_1$<60% predicted or <1.5L).[308] However, complication rates remain low even in patients with poor lung function.[309]

Bronchoprovocation can be done by using pharmacological agents, exercise, or voluntary hyperventilation. Pharmacological challenge can be done with agents which produce bronchoconstriction by directly stimulating airway smooth muscle receptors (methacholine, histamine) or agents which produce bronchoconstriction indirectly by releasing inflammatory mediators (mannitol, adenosine). Methacholine is one of the commonest pharmacologic agents used. During methacholine challenge test, the subject is made to breathe progressively stronger concentrations of methacholine according to a pre-specified protocol. The provocative concentration of methacholine causing a 20% fall in $FEV_1$ ($PC_{20}$) is noted. A $PC_{20}$ value greater than 16 mg/mL is considered a negative test.[308]

*Recommendations*

- **Because of their inherent risk for precipitating an acute attack of bronchospasm tests for bronchial hyperresponsiveness should be performed in specialised centers with facilities for resuscitation. (UPP)**
- **Lack of $PC_{20}$ response at 16 mg/mL concentration should be considered as a negative response during methacholine challenge testing. (2A)**

## Reference equations

### How to generate and select appropriate reference values?

For each lung function parameter, the expected normal value is calculated using 'reference' equations, also known as 'prediction' or 'regression' equations. Reference equations enable prediction of reference values as a combined function of gender, and anthropometric data such as height, weight and others.

Reference equations are developed by studying lung function of a large sample of carefully selected and well-defined 'normal' healthy subjects. Usually, only non-smokers are included in such an effort, and spirometers and test techniques should meet standard recommendations. A population sample (with a wide range of age and height) is preferred to a convenience sample (*e.g.*, using volunteers or patients referred to a clinic). There is some suggestion that at least 150 male and 150 female subjects would be necessary to validate reference values.[310] It should also be noted that the character of a population changes significantly with time. Hence, it is prudent to revise the reference equations periodically.[311]

Reference equations for various spirometric parameters are usually developed using standard statistical techniques employing multivariate regression analysis. Linear models are most commonly used. For example, the equation for FVC = constant + (coefficient × age) + (coefficient × height). The constant and the coefficients of the independent variables are derived from the regression analysis, usually by the least squares method. A residual standard deviation (RSD) or the standard error of estimate (SEE) provides information about the scatter of data points around the predicted value. The predictive ability of an equation is described in terms of the $R^2$, that is, the 'explained variance'. The selection of the best model takes into account the $R^2$, simplicity and ease of use of the equation, as well as the compliance with the requirements of the regression analysis.

Reference equations for spirometry are largely specific to the population they are intended for. Generally, Caucasians have lung volumes that are 10%–15% higher than Africans and Asians, for a given standing height.[312,313] Males, in general, have 10%–15% higher FVC and $FEV_1$ compared to females of similar age group.[314] Pulmonary function also varies with age. It continues to improve with age as long as physical growth occurs, and maximal lung function is obtained at about 18-20 years in males and 14-16 years in females.[315-317] After physical growth is complete, pulmonary function declines with further aging because of the progressive loss of elastic recoil of the lung with age.[318-320] Height is included in most reference equations, and usually has a positive relationship with spirometry variables. Weight may improve the predictive ability of the equation for some parameters, but only marginally. Lung function declines at both extremes of weight.[321-323] Obese patients have lower ERV and functional residual capacity (FRC); however, residual volume (RV), TLC, $FEV_1$, and FVC are not affected significantly unless the patient is massively obese.[322,323]

Selection of the appropriate reference equation is one of the most critical steps in spirometry as the interpretation of the spirometry data will depend on the selected equation. Most standard spirometry software offers a wide selection of reference equations. The spirometry technician should select the reference equation developed in the population

with same ethnicity as that of the subject being tested. The reference equations perform best when age, race/ethnicity, anthropometric, socio-economic characteristics, the instruments used and lung function measurement protocols are all matched between the study and the reference population. The reference equations may not be valid for ages and anthropometric characteristics that are beyond those of the reference population sample. All parameters, *i.e.* the $FEV_1$, FVC, $FEV_1$/ FVC and the flow rates should come from the same reference source. The reference equation used to interpret the study should be mentioned in the spirometry report.

**What are the reference equations available from India?**

Several reference equations are available from various geographical locations in India (Tables 9-15).[324-346] Yet, it is not uncommon to find the usage of Caucasian reference equations and obtaining predicted values, with an 'ethnic discounting' (*e.g.*, 10% reduction from the Caucasian equation predicted value).[347] Use of Caucasian prediction equations or a fixed percentage of their predicted values (*e.g.*, 90% of predicted) are not suitable for Indians. In a large study, involving 14,733 consecutive spirometry procedures in adults in North India, the use of Caucasian prediction equations (or 90% of predicted values) resulted in poor agreement with the Indian equations.[314]

Multi-ethnic reference equations for the age range 3-95 years were published in 2012 based on data from 33 countries with a potential for wider application.[28] However, it cannot be used in India at present owing to the under representation from Indian subcontinent. Moreover, the population in India is markedly heterogeneous. In fact, even prediction equations developed in one region of India may not be applicable to all Indians.[348,349] In a study comparing reference equations from different parts of India, spirometric records of 27,383 patients were interpreted using three sets of reference equations (North, West, and South Indian reference equations). The North and West Indian equations were discordant in 22.1% instances, and the North and South Indian equations in 12.9% instances, with kappa estimates of agreement being 0.626 and 0.781, respectively.[349]

**Table 9. Details of selected studies providing reference equations for spirometry from various parts of India**

| Study | Region | Study Subjects | Age Group | Instrument Used | Smokers |
|---|---|---|---|---|---|
| Desai *et al* 2016[324] | Mumbai | 310 healthy adults | 18-75 years | Fleisch pneumotachograph | Excluded |
| Dasgupta *et al* 2015[325] | Kolkata | 619 healthy adults | 15-69 years | Pneumotachograph | Excluded |
| Chhabra *et al* 2014[326] | Delhi | 685 healthy adults | 18-71 years | Fleisch pneumotachograph | Excluded |
| Saleem *et al* 2012[327] | Kashmir | 3080 healthy adults | 18-65 years | Digital turbine spirometer | Excluded |
| Phatak *et al* 2002[328] | Nagpur | 1200 elderly | >60 years | Wedge bellows spirometer | Excluded |
| Virani *et al* 2001[329] | Pondicherry | 397 healthy adults | 17-70 years | Digital turbine spirometer | Excluded |
| Mahajan *et al* 1997[330] | Rohtak | 137 healthy women | 18-52 years | | Excluded |
| Chaterjee and Saha 1993[331] | Kolkata | 230 healthy women | 20-59 years | Water-seal spirometer | Excluded |
| Rao *et al* 1992[332] | Ahmedabad | 96 healthy adults | 15-40 years | Wedge bellows spirometer | Excluded |
| Rao *et al* 1992[333] | Ahmedabad | 326 industrial workers | ≥15 years | Wedge bellows spirometer | Excluded |
| Jindal and Wahi 1991[334] | Chandigarh | 962 healthy adults | 15-74 years | Water-seal spirometer | Excluded |
| Vijayan *et al* 1990[335] | Chennai | 247 healthy adults | 15-40 years | Dry rolling seal spirometer | Included |
| Prakash 1990[336] | Bangalore | 560 healthy adults | ≥15 years | Water-seal spirometer | Excluded |
| Purohit *et al* 1989[337] | Jaipur | 1027 healthy adults | ≥15 years | Autospirometer | Excluded |
| Chatterjee *et al* 1988[338] | Kolkata | 334 healthy men | 20-60 years | Water-seal spirometer | Included |
| Udwadia *et al* 1986[339] | Mumbai | 760 healthy adults | 15-65 years | Fleisch pneumotachograph | Excluded |
| Verma *et al* 1983[340] | Delhi | 171 healthy men | 21-69 years | Not specified | |
| Kamat *et al* 1977[341] | Tamil Nadu | 1247 healthy adults | 15-55 years | Water-seal spirometer | Included |
| Joshi *et al* 1973[342] | Ludhiana | 148 healthy men | 18-61 years | Water-seal spirometer | Included |
| Jain and Ramiah 1969[343] | Delhi | 108 healthy men | 15-40 years | Water-seal spirometer | Excluded |
| Jain *and Gupta* 1967[344] | Delhi | 70 healthy men | 40-65 years | Water-seal spirometer | Excluded |
| Jain and Ramiah 1967[345] | Delhi | 144 healthy women | 15-40 years | Water-seal spirometer | Excluded |
| Milledge 1965[346] | Tamil Nadu | 479 healthy men | 20-55 years | Water-seal spirometer | Included |

**Table 10. Selected reference equations for forced vital capacity in men**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Deasi *et al* 2016[324] | exp(–1.048 + 0.015H – 0.0045A) | |
| Dasgupta *et al* 2015[325] | –2.537 + 0.0418H – 0.0211A | 0.518 |
| Chhabra *et al* 2014[326] | –5.048 + 0.054H – 0.014A + 0.006W | 0.479 |
| Saleem *et al* 2012[327] | –0.416 + 0.032H – 0.021A [<30 years] | 0.685 |
| | 0.411 + 0.025H – 0.005A [31-50 years] | 0.671 |
| | –1.747 + 0.04H – 0.031A [≥50 years] | 0.589 |
| Phatak *et al* 2002[328] | 2.8514 + 0.0056H – 0.0153A | |
| Virani *et al* 2001[329] | –3.29 + 0.043H – 0.017A | 0.400 |
| Rao *et al* 1992[332] | –3.98 + 0.042H – 0.036A + 0.03W | 0.500 |
| Rao *et al* 1992[333] | –4.557 + 0.048H – 0.019A + 0.006W | 0.492 |
| Jindal and Wahi 1991[334] | –3.44 + 0.048H – 0.013A – 0.00005$A^2$ | 0.497 |
| Vijayan *et al* 1990[335] | –6.857 + 0.062H | 0.481 |
| Prakash 1990[336] | 0.5612 + 0.0167H + 0.0009A | |
| Purohit *et al* 1989[337] | –3.60 + 0.049H – 0.027A | |
| Chatterjee *et al* 1988[338] | -4.129 + 0.0522H – 0.0214A | 0.422 |
| Udwadia *et al* 1986[339] | –6.058 + 0.055H + 0.019A [<30 years] | 0.505 |
| | –4.832 + 0.054H – 0.018A [≥30 years] | 0.462 |
| Verma *et al* 1983[340] | –2.472 + 0.0438H – 0.0281A | 0.465 |
| Kamat *et al* 1977[341] | –4.488 + 0.0503H – 0.0136A | |
| Joshi *et al* 1973[342] | –2.69 + 0.04H | 0.710 |
| Jain and Ramiah 1967[343] | –3.3129 + 0.04391H | 0.492 |
| Jain and Gupta 1967[344] | –2.5788 + 0.0468H – 0.0163A – 0.1357W | 0.495 |
| Milledge 1965[346] | –6.5014 + 0.3995H – 0.0166A | |

*Definition of abbreviations:* A=Age (years), H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

**Table 11. Selected reference equations for forced vital capacity in women**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Deasi *et al* 2016[324] | exp(–1.616 + 0.015H + 0.014A – 0.000219$A^2$) | |
| Dasgupta *et al* 2015[325] | 0.0972 + 0.0216H – 0.0186A | 0.465 |
| Chhabra *et al* 2014[326] | 20.07 – 0.261H + 0.000972$H^2$ – 0.01A | 0.315 |
| Saleem *et al* 2012[327] | 0.244 + 0.022H – 0.022A [<30 years] | 0.454 |
| | 0.508 + 0.016H – 0.004A [31-50 years] | 0.446 |
| | –0.772 + 0.022H – 0.002A [≥50 years] | 0.442 |
| Phathak *et al* 2002[328] | 0.819091 + 0.009661H – 0.00689A | |
| Virani *et al* 2001[329] | –1.163 + 0.026H – 0.015A | 0.290 |
| Mahajan *et al* 1997[330] | –3.12 + 0.04H + 0.01A | |
| Chatterjee and Saha 1993[331] | –0.902 + 0.027H – 0.025A | 0.310 |
| Rao *et al* 1992[332] | –3.03 + 0.024H + 0.024A + 0.03W | 0.400 |
| Jindal and Wahi 1991[334] | –2.05 + 0.035H – 0.014A – 0.00004$A^2$ | 0.447 |
| Vijayan *et al* 1990[335] | –2.883 + 0.035H | 0.325 |
| Prakash 1990[336] | –1.754 + 0.0256H + 0.007A | |
| Purohit *et al* 1989[337] | –1.48 + 0.32H – 0.024A | |
| Udwadia *et al* 1986[339] | –2.284 + 0.03H + 0.006A [<30 years] | 0.377 |
| | –3.755 + 0.043H – 0.01A [≥30 years] | 0.341 |
| Kamat *et al* 1977[341] | –3.187 + 0.037H – 0.007A | |
| Jain and Ramiah 1967[345] | –2.916 + 0.03561H + 0.00412A | 0.339 |

*Definition of abbreviations:* A=Age (years), B=Body surface area, H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

**Table 12. Selected reference equations for forced expiratory volume in one second in men**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Desai *et al* 2016[324] | –3.275 + 0.043H – 0.020A | 0.346 |
| Dasgupta *et al* 2015[325] | –1.7649 + 0.0337H – 0.0218A | 0.434 |
| Chhabra *et al* 2014[326] | –3.682 + 0.046H – 0.024A | 0.402 |
| Saleem *et al* 2012[327] | –1.136 + 0.033H – 0.014A [<30 years] | 0.627 |
| | 0.242 + 0.023H – 0.005A [31-50 years] | 0.634 |
| | –1.483 + 0.037H – 0.03A [≥50 years] | 0.563 |
| Phathak *et al* 2002[328] | 3.0039 + 0.0022H – 0.0167A | |
| Virani *et al* 2001[329] | –1.452 + 0.031H – 0.020A | 0.330 |
| Rao *et al* 1992[332] | –3.53 + 0.043H – 0.045A + 0.014W | |
| Rao *et al* 1992[333] | –2.757 + 0.38H + 0.022A + 0.006W | 0.492 |
| Jindal and Wahi 1991[334] | –1.9 + 0.036H – 0.025A + 0.00006$A^2$ | |
| Vijayan *et al* 1990[335] | –6.195 + 0.057H – 0.00023$A^2$ | 0.415 |
| Prakash 1989[336] | 1.49 + 0.013H – 0.027A | |
| Purohit *et al* 1989[337] | –3.64 + 0.046H – 0.024A | |
| Chatterjee *et al* 1988[338] | –4.6899 + 0.0533H – 0.0286A | 0.326 |
| Udwadia *et al* 1986[339] | –3.266 + 0.039H – 0.01A [<30 years] | 0.392 |
| | –2.65 + 0.037H – 0.022A [≥30 years] | 0.328 |
| Verma *et al* 1983[340] | –1.0474 + 0.0312H – 0.0286A | 0.450 |
| Kamat *et al* 1977[341] | –3.13 + 0.0396H – 0.0212A | |
| Joshi *et al* 1973[342] | –2.339 + 0.026H + 0.021A | 0.372 |

*Definition of abbreviations:* A=Age (years), H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

**Table 13. Selected reference equations for forced expiratory volume in one second in women**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Deasi *et al* 2016[324] | exp(–1.552 + 0.015H + 0.0043A – 0.000144$A^2$) | |
| Dasgupta *et al* 2015[325] | 0.0381 + 0.0196H – 0.0197A | 0.370 |
| Chhabra *et al* 2014[326] | –2.267 + 0.033H – 0.019A | 0.286 |
| Saleem *et al* 2012[327] | –0.468 + 0.023H – 0.015A [<30 years] | 0.442 |
| | 0.063 + 0.017H – 0.004A [31-50 years] | 0.416 |
| | –1.356 + 0.024H – 0.002A [≥50 years] | 0.410 |
| Phathak *et al* 2002[328] | 0.437672 + 0.01242H – 0.01149A | |
| Virani *et al* 2001[329] | –0.457 + 0.020H – 0.016A | 0.230 |
| Chatterjee and Saha 1993[331] | –0.254 + 0.021H – 0.027A | 0.284 |
| Rao *et al* 1992[332] | –0.82 + 0.02H – 0.025A + 0.02W | 0.300 |
| Jindal and Wahi 1991[334] | –1.07 + 0.027H – 0.03A + 0.00013$A^2$ | 0.323 |
| Vijayan *et al* 1990[335] | –1.9 + 0.026H | 0.304 |
| Prakash 1990[336] | 0.5 + 0.014H + 0.021A | |
| Purohit *et al* 1989[337] | –3.95 + 0.044H – 0.015A | |
| Udwadia *et al* 1986[339] | –1.424 + 0.025H – 0.011A [<30 years] | 0.341 |
| | –2.58 + 0.032H – 0.012A [≥30 years] | 0.309 |
| Kamat *et al* 1977[341] | –1.995 + 0.0274H – 0.0103A | |

*Definition of abbreviations:* A=Age (years), H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

**Table 14. Selected reference equations for $FEV_1$/FVC in men**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Desai *et al* 2016[324] | 89.09 – 0.179A | 4.73 |
| Dasgupta *et al* 2015[325] | 108.994 – 0.12H – 0.133A | 9.2 |
| Chhabra *et al* 2014[326] | 102.56 – 0.679A + 0.00477$A^2$ – 0.080W | 5.79 |
| Saleem *et al* 2012[327] | 72.742 + 0.089H + 0.106A [<30 years] | 2.891 |
| | 85.516 + 0.026H – 0.004A [31-50 years] | 2.722 |
| | 84.987 + 0.047H – 0.085A [≥50 years] | 3.537 |
| Jindal and Wahi 1991[334] | 103 – 0.07H – 0.35A + 0.002$A^2$ | 6.6 |
| Vijayan *et al* 1990[335] | 76.695 + 0.08H – 0.00613$A^2$ | 6.638 |
| Chatterjee *et al* 1988[338] | 58.76 + 0.2136H – 0.3093A | 6.019 |
| Udwadia *et al* 1986[339] | 119.3640 – 0.1756H – 0.2457A | 7.7411 |
| Joshi *et al* 1973[342] | 89.41 – 0.455A | 7.139 |

*Definition of abbreviations:* $FEV_1$=Forced expiratory volume in one second, FVC=Force vital capacity, A=Age (years), H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

**Table 15. Selected reference equations for $FEV_1$/FVC in women**

| Study | Regression Formula | RSD/SEE |
|---|---|---|
| Desai *et al* 2016[324] | 104.35 – 0.085A + 0.0065$A^2$ | 6.34 |
| Dasgupta *et al* 2015[325] | 92.05 + 0. 001H – 0.0214A | 7.6 |
| Chhabra *et al* 2014[326] | 97.182 – 0.44A | 4.97 |
| Saleem *et al* 2012[327] | 67.8 + 0.105H + 0.137A [<30 years] | 3.139 |
| | 75.836 + 0.077H – 0.012A [31-50 years] | 3.095 |
| | 54.976 + 0.205H – 0.021A [≥50 years] | 3.166 |
| Chatterjee and Saha 1993[331] | 86.1 – 0.241A | 5.680 |
| Jindal and Wahi 1991[334] | 111 – 0.1H – 0.36A + 0.003$A^2$ | 5.8 |
| Vijayan *et al* 1990[335] | 94.917 – 0.011H – 0.00734$A^2$ | 5.639 |
| Udwadia *et al* 1986[339] | 94.8867 – 0.0334H – 0.2146A | 11.0011 |

*Definition of abbreviations:* $FEV_1$=Forced expiratory volume in one second, FVC=Force vital capacity, A=Age (years), H=Height (cm), W=Weight (kg), RSD=Residual standard deviation, SEE=Standard error of estimate

## Training in spirometry

### What basic skills are expected from spirometry technicians?

The minimum requirements for the personnel conducting pulmonary function tests include sufficient education and training to understand the fundamentals of the tests and the interpretation of the acquired pulmonary function data. The ATS guidelines suggest that completion of secondary education and at least two years of college education are required, and prior education/training related to health-related sciences (nursing, respiratory therapy and others) is desirable, to understand and perform the complete range of tasks in spirometry.[14] In addition, formal spirometry training significantly improves the quality of the spirogram obtained.[350]

The current guideline committee unanimously agreed that the spirometry technician should have received at least senior secondary education or 2–3 years of college education and a course or training in respiratory therapy/respiratory care. The technician should have basic computational skills and a basic knowledge of lung physiology. The technician should also be familiar with the theory and practical aspects of spirometry techniques, measurements, calibrations, quality control, infection control, and other aspects of testing. The physician in charge of the laboratory should have received formal training in the performance and interpretation of spirometry along with a good knowledge of the equipment.

*Recommendation*

- **Formal training of the personnel (physician and technician) conducting spirometry is strongly recommended. (2A)**

### Is there a role for refresher training courses in spirometry?

Refresher training helps spirometry technicians to maintain or refine their acquired skills and also helps them to keep themselves up-to-date of developments in the field. Refresher training should be conducted at a frequency of every 3–5 years, or shortly after any changes to existing spirometry standards.

The Lung Health Study demonstrated that the spirometry quality of inexperienced technicians declines over time despite initial training. Technician performance improved somewhat after site visits by instructors, and was markedly improved and

sustained following the implementation of a quality-assurance program that included performance feedback to the technicians.[351]

## Unmet Need

Efforts should be made by the national societies to have an arrangement of accreditation for spirometry laboratories. Efforts for dissemination of the spirometry guidelines should also be made by the national societies, the participating members, and other prominent faculty.

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