Guidelines

Joint Indian Chest Society-National College of Chest Physicians (India) guidelines for spirometry

Ashutosh Nath Aggarwal, Ritesh Agarwal, Sahajal Dhooria, KT Prasad, Inderpaul S Sehgal, Valliappan Muthu, Navneet Singh, D Behera, SK Jindal, Virendra Singh, Rajesh Chawla, JK Samaria, SN Gaur, Anurag Agrawal, SK Chhabra, Vishal Chopra, DJ Christopher, Raja Dhar, Aloke G Ghoshal, Randeep Guleria, Ajay Handa, Nirmal K Jain, Ashok K Janmeja, Surya Kant, GC Khilnani, Raj Kumar, Ravindra Mehta, Narayan Mishra, Anant Mohan, PR Mohapatra, Dharmesh Patel, Babu Ram, SK Sharma, Rupak Singla, JC Suri, Rajesh Swarnakar, Deepak Talwar, R Lakshmi Narasimhan, Saurabh Maji, Ankan Bandopadhyay, Nita Basumatary, Arindam Mukherjee, Milind Baldi, Nandkishore Baikunje, Hariprasad Kalpakam, Pratap Upadhya, Rakesh Kodati

Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India

ABSTRACT

Although a simple and useful pulmonary function test, spirometry remains underutilized in India. The Indian Chest Society and National College of Chest Physicians (India) jointly supported an expert group to provide recommendations for spirometry in India. Based on a scientific grading of available published evidence, as well as other international recommendations, we propose a consensus statement for planning, performing and interpreting spirometry in a systematic manner across all levels of healthcare in India. We stress the use of standard equipment, and the need for quality control, to optimize testing. Important technical requirements for patient selection, and proper conduct of the vital capacity maneuver, are outlined. A brief algorithm to interpret and report spirometric data using minimal and most important variables is presented. The use of statistically valid lower limits of normality during interpretation is emphasized, and a listing of Indian reference equations is provided for this purpose. Other important issues such as peak expiratory flow, bronchodilator reversibility testing, and technician training are also discussed. We hope that this document will improve use of spirometry in a standardized fashion across diverse settings in India.

KEY WORDS: Guidelines, India, spirometry

Address for correspondence: Dr. Ashutosh Nath Aggarwal, Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India. E-mail: aggarwal.ashutosh@outlook.com

EXECUTIVE SUMMARY

Spirometry is one of the most common and most widely used lung function tests but remains underutilized 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.

Standardization of spirometry

- The spirometer must be capable of continuously accumulating volume for at least 15 s, accommodating a total volume of at least 8 L, with flows between 0 and 14 L/s (2A)
- The spirometer should have an accuracy of at least ±3% or ±50 mL (whichever is greater) (3A)
- 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 <1.5 cm H_2O/L/s at an airflow of 14 L/s (3A)

Access this article online

Quick Response Code:

Website: www.lungindia.com

DOI: 10.4103/lungindia.lungindia_300_18

How to cite this article: Aggarwal AN, Agarwal R, Dhooria S, Prasad KT, Sehgal IS, Muthu V, *et al*. Joint Indian Chest Society-National College of Chest Physicians (India) guidelines for spirometry. Lung India 2019;36:S1-35.

- 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 (usual practice point [UPP])
- All spirometry values should be reported after suitable body temperature, ambient pressure, saturated with water vapor (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)
- 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 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 outlined 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 optimized 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 in 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 5 min 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 in 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 noncardiothoracic 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 such as COPD, asthma, bronchiectasis, interstitial lung disease (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 such as 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 standardize 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 1st s (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), VC (FVC or slow VC [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 VC is determined by both slow and 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 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 categorize 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 categorized as mild, moderate, and severe when FEV_1 is ≥70%, 50%–69%, and <50% predicted, respectively (UPP).

What is the place of forced expiratory volume in 6 s in spirometry interpretation?

- Forced expiratory volume in 6 s (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?

- The 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 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. They can be misleading and are not recommended for interpretation of spirometry (2A).

What equipment and procedure are 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 various different equipment may not be considered as interchangeable (1A)
- PEF meters should use nonlinear scales such as the ATS or European Union 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 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) 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 min 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 min (2B)
- The bronchodilator should be delivered with a metered dose inhaler (MDI) device, ideally with a spacer, using correct technique (1A)

- Alternative preparations such as nebulization 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?

- 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 chronic obstructive pulmonary disease?

- BDR 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 recognizing 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 specialized 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).

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 I: High-quality evidence backed by consistent results from well-performed randomized controlled trials, or overwhelming evidence from well-executed observational studies with strong effects
Level 2: Moderate-quality evidence from randomized 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

INTRODUCTION

Spirometry is one of the most common and most widely used lung function tests, with utility comparable to blood pressure measurement, or electrocardiography. However, one needs to pay careful attention to following standard procedures while performing and interpreting the test. The available international guidelines clearly stress the importance of performing pulmonary function tests in a standardized fashion. Despite being available for several years, spirometry remains underutilized in India. The nonavailability of good equipment, paucity of trained technicians, lack of time, inability to interpret computerized 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 of 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 of the two National Respiratory Associations (Indian Chest Society and National College of Chest Physicians), 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 performed by searching the electronic databases (PubMed, EMBASE, and Cochrane). Besides a systematic review of literature, the Indian studies were specifically analyzed to arrive at simple and practical recommendations. Major guidelines from American Thoracic Society (ATS), British Thoracic Society, European Respiratory Society (ERS), and other international professional bodies were also reviewed in detail.[1-8]

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 vapor 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

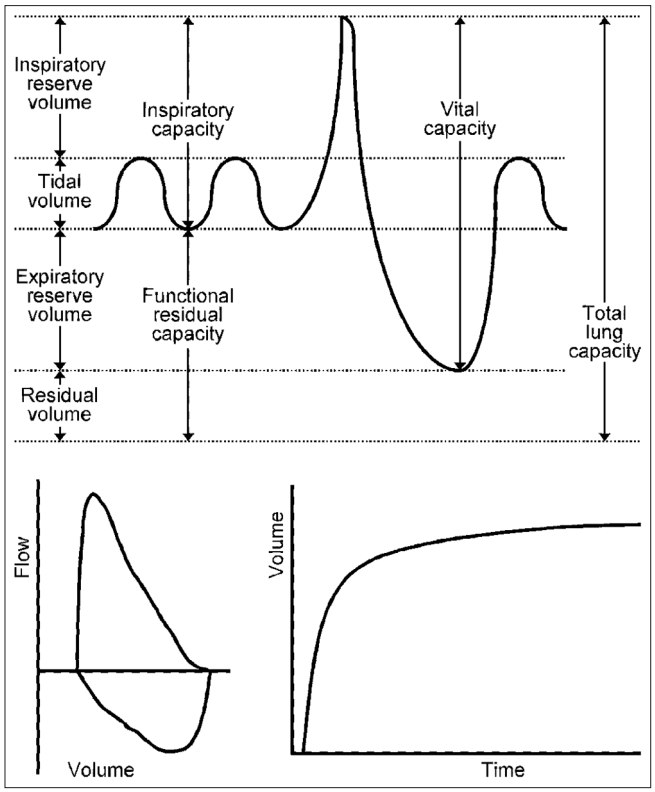

Figure 1: The top panel shows various lung volumes and capacities in relation to the spirometry tracing (top panel). Note that spirometry can determine vital capacity and its subdivisions but not the residual volume. The bottom panel shows standard normal flow-volume loop and volume-time curve tracings

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/standardizing 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 was 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 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]

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 subdivisions [Figure 1].

Volume-sensing devices may be further classified as wet or dry depending on whether they 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 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 lightweight 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 subject's respiration. The bellows type spirometer uses collapsible bellows that fold or expand in response to the subject's breathing movements.

The majority of 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, they may be difficult to calibrate as volume is calculated indirectly by time integration. Thermal flowmeters 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

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

	Instrument display		Hard copy output	
	Resolution	Scale factor	Resolution	Scale factor
Volume[#]	0.050 L	5 mm/L	0.025 L	10 mm/L
Flow[#]	0.200 L/s	2.5 mm/L/s	0.100 L/s	5 mm/L/s
Time	0.2 s	10 mm/s	0.2 s	20 mm/s

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

flow using a system of vanes, the rotations of which are measured by an infrared beam. Such devices are often used for office spirometry. Pneumotachographs utilize 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 (Screen type or Lilly type), a series of parallel capillaries (capillary type 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 is 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.

Standardization of spirometry

Efforts to standardize the procedure of spirometry have been ongoing since its formal description in medical literature.[11] The European Community for Coal and Steel 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 standardize 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 standardize the procedures further, the ATS and the ERS issued a joint statement in 2005.[14] This is the last major international update on standardization 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 L for at least 15 s with flow between 0 and 14 L/s can cater to the majority of the population.[15] In a single-center experience from nearly one lakh tests performed over more than a decade, these volume and flow specifications were adequate for more than 99.99% of subjects (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 <1.5 cm H_2O/L/s at an airflow of 14 L/s.[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 standardization of spirometry has recommended a minimum set of requirements for flow, volume, and time for the instrument display screen and hardcopy output.[14] In the absence of any studies on the minimum set of scale and resolution required, the group endorsed these recommendations [Table 3].

Recommendations

- The spirometer must be capable of continuously accumulating volume for at least 15 s, accommodating a total volume of at least 8 L, with flows between 0 and 14 L/s (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 <1.5 cm H_2O/L/s at an airflow of 14 L/s (3A)
- The on-screen display and the hardcopy output of the spirometry equipment should meet the specifications recommended by the ATS/ERS Task Force (see above) (UPP).

Volume corrections

The volume of 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 standardized to conditions within the human body (body temperature, ambient pressure, saturated with water vapor [BTPS]). The BTPS correction factor may be calculated as follows: $[(P_B - P_{H\,2O}) \div (P_B - 47)] \times [(273 + 37) \div (273 + T)]$, 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 vapor 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 incorporates the same in the device software.

Recommendations

- 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, they need to be accurately recorded.[28] Age is usually rounded off to the nearest integer and not recorded in decimals. A 1-year age bias due to truncating age to the last birthday can lead to a bias in predicted FEV_1 or 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 adults.

The 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 1 mm.[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 incorporating height. 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 nonlinearly 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 subjects in whom nasal leak is suspected, rather than routinely using it for all.

Recommendations

- 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 which 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 they 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 a 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 constant pressure to the spirometer (occluded at its mouthpiece) for at least 1 min and checking for any evidence of air leak.

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

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 suboptimal spirometers with systematic sources of error, drift, and bias. They found that a cut-off value of ±2% could identify these faulty spirometers which were missed using a cut-off value of ±3.5%. They also found that suboptimal 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 laboratory spirometers. Different guidelines recommend different validation frequencies 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.

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 subjects.[55] Healthy adults with no respiratory symptoms between 18 and 65 years of age with no history of lung disease can serve as biologic 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 subject is asked to perform spirometry at the same time of the day on 10 different days. The mean of these spirometric measurements is 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 optimized in a spirometry laboratory?

Infection control measures aim to prevent transmission of infection from the subject 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 mouthpiece and the adjoining surfaces of valves or tubing come in direct contact with respiratory secretions and may transmit these infections. Several studies have documented colonization 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 colonized with microorganisms 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 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 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 subjects 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 patients as it has been shown that the bacterial burden in the air increases immediately after mopping.[70]

A simulation model has shown that significant transfer of aerosolized organisms does not occur during routine pulmonary function testing if an interval of 5 min or more is allowed between tests.[71] Hence, wherever feasible, a time interval of at least 5 min 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 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 instruction for cleaning and disinfecting 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 they do not harm the equipment.

Mouthpiece is the most contaminated part of the spirometry equipment and ideally should not be shared between patients.[73] If a reusable mouthpiece is used, it should be appropriately cleaned and disinfected before reuse.

It is practically difficult to disinfect the entire spirometry equipment in between 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 always be 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 mobilization (i.e., detachment and aerosolization 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. Although most manufacturers claim bacterial removal efficiency to the tune of 99.9% for these filters, the 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 has been shown to significantly increase the airway resistance (Raw), resulting in reduction of the measured FEV_1, FVC, and 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 mouthpiece is recommended. If a reusable mouthpiece is used, it should be appropriately disinfected before using it in 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) at least 5 min 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 in 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. They 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 function by patients themselves.[86-89] Handheld devices may not meet the stringent standards of conventional spirometers. Moreover, despite having adequate precision, they may not be as accurate as laboratory spirometers.[90-93] Hence, at present, most handheld devices cannot be considered as replacement for conventional spirometers.

Recommendations

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 such as 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 (COPD) 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 sensitivity of 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, asthma was underdiagnosed in 21% of the subjects who sought medical attention

when spirometry was not employed.[100] However, normal spirometry does not exclude a diagnosis of asthma.

Interstitial lung disease

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

Chronic obstructive pulmonary disease

In COPD, worsening airflow limitation is associated with increased mortality, risk of exacerbations, and hospitalization.[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 multicenter prospective study of COPD patients (ECLIPSE study), annual 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, which found the multi-dimensional BODE index to be a better measure of disease progression in COPD compared to FEV_1.[109]

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 ≥5%, ≥12%, and ≥15%, respectively, even in healthy individuals.[110] However, assessment of FEV_1 may be useful in certain situations. Some asthmatics (poor perceivers such as elderly and subjects 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 optimization 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 risk of asthma attacks which may require hospitalization.[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* colonization of the airway, whereas both obstructive and restrictive patterns have been associated with more severe disease and increased risk of hospitalization.[115] Several studies have correlated low pulmonary function test results with more severe disease, higher risk of exacerbations requiring hospitalizations, and mortality.[116,117] In addition, a rapid decline in lung function has been associated with increased mortality in bronchiectasis.[118]

Interstitial lung disease

Serial measurement of FVC is one of the most useful parameters for the assessment of disease progression in idiopathic pulmonary fibrosis (IPF). A decline in FVC by 10% over 6–12 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 preoperative spirometry for risk assessment for postoperative 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 surgery (CABG), progressively worsening airway obstruction was clearly associated with increased morbidity and mortality.[124] Subsequent studies have confirmed this association of airflow obstruction with postoperative 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% confidence interval [CI], 1.12–2.55) after lung resection.[127] In the NETT trial, which evaluated lung volume reduction surgery (LVRS) for emphysema, patients with FEV_1 ≤20% along with homogeneous distribution of emphysema on CT or a diffusion capacity of the lung for carbon monoxide (DLCO) ≤20% had a 30-day

Table 5: Contraindications for spirometry

Unstable cardiovascular status such as myocardial infarction within previous 1 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 mouthpiece
Active hemoptysis
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

mortality of 16% as compared to 0% in medically treated patients.[128] A diagnosis of COPD has been associated with postoperative pulmonary complications after both thoracic and nonthoracic surgery.[126,129,130] On the other hand, mere reduction in spirometry parameters has not been independently associated with an increased risk of postoperative pulmonary complications after nonthoracic 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 have 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 randomized control 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 programs employing validated questionnaire.[141-144] However, in selected high-risk settings, spirometry can be used as a part of comprehensive screening program.[145,146]

Recommendations

- 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 noncardiothoracic 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 such as 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 such as 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 of 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.

What are the minimum prechecks for spirometry?

Several drugs and patient activities can alter results from spirometry testing. In general, subjects should avoid oral bronchodilators and long-acting inhaled bronchodilators for at least 24 h and short-acting inhaled bronchodilators for at least 6 h, before the procedure. Oral/inhaled steroids need not be discontinued. They should avoid intake of caffeine-containing products (tea, coffee, and cola) for at least 6 h and alcohol for at least 4 h, before the test. They should not eat a large meal for at least 2 h before spirometry and avoid smoking for at least 1 h. Vigorous exercise should be avoided for at least 30 min before the procedure. Subjects 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. They found 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.

Recommendations

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

How should the vital capacity maneuver be performed?

Definitions

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 [IC]) 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 VC (FVC). The slow expiratory VC and slow inspiratory VC (IVC) are, respectively, referred to us slow VC (SVC), or just VC, and IVC, respectively. IC 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 sitting 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

Table 6: 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 artifacts
Cough during the 1st s of exhalation
Effort that is not maximal throughout
Obstructed mouthpiece
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 s, and the subject has tried to exhale for at least 6 s 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 cannot 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 ≤ 1 L, the two largest values must be within 100 mL of each other. FEV_1: Forced expiratory volume in 1st s, FVC: Forced vital capacity

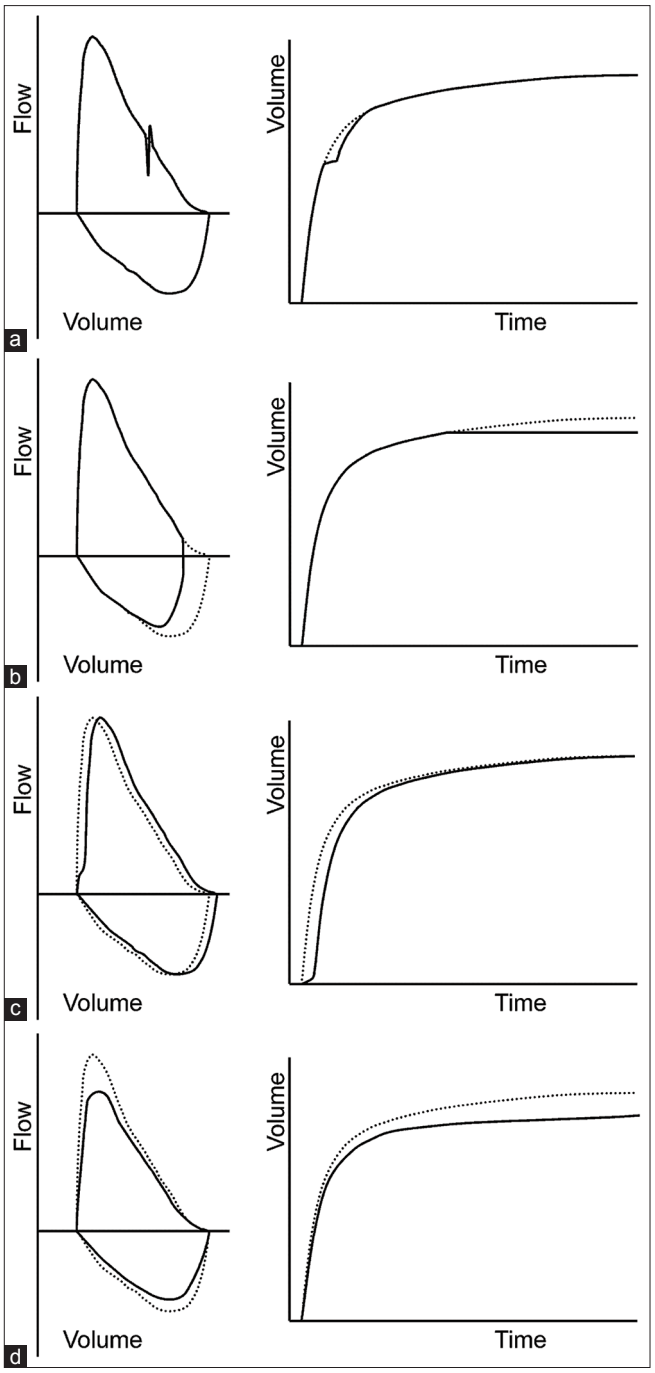

Figure 2: Abnormalities seen on flow-volume loops and volume-time curves in relation to (a) coughing, (b) early glottic closure, (c) hesitant start and (d) submaximal effort

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 observed that FVC, FEV_1, and PEF values obtained with dentures were slightly better than those obtained without dentures.[155] 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 spirometry.

Procedure

Forced expiratory maneuver can be done by either closed- or open-circuit method. During a closed-circuit procedure, the subjects inhale and exhale exclusively through the mouthpiece of the spirometer with no communication with ambient air. In open-circuit technique, the subject takes a maximal inspiration from the room, inserts the mouthpiece 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 mouthpiece 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 are 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.[156,157]

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 forced vital capacity 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 1st s, or that which interferes with accurate measurements in the technician's judgment, makes that maneuver unacceptable. Variable or submaximal effort results in an undulating or wavy pattern in the curves. Abrupt cessation of flow toward 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 mouthpiece 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 they 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 6].[14]

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 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 test. The initial expiratory portion of the flow-volume curve should demonstrate a steep and early (typically <120 ms) rise to PEF.

The end of expiration is reached when the expired volume is <25 mL in 1 s (the plateau criterion) or the subject cannot continue exhaling further. Normally, expiratory time should exceed 6 s for the maneuver to be termed

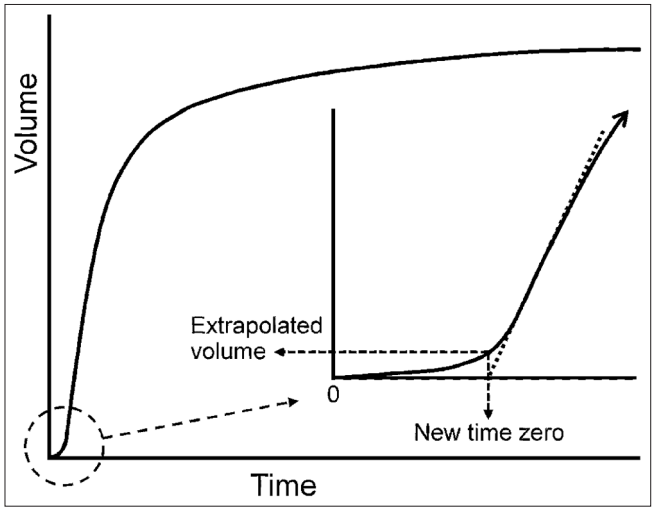

Figure 3: A typical volume-time trace from spirometry. Note the smooth and rapid rise in expired volume, and a volume plateau towards the end of exhalation. The graphical method to calculate time of start of test, as well as extrapolated volume, from the early portion of the curve is also illustrated

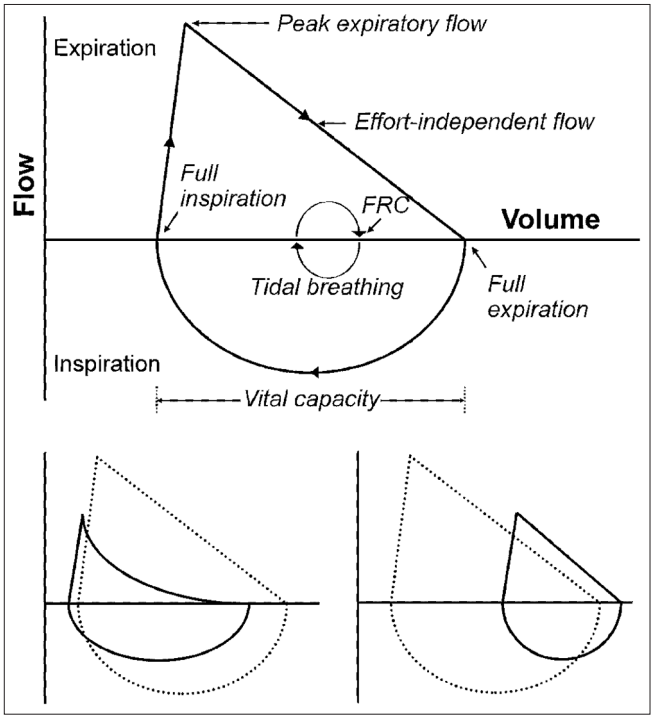

Figure 4: Flow-volume loops. The upper panel shows a typical flow-volume loop and the various subdivisions of lung volume. The bottom panel shows changes in the shape of flow volume loop in obstructive (right) and restrictive (left) defects, with the dotted line representing the normal loop. FRC: Functional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

satisfactory. One can also terminate the effort after 15 s of exhalation to avoid syncope. However, subjects can conclude the maneuver at any time if they experience discomfort. Although an exhalation time exceeding 6 s is desirable, early termination is not enough reason to exclude the maneuver from further analysis. In situations where forced expiratory volume at 6 s (FEV_6) is used as a surrogate of FVC, a forced exhalation time of 6 s 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 $EV/FEV_6 \geq 5.25\%$ and $EV/FEV_3 \geq 5.59$ s corresponded to EV/FVC ≥5%.[159] In addition, 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 reproducibility 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 6].[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/STANDARDIZING NUMERICAL AND GRAPHICAL DATA, INTERPRETATIVE ALGORITHMS, AND TEST REPORTING

How to standardize 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 organizations 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 the standard recommendations [Table 3].[163] Flow–volume loops are essential as they provide an idea on the quality of the spirometry. In addition, they 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, 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?

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 IVC, 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 or flow measured between 25% and 75% of the FVC maneuver ($FEF_{25-75\%}$ or MMEF), PEF, forced expiratory time (FET), peak inspiratory flow (PIF), expiratory reserve volume (ERV), and inspiratory reserve volume (IRV). Among these, FEV_1, VC, and FEV_1/VC are the most important parameters in interpretation of spirometry.

FVC 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 underestimates 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, the 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 among 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] Furthermore, 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 computerized spirometer outputs, usually provides no additional information and is 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 was 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 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 and 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 spirometry is to identify individuals with abnormal lung function. To identify what is abnormal, one should define what constitutes 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 subclinical disease burden in a population could lead to less stringent reference normal values, due to inclusion of apparently healthy subjects with subclinical 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 utilized 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 favoring such a practice. In children, using a fixed cut-off may be acceptable; however, 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, wherein the results are reported using the "Z-score." The Z-score can be calculated as $(x - \mu)/\sigma$, where x is the value obtained, μ is the population mean, and σ 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: FEV1, 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 tumors, and others. Patients with upper airway obstruction can be further characterized 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.[103,174,175] 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%.[103] Hence, the presence of a normal VC may obviate the need for performing lung volume measurements to exclude restrictive lung disease.[176] 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 cardiometabolic morbidity, first seen in the Framingham cohort and replicated in multiple studies since then.[177-179] It is also not clear whether the lower VC and higher cardiometabolic 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

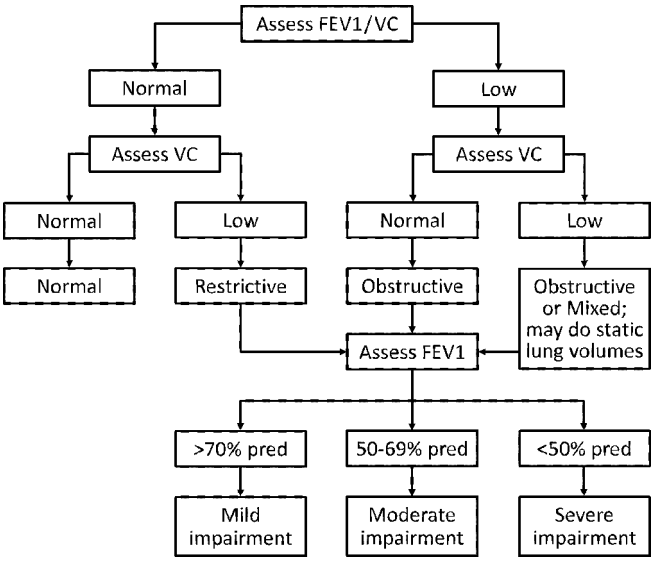

Figure 5: A basic algorithm for spirometry interpretation. FEV1: Forced expiratory volume in 1st s, VC: Vital capacity, % pred: Percentage of predicted normal value

be decreased due to air trapping (hyperinflation), thereby normalizing the FEV_1/FVC ratio (mimicking a restrictive defect). The differentiation of this "pseudorestriction" from true restriction requires measurement of total lung capacity. 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% of subjects with low FEV_1/FVC and normal FVC had low TLC.[103] 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 nonspecific pattern.[180] 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 favor 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).[180-182] In the absence of lung volume measurement, this pattern cannot be recognized 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.[183,184] 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.[185] 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.[184] In a larger retrospective study of 280 individuals, airway hyperresponsiveness was demonstrated in 28% of patients with FEV_1/FVC <LLN and FEV_1 ≥90% predicted.[186] Therefore, symptom assessment and additional testing to rule out airway hyperresponsiveness is essential, before labeling 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 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).

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

The 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).[187] A fixed cut-off for FEV_1/VC fails to consider the age, sex, and body habitus of the individual. Moreover, LLN for FEV1/FVC is above this fixed cut-off of 0.7 in many elderly individuals.[188] A statistically derived LLN is therefore more reliable and reduces the frequency misclassification (especially in elderly).[189-198] Using this fixed ratio may lead to underdiagnosis of asthma in younger patients). The GINA guidelines on asthma suggest an 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.[199] 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 favor the use of a fixed ratio.[200,201] 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.[202-204] It has also been argued that the GOLD criteria tend to pick up early cases of COPD and have good correlation with respiratory symptoms.[200,205,206] 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.[207-209]

Even though some researchers have provided evidence in favor of the fixed ratio for 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 such as asthma could lead to significant misdiagnosis 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. In conclusion, 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.[173,188,198] However, in situations where data on statistically valid LLN figures are not available (or impractical to calculate, as in some field settings), FEV1/VC ratio <70% may be employed to define airway obstruction in a high probability clinical setting.

Recommendation

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

How to categorize the severity of an abnormal spirometry report?

The severity of impaired lung function in obstructive airway diseases has been conventionally classified based on FEV_1 (% predicted) and has been shown to predict mortality from both cardiovascular and respiratory diseases.[177,210] This increase in all-cause mortality has been noted irrespective of the smoking status.[211] Follow-up studies have demonstrated strong correlation between degree of airflow obstruction and COPD-related mortality.[210,212] FEV_1 is also useful in predicting long-term outcome as well as risk of exacerbation in asthmatics.[113,213] Spirometric indices also correlate well with respiratory symptoms and other aspects of quality of life.[214,215]

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. FEV_1 expressed as a percentage of predicted normal value can be employed to categorize severity of impairment of lung function (both restrictive and obstructive). Although the correlation of lung function to morbidity and mortality is well established, there is no universally accepted scheme of categorization of severity of pulmonary function.[110] Severity classification suggested by the GOLD (for COPD) and ERS/ATS (for obstructive airway diseases) includes five categories based on postbronchodilator FEV_1% predicted. VC is reduced in restrictive diseases, including parenchymal lung diseases and neuromuscular diseases. The classification of severity of restrictive defects was conventionally 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 and 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. However, they cannot be used interchangeably since up to 31.3% were noted to have discordant categorization.[216]

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 categorized as mild, moderate, and severe when FEV_1 is ≥70%, 50%–69%, and <50% predicted, respectively (UPP).

What is the place of forced expiratory volume in 6 s in spirometry interpretation?

FEV_6 is the maximal volume of air that is expelled in the first 6 s of a FVC maneuver. 99% individuals can obtain their FVC in 6.64 s or less.[217] Measurement of FVC requires patient effort and cooperation and may not be obtained in all patients, especially in the elderly.[218] In such patients where FVC is unreliable or not feasible, and the obstruction is mild, measuring FEV_6 may be useful.[219] 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.[218]

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.[219-227] A meta-analysis of 11 studies involving 31,333 participants, of whom 10,171 had airway obstruction, revealed that FEV_1/FEV_6 had an estimated sensitivity of 0.89 (95% CI, 0.83–0.93) and specificity of 0.98 (95% CI, 0.95–0.99) with an area under the summary receiver operating curve (ROC) of 0.97.[228] 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.[229]

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.[168,221,223,230-233] 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.[234] 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 favoring the use of FEV_6.

In conclusion, there are sufficient data suggesting that FEV_6 may be a reasonable surrogate for FVC. However, there are little data from India and reference equations need to be generated before the routine use of FEV_6.[235]

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.[236] 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.[237]

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.[238] 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, and $PEF_{50\%}/PIF_{50\%}$ <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.[237,239]

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 ROC for anyone, or more than one of the above-mentioned spirometric visual or quantitative criteria was only 0.522 and 0.605, respectively.[237] The presence of these criteria may thus point toward 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 until the tracheal lumen narrows to 8 mm or less.[240]

In conclusion, spirometry is insufficient to rule out central/upper airway obstruction and more definitive tests are required.[237] 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 best.

Recommendations

- The 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?

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.[241-243] A large study on 22,767 spirometries demonstrated that when the FEV_1, FVC, and FEV_1/FVC are normal, only 2.75% and 1.29% of subjects 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 normal and abnormal values. For instance, the statistically derived LLN for $FEF_{25\%–75\%}$ for children and elderly (>80 years) has 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 NHANES III database, 64% of subjects with a low FEV_1/FVC ratio were found to have a normal $FEF_{25\%–75\%}$.[244] 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.[245] $FEF_{25\%–75\%}$ 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. They can be misleading and are not recommended for the interpretation of spirometry (2A).

MISCELLANEOUS AND SPECIAL ISSUES

Peak expiratory flow

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

Equipment for measuring peak expiratory flow

PEF can be measured using spirometers or PEF meters. Although PEF meters measure PEF alone (unlike spirometers which measure various other parameters as well), they 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 handheld devices have been described for the measurement of PEF. The oldest one that gained prominence was the Wright's peak flow meter.[246] Several devices followed include 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 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, nonlinear 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%.[247-249] Several studies have shown that significant variation exists between PEF measured using the variable types of portable PEF meters.[249-252] 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.[253] 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 handheld PEF meter.[247,256]

Scale for peak expiratory flow 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 subjects, which included patients with lung diseases.[246] Miller *et al*. demonstrated that PEF has nonlinear characteristics and this led 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.[255] Subsequently, nonlinear scales (ATS scale and the EU scale) were developed to overcome this issue.[7,256]

PEF meters should clearly specify the scale which they are using as the ATS and EU scales are not identical. Pesola *et al*. 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 were 2.8% higher than the EU peak flow meter across a range of flows.[247] 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: Corrected PEF = (0.00090 × Measured PEF^2) + (0.373 × Measured PEF) +47.4.[257]

Equipment specifications for peak expiratory flow meters

Resistance of the equipment used to measure PEF will affect the measured PEF values.[258-260] For variable orifice PEF meters, the resistance falls as the flow increases, while the reverse is true for fixed orifice PEF meters.[260] In one study, it was shown that a PEF meter with a resistance of 2.1 cm H_2OL/s (at 600 L/min flow) under-read the PEF values by 8% in comparison with a pneumotachometer.[259] Earlier, the recommended resistance limits for spirometers, i.e., <0.5–1.5 cm H_2O/L/s 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 cm to 3.5 cm H_2O/L/s across their flow ranges.[255,260] Hence, existing guidelines recommend that the mean instrument resistance (measured across the range of the instrument) should be <2.5 cm H_2O/L/s.[14]

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

Calibration of peak expiratory flow 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 1 year of use.[253,261] 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.[261]

This should include visual inspection of the PEF meter for any cracks or deformity on its body. In addition, 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 peak expiratory flow meter testing

The accuracy and repeatability of PEF meters should be verified by the equipment manufacturer using flow-time waveforms delivered by computerized mechanical syringes. Initially, the same set of 24 flow-time waveforms used for testing spirometers was recommended for testing PEF meters as well by the ATS.[3] However, in 1995, Hankinson *et al*. published a set of 26 flow-time waveforms developed specifically for the testing of PEF meters.[262] 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.[263,264]

Procedure for measurement of peak expiratory flow

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 an FVC maneuver. PEF values obtained with the PEF maneuver are significantly higher as compared to those obtained with the FVC maneuver.[248,265]

PEF 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.[266,267] However, there is no significant difference between the PEF recorded in the sitting and standing positions or supine and prone positions.[266,267] 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.[268] Extension of neck may lead to an increase in PEF by elongating and stiffening the trachea, but this effect has not been demonstrated consistently.[268,269] If there is a pause between the maximal inspiration and the expiratory maneuver (i.e., a breath hold at TLC), it results in decrease in PEF.[268] 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.

Table 7: Expiratory maneuver for measuring vital capacity

Place the mouthpiece in mouth and close lips around the mouthpiece.
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 3 acceptable maneuvers. If repeatability criteria are not met, more maneuvers should be performed as needed (not more than a total of 8 maneuvers)

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 to 5 AM.[270] 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 aging leads to a fall in PEF.[271]

Within- and between-maneuver acceptability for peak expiratory flow maneuver

Ninety-five percent of trained healthy subjects can usually reproduce PEF within 30 L/min.[272] 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.[259] Hence, it is recommended that the largest two of the acceptable blows should be within 40 L/min of each other [Table 7]. If acceptable reproducibility is not achieved within five PEF maneuvers, further testing is unlikely to be helpful and hence not recommended.[273]

Recommendations

- Handheld 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 nonlinear scales such as 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?

The PEF is a nonspecific 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.[274]

Chronic obstructive pulmonary disease

Although there is a steady decline in the expiratory flow in normal subjects 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.[274] Thus, PEF cannot act as a surrogate for FEV_1 for diagnosis of airflow obstruction or severity classification of COPD.[275,276] In a study reported from Thailand for screening for COPD in the elderly, even at the best cutoff for accuracy, PEF had a sensitivity of only 72.7% and a specificity of 81.1%.[277] 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.[278] 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.[279]

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 diagnosis asthma. A diurnal variability (over 2 weeks) of more than 10% in adults (13% in children) suggests significant variability of airflow obstruction.[280] A significant increase (>20%) in PEF after 4 weeks of anti-inflammatory treatment is also a pointer toward variable expiratory airflow limitation.[280] 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.[281] Serial PEF measurements have also been shown to have good sensitivity and specificity for the diagnosis of occupational asthma.[282]

Excessive variability in PEF suggests poor asthma control and increased risk of exacerbation.[283] Trends in PEF monitored as a part of a written asthma plan may be used to guide self-adjustment of therapy in asthma.[280,284] GINA recommends a short course of oral corticosteroids for patients in whom the PEF deteriorates to <60% of their personal best or predicted value.[280] PEF monitoring may also be helpful in severe asthma patients 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.[285] Further, it has been demonstrated that action points based on "personal best" PEF provide greater health benefits, than those based on predicted PEF.[284]

Restrictive lung diseases

The PEF is reduced in parenchymal lung diseases.[286-289] However, its sensitivity for this condition is poor as compared to FVC.[288,289] PEF is also reduced in neuromuscular diseases, and this reduction may be used as an index of disease severity and progression.[290-292]

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?

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.

Table 8: Bronchodilator reversibility criteria used in various guidelines

Guideline	Criteria
ACCP 1974[293]	ΔFEV_1>15% of baseline value
ATS 1991[4]	ΔFEV_1 or ΔFVC >12% of baseline value AND >200 mL
ERS 1993[5]	ΔFEV_1>9% of predicted value
ERS 1995[294]	ΔFEV_1≥10% of predicted value
BTS/SIGN 2003[295]	ΔFEV_1>15% of baseline value AND >200 mL
NICE 2004[296]	ΔFEV_1>400 mL
ATS/ERS 2005[110]	ΔFEV_1 and/or ΔFVC >12% of baseline value AND >200 mL
GOLD 2010[297]	ΔFEV_1 and/or ΔFVC >12% of baseline value AND >200 mL
BTS/SIGN 2016[298]	ΔFEV_1>12% of baseline value AND >200 mL
GINA 2017[280]	ΔFEV_1>12% of baseline value AND >200 mL

ΔFEV_1: Post-BDR FEV_1: Baseline FEV_1. ACCP: American College of Chest Physicians, ATS: American Thoracic Society, BTS: British Thoracic Society, ERS: European Respiratory Society, FEV_1: Forced expiratory volume in 1st s, GINA: Global Initiative for Asthma, GOLD: Global Initiative for Chronic Obstructive Lung Disease, NICE: National Institute for Clinical Excellence, SIGN: Scottish Intercollegiate Guidelines Network

Several drugs and dosages have been used in previous major studies on bronchodilator reversibility; most recent studies have used short-acting beta-agonists (SABA), especially salbutamol. Most commonly, BDR test involves repeating spirometry between 15 and 20 min 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 min. The bronchodilator should be delivered with a metered dose inhaler (MDI) device, ideally with a spacer, using correct technique. Alternatives such as nebulization 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 min 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 min (2B)
- The bronchodilator should be delivered with an MDI device, ideally with a spacer, using correct technique (1A)
- Alternative preparations such as nebulization 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?

BDR may be expressed as the absolute increment in FEV_1 (ΔFEV_1), as a percentage improvement over baseline (ΔFEV_1% baseline) or predicted FEV_1 (ΔFEV_1% predicted), or as a percentage of maximally achievable reversibility (ΔFEV_1% [Predicted − Baseline]). However, percentage of maximally 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 are summarized in Table 8.[4,5,110,280,293-298] 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, ΔFEV_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 ΔFEV_1% baseline, even when ΔFEV_1 is small). This error may be partly nullified by adding an absolute ΔFEV_1 criterion. In a study of 660 subjects with COPD, investigators found that ΔFEV_1% baseline showed an apparently elevated response when the baseline FEV_1 is low and this relationship persisted even when the ATS absolute ΔFEV_1 criterion were applied.[299] The expression of ΔFEV_1 as a percentage of the predicted FEV_1 avoids this error, in addition to avoiding bias due to age and sex.[299,300] In a study comparing different reversibility criteria in subjects with asthma, ΔFEV_1% predicted >9% had a reasonable sensitivity (87%) and a much better specificity (95% vs. 67%) as compared to ΔFEV_1% baseline with ΔFEV_1 >200 mL as the gold standard.[301] However, since the most widely followed ATS/ERS recommendations endorsed ΔFEV_1% baseline, we decided to retain ΔFEV_1% baseline for defining BDR until further evidence emerges.

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 to define BDR [Table 8].

Recommendations

- 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 chronic obstructive pulmonary disease?

COPD has conventionally been considered to be a disease with poorly reversible lung function. However, in a recent *post hoc* analysis of the UPLIFT trial, 39%–73% of COPD patients exhibited BDR according to various criteria.[302] In another analysis of data from two randomized trials consisting of subjects with moderate-to-severe COPD, large proportions of patients met the ATS BDR criterion for FEV_1 (57%–59%) and FVC (57%–67%).[303] In addition, several patients of asthma may not exhibit BDR at time of spirometric evaluation. These data highlight the existence of substantial overlap in BDR between asthma and COPD. Therefore, the diagnostic ability of acute bronchodilator responsiveness in separating asthma from COPD is limited. Moreover, using different expressions or cut-offs of BDR criteria may still not help differentiate asthma from COPD.[304,305]

Recommendations

- BDR 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 recognizing 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. They may be of use in subjects in whom asthma is strongly suspected but spirometry results are normal. However, they should not be used routinely for the diagnosis of asthma.[99] Demonstration of nonspecific bronchial hyperresponsiveness using bronchoprovocative tests may also be useful in the diagnosis of work-related asthma.[306]

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 <1 L) and be preferably avoided in subjects with moderate airflow limitation (FEV_1 <60% predicted or <1.5 L).[307] However, complication rates remain low even in patients with poor lung function.[308]

Bronchoprovocation can be done 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 most common pharmacologic agents used. During methacholine challenge test, the subject is made to breathe progressively stronger concentrations of methacholine according to a prespecified protocol. The provocative concentration of methacholine causing a 20% fall in FEV_1 (PC_{20}) is noted. A PC_{20} value >16 mg/mL is considered a negative test.[307]

Recommendations

- Because of their inherent risk for precipitating an acute attack of bronchospasm tests for bronchial hyperresponsiveness should be performed in specialized 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 and weight.

Reference equations are developed by studying lung function of a large sample of carefully selected and well-defined "normal" healthy subjects. Usually, only nonsmokers 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.[309] It should also be noted that the

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

Study	Region	Study subjects	Age group (years)	Instrument used	Smokers
Desai *et al*. 2016[323]	Mumbai	310 healthy adults	18-75	Fleisch pneumotachograph	Excluded
Dasgupta *et al*. 2015[324]	Kolkata	619 healthy adults	15-69	Pneumotachograph	Excluded
Chhabra *et al*. 2014[325]	Delhi	685 healthy adults	18-71	Fleisch pneumotachograph	Excluded
Saleem *et al*. 2012[326]	Kashmir	3080 healthy adults	18-65	Digital turbine spirometer	Excluded
Phatak *et al*. 2002[327]	Nagpur	1200 elderly subjects	>60	Wedge bellows spirometer	Excluded
Virani *et al*. 2001[328]	Pondicherry	397 healthy adults	17-70	Digital turbine spirometer	Excluded
Mahajan *et al*. 1997[329]	Rohtak	137 healthy women	18-52	Dry rolling seal spirometer	Excluded
Chatterjee and Saha 1993[330]	Kolkata	230 healthy women	20-59	Water-seal spirometer	Excluded
Rao *et al*. 1992[331]	Ahmedabad	96 healthy adults	15-40	Wedge bellows spirometer	Excluded
Rao *et al*. 1992[332]	Ahmedabad	326 industrial workers	≥15	Wedge bellows spirometer	Excluded
Jindal and Wahi 1991[333]	Chandigarh	962 healthy adults	15-74	Water-seal spirometer	Excluded
Vijayan *et al*. 1990[334]	Chennai	247 healthy adults	15-40	Dry rolling seal spirometer	Included
Prakash 1990[335]	Bangalore	560 healthy adults	≥15	Water-seal spirometer	Excluded
Purohit *et al*. 1989[336]	Jaipur	1027 healthy adults	≥15	Autospirometer	Excluded
Chatterjee *et al*. 1988[337]	Kolkata	334 healthy men	20-60	Water-seal spirometer	Included
Udwadia *et al*. 1986[338]	Mumbai	760 healthy adults	15-65	Fleisch pneumotachograph	Excluded
Verma *et al*. 1983[339]	Delhi	171 healthy men	21-69	Not specified	Included
Kamat *et al*. 1977[340]	Tamil Nadu	1247 healthy adults	15-55	Water-seal spirometer	Included
Joshi *et al*. 1973[341]	Ludhiana	148 healthy men	18-61	Water-seal spirometer	Included
Jain and Ramiah 1969[342]	Delhi	108 healthy men	15-40	Water-seal spirometer	Excluded
Jain and Gupta 1967[343]	Delhi	70 healthy men	40-65	Water-seal spirometer	Excluded
Jain and Ramiah 1967[344]	Delhi	144 healthy women	15-40	Water-seal spirometer	Excluded
Milledge 1965[345]	Tamil Nadu	479 healthy men	20-55	Water-seal spirometer	Included

Table 10: Selected reference equations for forced vital capacity in men

Study	Regression formula	RSD/ SEE
Deasi *et al.* 2016[323]	Exp (−1.048 + 0.015H − 0.0045A)	
Dasgupta *et al*. 2015[324]	−2.537 + 0.0418H − 0.0211A	0.518
Chhabra *et al*. 2014[325]	−5.048 + 0.054H − 0.014A + 0.006W	0.479
Saleem *et al*. 2012[326]	−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[327]	2.8514 + 0.0056H − 0.0153A	
Virani *et al*. 2001[328]	−3.29 + 0.043H − 0.017A	0.400
Rao *et al*. 1992[331]	−3.98 + 0.042H − 0.036A + 0.03W	0.500
Rao *et al*. 1992[332]	−4.557 + 0.048H − 0.019A + 0.006W	0.492
Jindal and Wahi 1991[333]	−3.44 + 0.048H − 0.013A − 0.00005A^2	0.497
Vijayan *et al*. 1990[334]	−6.857 + 0.062H	0.481
Prakash 1990[335]	0.5612 + 0.0167H + 0.0009A	
Purohit *et al*. 1989[336]	−3.60 + 0.049H − 0.027A	
Chatterjee *et al*. 1988[337]	-4.129 + 0.0522H − 0.0214A	0.422
Udwadia *et al*. 1986[338]	−6.058 + 0.055H + 0.019A (<30 years)	0.505
	−4.832 + 0.054H − 0.018A (≥30 years)	0.462
Verma *et al*. 1983[339]	−2.472 + 0.0438H − 0.0281A	0.465
Kamat *et al*. 1977[340]	−4.488 + 0.0503H − 0.0136A	
Joshi *et al*. 1973[341]	−2.69 + 0.04H	0.710
Jain and Ramiah 1967[342]	−3.3129 + 0.04391H	0.492
Jain and Gupta 1967[343]	−2.5788 + 0.0468H − 0.0163A − 0.1357W	0.495
Milledge 1965[345]	−6.5014 + 0.3995H − 0.0166A	

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[323]	Exp (−1.616 + 0.015H + 0.014A − 0.000219A^2)	
Dasgupta *et al*. 2015[324]	0.0972 + 0.0216H − 0.0186A	0.465
Chhabra *et al*. 2014[325]	20.07 − 0.261H + 0.000972H^2 − 0.01A	0.315
Saleem *et al*. 2012[326]	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 2002[327]	0.819091 + 0.009661H − 0.00689A	
Virani *et al*. 2001[328]	−1.163 + 0.026H − 0.015A	0.290
Mahajan 1997[329]	−3.12 + 0.04H + 0.01A	
Chatterjee and Saha 1993[330]	−0.902 + 0.027H − 0.025A	0.310
Rao *et al*. 1992[331]	−3.03 + 0.024H + 0.024A + 0.03W	0.400
Jindal and Wahi 1991[333]	−2.05 + 0.035H − 0.014A − 0.00004A^2	0.447
Vijayan *et al*. 1990[334]	−2.883 + 0.035H	0.325
Prakash 1990[335]	−1.754 + 0.0256H + 0.007A	
Purohit *et al*. 1989[336]	−1.48 + 0.32H − 0.024A	
Udwadia *et al*. 1986[338]	−2.284 + 0.03H + 0.006A (<30 years)	0.377
	−3.755 + 0.043H − 0.01A (≥30 years)	0.341
Kamat *et al*. 1977[340]	−3.187 + 0.037H − 0.007A	
Jain and Ramiah 1967[344]	−2.916 + 0.03561H + 0.00412A	0.339

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

character of a population changes significantly with time. Hence, it is prudent to revise the reference equations periodically.[310]

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.

Table 12: Selected reference equations for forced expiratory volume in 1st s in men

Study	Regression formula	RSD/ SEE
Desai *et al.* 2016[323]	−3.275 + 0.043H − 0.020A	0.346
Dasgupta *et al*. 2015[324]	−1.7649 + 0.0337H − 0.0218A	0.434
Chhabra *et al*. 2014[325]	− 3.682 + 0.046H − 0.024A	0.402
Saleem *et al*. 2012[326]	−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 2002[327]	3.0039 + 0.0022H − 0.0167A	
Virani *et al*. 2001[328]	−1.452 + 0.031H − 0.020A	0.330
Rao *et al*. 1992[331]	−3.53 + 0.043H − 0.045A + 0.014W	
Rao *et al*. 1992[330]	−2.757 + 0.38H + 0.022A + 0.006W	0.492
Jindal and Wahi 1991[333]	−1.9 + 0.036H − 0.025A + 0.00006A^2	
Vijayan *et al*. 1990[334]	−6.195 + 0.057H − 0.00023A^2	0.415
Prakash 1989[335]	1.49 + 0.013H − 0.027A	
Purohit *et al*. 1989[336]	−3.64 + 0.046H − 0.024A	
Chatterjee *et al*. 1988[337]	−4.6899+0.0533H − 0.0286A	0.326
Udwadia *et al*. 1986[338]	−3.266 + 0.039H − 0.01A (<30 years)	0.392
	−2.65 + 0.037H − 0.022A (≥30 years)	0.328
Verma *et al*. 1983[339]	−1.0474 + 0.0312H − 0.0286A	0.450
Kamat *et al*. 1977[340]	−3.13 + 0.0396H − 0.0212A	
Joshi *et al*. 1973[341]	−2.339 + 0.026H + 0.021A	0.372

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 1st s in women

Study	Regression formula	RSD/ SEE
Deasi *et al.* 2016[323]	Exp (−1.552 + 0.015H + 0.0043A − 0.000144A^2)	
Dasgupta *et al*. 2015[324]	0.0381 + 0.0196H − 0.0197A	0.370
Chhabra *et al*. 2014[325]	−2.267 + 0.033H − 0.019A	0.286
Saleem *et al*. 2012[326]	−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 2002[327]	0.437672 + 0.01242H − 0.01149A	
Virani *et al*. 2001[328]	−0.457 + 0.020H − 0.016A	0.230
Chatterjee and Saha 1993[330]	−0.254 + 0.021H − 0.027A	0.284
Rao *et al*. 1992[331]	−0.82 + 0.02H − 0.025A + 0.02W	0.300
Jindal and Wahi 1991[333]	−1.07 + 0.027H − 0.03A + 0.00013A^2	0.323
Vijayan *et al*. 1990[334]	−1.9 + 0.026H	0.304
Prakash 1990[335]	0.5 + 0.014H + 0.021A	
Purohit *et al*. 1989[336]	−3.95 + 0.044H − 0.015A	
Udwadia *et al*. 1986[338]	−1.424 + 0.025H − 0.011A (<30 years)	0.341
	−2.58 + 0.032H − 0.012A (≥30 years)	0.309
Kamat *et al*. 1977[340]	−1.995 + 0.0274H − 0.0103A	

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

Table 14: Selected reference equations for forced expiratory volume in 1st s/forced vital capacity in men

Study	Regression formula	RSD/ SEE
Desai *et al*. 2016[323]	89.09 − 0.179A	4.73
Dasgupta *et al*. 2015[324]	108.994 − 0.12H − 0.133A	9.2
Chhabra *et al*. 2014[325]	102.56 − 0.679A + 0.00477A^2 − 0.080W	5.79
Saleem *et al*. 2012[326]	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[333]	103 − 0.07H − 0.35A + 0.002A^2	6.6
Vijayan *et al*. 1990[334]	76.695 + 0.08H − 0.00613A^2	6.638
Chatterjee *et al*. 1988[337]	58.76 + 0.2136H − 0.3093A	6.019
Udwadia *et al*. 1986[338]	119.3640 − 0.1756H − 0.2457A	7.7411
Joshi *et al*. 1973[341]	89.41 − 0.455A	7.139

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

Table 15: Selected reference equations for forced expiratory volume in 1st s/forced vital capacity in women

Study	Regression formula	RSD/ SEE
Desai *et al*. 2016[323]	104.35 − 0.085A + 0.0065A2	6.34
Dasgupta *et al*. 2015[324]	92.05 + 0. 001H − 0.0214A	7.6
Chhabra *et al*. 2014[325]	97.182 − 0.44A	4.97
Saleem *et al*. 2012[326]	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[330]	86.1 − 0.241A	5.680
Jindal and Wahi 1991[333]	111 − 0.1H − 0.36A + 0.003A^2	5.8
Vijayan *et al*. 1990[334]	94.917 − 0.011H − 0.00734A^2	5.639
Udwadia *et al*. 1986[338]	94.8867 − 0.0334H − 0.2146A	11.0011

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

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 given standing height.[311,312] Males in general have 10%–15% higher FVC and FEV_1 compared to females of similar age group.[313] 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.[314-316] After physical growth is complete, pulmonary function declines with further aging because of the progressive loss of elastic recoil of the lung with age.[317-319] 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.[320-322] Obese subjects have lower ERV and FRC; however, RV, TLC, FEV_1, and FVC are not affected significantly unless the patient is massively obese.[321,322]

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, socioeconomic 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].[323-345] 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).[346] 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.[313]

Multiethnic 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 the 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.[347,348] 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.[348]

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 2 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 spirograms obtained.[349]

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.

Recommendations

- 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.[350]

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.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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