PAKISTAN CHEST SOCIETY
STRIVING FOR PULMONARY CARE

Clinical Practice Guidelines

Spirometry

PAKISTAN CHEST SOCIETY-2026

Guidelines On

Spirometry

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PAKISTAN CHEST SOCIETY
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Preface

Efforts to quantify the volume of air within the human lungs spans a long history of scientific research. The true origin of pulmonary function testing dates back to 1846, when John Hutchinson who was an English physician transformed a gasometer into one of the first spirometer. His innovation provided a reliable means to measure exhaled air and laid the cornerstone for respiratory physiological measurements. Over the following century, refinements such as the introduction of water-sealed spirometers allowed more precise measurement of dynamic lung volumes, including the development of the forced expiratory volume (FEV_1) concept in the 1940s. The latter half of the 20th century saw the transition from mechanical and water-based instruments to pneumotachographs and turbine-based systems, enhancing accuracy and portability. With the advent of digital technology in the 1980s and beyond, spirometry entered a new era, enabling automated calibration, graphical display and data storage, which transformed this tool into an indispensable necessity in modern respiratory medicine.[12]

Spirometry is now considered an important and cost-effective diagnostic tool for evaluation of lung function.

It is mandatory for diagnosing, monitoring, and treating pulmonary diseases like asthma, COPD, ILDs, and various occupational lung diseases.2 In Pakistan, the burden of respiratory disease is substantial and growing. Studies in urban areas report high prevalence of chronic cough, wheezing, breathlessness and obstruction on spirometry, both in general adults and in high exposure populations such as textile workers.[3,4]

Considering the increasing air pollution, urbanization with associated occupational risks, poor air quality index in urban areas and frequent exposures to fog/smog like phenomena in our environment, there is a strong need to spread awareness at a national level regarding the hazards of these environmental changes which directly affect human lungs. At the same time, we also need to enhance our capabilities to diagnose various respiratory conditions which are becoming increasingly common by utilizing available medical tools in the right manner, i.e. lung function testing. These guidelines, developed under the Pakistan Chest Society (Punjab Chapter), aim to standardize spirometry practices and improve the reliability and quality of pulmonary function testing across local institutions. More importantly, they will emphasize the critical importance of proper spirometry performance, fostering uniformity in diagnosis, disease monitoring, and assessment of treatment outcomes in respiratory disorders. In the absence of standardized criteria for acceptability, repeatability, calibration, and reporting, spirometry results often vary considerably between clinics, hospitals, and operators. Such inconsistencies can lead to confusioan, resulting in misdiagnosis or inappropriate management. Despite growing awareness, reports suggest that spirometers remain unavailable or are not functioning to required specifications in many parts of Pakistan. One of the key aims of these guidelines is to emphasize the importance of proper operator training with periodic competency assessments. Spirometry personnel should be well-trained in equipment handling, test performance, and basic maintenance procedures. Competent respiratory therapists form the cornerstone of an effective and reliable spirometry service. Currently, many studies in Pakistan report respiratory symptoms without corresponding lung function data, a gap that limits both diagnosis and insight.5 Ensuring uniform, high-quality spirometry will strengthen disease surveillance, clinical research, and the understanding of disease patterns, risk factors, and treatment outcomes.

Target Audience and Implementation Strategies

The audience who should learn spirometry standards extends well beyond respiratory specialists. Primary care physicians, general practitioners, and family doctors are often the first point of contact for patients with breathing difficulties, making it crucial for them to understand how to interpret spirometry accurately. Nurses, physiotherapists, and respiratory therapists also play a vital role in performing the test and ensuring quality control, so structured and standardized training is essential for them. Medical students and postgraduate trainees should be introduced early to proper spirometry practices, helping them develop sound habits from the start of their careers. Moreover, policymakers and health administrators benefit from understanding these standards, as this knowledge supports better public health planning, equipment procurement, and the development of competency-based training requirements. In essence, everyone involved in the performance, interpretation, or oversight of respiratory care should be familiar with spirometry standards to ensure accurate, reproducible, and patient-centered outcomes.[2,6]

Having a standardized spirometry laboratory in clinical practice creates a powerful positive impact on both patient care and healthcare delivery. It ensures that lung function tests are performed with accuracy, consistency, and reliability, allowing clinicians to make confident diagnostic and therapeutic decisions. A standardized setup with calibrated equipment, trained staff, and adherence to international quality criteria reduces errors, avoids misclassification of disease, and improves patient safety.[7]

To translate these principles into practice, structured implementation is key. Training programs, regular competency assessments, and periodic audits should be organized under the guidance of the Pakistan Chest Society and collaborating institutions. Integration of these standards into medical curricula, professional development courses, and institutional policies will further ensure sustainability. Only through a coordinated, system-wide approach can spirometry become a consistently reliable and effective diagnostic tool across Pakistan's healthcare landscape.[8,9]

Message by the President

Pakistan Chest Society

Spirometry is the cornerstone of objective respiratory assessment and an essential tool in modern pulmonary practice. These guidelines stress the importance of proper technique, quality control, and accurate interpretation. The Pakistan Chest Society strongly advocates for wider availability and standardized use of spirometry to improve diagnostic accuracy nationwide.

Prof. Shereen Khan
President
Pakistan Chest Society

Message by the Chairman

Guideline Committee, Pakistan Chest Society

It gives me great pleasure to present the Guidelines for the Standardized Use and Interpretation of Spirometry by the Pakistan Chest Society. This document represents an important step toward improving the diagnosis and monitoring of respiratory diseases across Pakistan. Although spirometry is a simple and essential test, its use has often been inconsistent, leading to delays in diagnosis and inadequate patient management.

Given the high burden of asthma, COPD, post-tuberculosis lung disease, and environmental exposures in our population, accurate spirometric assessment is crucial. These guidelines, developed under the Chair of Dr. Kashif Sardar, review international standards while adapting them to local healthcare realities, ensuring that the recommendations are both practical and achievable.
The guidelines emphasize proper test performance, patient preparation, equipment calibration, quality control, and recognition of acceptable and reproducible maneuvers. They also provide clear guidance on interpreting obstructive, restrictive, and mixed patterns, enabling clinicians to make informed decisions. Training of technicians, standardized reporting, and regular quality assurance are strongly encouraged to ensure accuracy and consistency.

By promoting early diagnosis, objective monitoring, and better-informed treatment decisions, these guidelines aim to enhance the quality of respiratory care in Pakistan.
On behalf of the Guidelines Committee, I extend sincere appreciation to all contributors, especially Dr. Kashif Sardar, for their dedication and efforts. Together, we continue our commitment to strengthening evidence-based respiratory practice across the country.

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1. Fundamentals of Spirometry and Basic Lung Physiology

Spirometry is the most widely used pulmonary function test and provides objective information on lung volumes, airflow and ventilatory patterns. It is grounded in fundamental respiratory physiology, as it assesses the mechanical properties of the lungs, airways, and respiratory muscles by recording the volume of air a person can exhale and inhale as a function of time. Understanding the physiological basis of spirometry is essential for accurate interpretation and clinical application.[10]

Spirometry involves several key terms and measurements that describe lung function. These can be broadly divided into volumes, capacities, and indices (Figure 1).[11,12]

1. Tidal Volume (VT)

- The amount of air inhaled or exhaled during normal, quiet breathing.
- It reflects baseline ventilation and is usually around 500 mL in a healthy adult.[11]

2. Inspiratory Reserve Volume (IRV)

- The maximum amount of air that can be inhaled after a normal inspiration.
- Indicates inspiratory muscle strength and lung expansion potential.

3. Expiratory Reserve Volume (ERV)

- The maximum volume of air that can be exhaled after the end of a normal expiration.
- Reflects expiratory muscle effort and chest wall mechanics.

4. Residual Volume (RV)

- The volume of air remaining in the lungs after maximal exhalation.
- Cannot be measured directly by spirometry (requires special techniques like helium dilution or body plethysmography).

5. Vital Capacity (VC)

- The total volume of air that can be exhaled after a full inspiration.
- VC = IRV + VT + ERV.[11]

6. Forced Vital Capacity (FVC)

- The maximum volume of air exhaled forcefully and rapidly after full inspiration.
- One of the most important spirometric measurements.

7. Forced Expiratory Volume in One Second (FEV_1)

- The volume of air forcibly exhaled in the first second of the FVC maneuver.
- Strongly dependent on airway caliber and resistance.

8. FEV_1/FVC Ratio

- The percentage of the total exhaled air (FVC) expelled in the first second.
- A critical index to differentiate obstructive (low ratio) from restrictive (normal or high ratio) patterns.

9. Peak Expiratory Flow (PEF)

- The maximum flow achieved during forced expiration.
- Reflects large airway function and patient effort.

10. Forced Expiratory Flow (FEF_{25-75}%)

- The average flow rate during the middle half of FVC (between 25% and 75% of volume exhaled).
- Sensitive to changes in small airways.

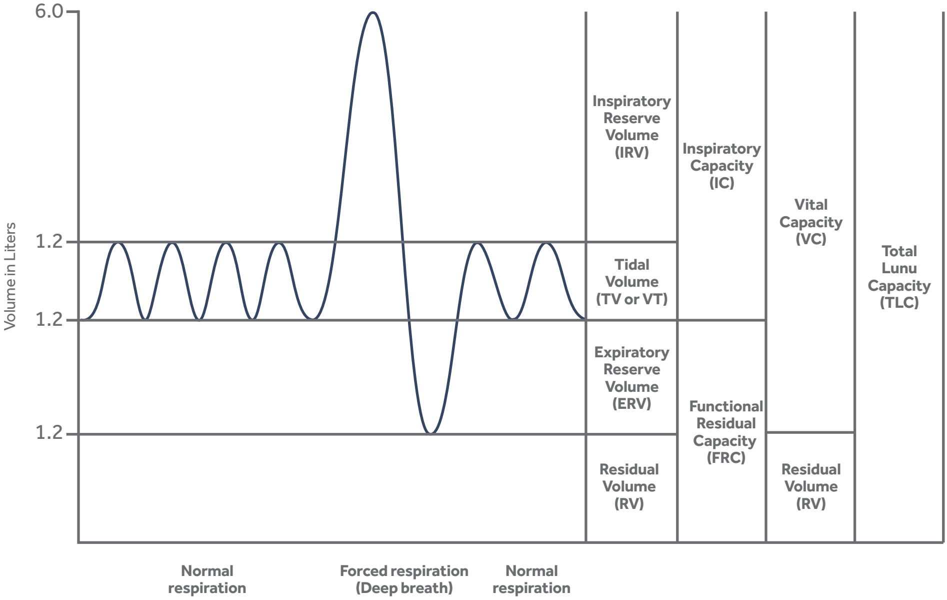
11. Predicted Values

- Reference values calculated based on population studies, adjusted for age, sex, height, and ethnicity.
- A patient's measured values are compared with predicted to assess normality.

12. Lower Limit of Normal (LLN)

- The lowest value expected in a healthy person of the same demographics, usually defined as the 5th percentile.
- Helps avoid misclassification that might occur if using fixed cut-offs alone.
  Indicates inspiratory muscle strength and lung expansion potential.

Figure 1: Schematic diagram showing different lung volumes and capacities.



2. Static And Dynamic Lung Volumes

Understanding the distinction between static and dynamic lung volumes is essential in spirometry, as it allows clinicians to differentiate between disorders affecting lung size and impairing airflow. In addition, recognizing this difference ensures accurate interpretation, guiding diagnosis, disease classification, and therapeutic decision-making in respiratory medicine.[10]

Static Lung Volumes:

Static lung volumes represent the absolute volumes of air within the lungs measured without reference to time. They primarily reflect lung size, compliance, and mechanical properties of the respiratory system. Static lung volumes are measured during slow breathing maneuvers to minimize the influence of airway resistance and flow-dependent changes that occur during forced efforts. Slow, relaxed breathing allows the lungs and chest wall to reach equilibrium at each phase of the respiratory cycle, providing a true representation of the absolute air volumes contained within the thoracic cavity. In contrast, forced maneuvers introduce dynamic factors—such as turbulence, airway compression, and increased intrathoracic pressure that can distort static measurements. For this reason, techniques such as helium dilution, nitrogen washout, and body plethysmography are performed under steady-state conditions to ensure accuracy and reproducibility of static volume assessment.[11]

The measurable parameters include:

- Tidal Volume (VT)
- Inspiratory Reserve Volume (IRV)
- Expiratory Reserve Volume (ERV)
- Residual Volume (RV)
- Vital Capacity (VC)
- Total Lung Capacity (TLC)
- Functional Residual Capacity (FRC)

Static lung volumes provide essential information for distinguishing between obstructive and restrictive ventilatory defects. In obstructive lung diseases, such as COPD or asthma, air trapping and hyperinflation lead to an increase in residual volume (RV) and functional residual capacity (FRC), while total lung capacity (TLC) may also be elevated. In contrast, restrictive lung diseases, including interstitial lung disease, chest wall deformities, or neuromuscular weakness—are characterized by proportionate reductions in all static volumes, particularly TLC and VC, reflecting decreased lung compliance or limited expansion. Evaluating these patterns helps clinicians differentiate pathophysiologic mechanisms and assess disease severity beyond spirometric indices alone.[13]

Dynamic Lung Volumes:

Dynamic lung volumes are time-dependent measurements obtained during forced respiratory maneuvers. They assess both the rate and pattern of airflow through the bronchial tree under maximal effort, providing insight into airway caliber, resistance, and elastic recoil. Parameters such as the Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1) are central to this evaluation. Forced maneuvers accentuate flow limitations, thereby unmasking obstructive abnormalities that may not be evident during quiet breathing. By analyzing expiratory performance over time, dynamic lung volumes assist in differentiating obstructive from restrictive ventilatory defects, determining bronchodilator responsiveness, and grading disease severity in conditions such as asthma and COPD.[11,13]

In contrast to static lung volumes which require specialized equipment, Dynamic lung volumes can be readily measured using routine office spirometry and can be easily performed at the bedside or in an outpatient setting. Measurable parameters include:

- Forced Vital Capacity (FVC)
- Forced Expiratory Volume in 1 Second (FEV_1)
- FEV_1/FVC Ratio
- Peak Expiratory Flow (PEF)
- Forced Expiratory Flow at 25–75% of FVC (FEF_{25-75}%)

Dynamic lung volumes provide crucial information about airflow limitation, ventilatory mechanics, and the nature of underlying lung disease. In obstructive disorders such as asthma and COPD, expiratory flow rates are reduced due to increased airway resistance and loss of elastic recoil, resulting in a disproportionate fall in FEV_1 and a reduced FEV_1/FVC ratio. Peak Expiratory Flow (PEF) and mid-expiratory flow (FEF_{25-75}%) are also diminished, reflecting variable involvement of large and small airways. Forced Vital Capacity (FVC) may be normal or reduced depending on the degree of air trapping. In restrictive diseases—such as interstitial lung disease or chest wall disorders—FEV_1 and FVC are both proportionately reduced, maintaining a normal or elevated FEV_1/FVC ratio. Flow-related parameters (PEF, FEF_{25-75}%) may be relatively preserved or mildly reduced. The pattern and proportion of change in these indices allow accurate differentiation between obstructive and restrictive ventilatory defects and guide further evaluation and management.

In addition to the Forced Vital Capacity (FVC), the Slow Vital Capacity (SVC) represents another dynamic measurement obtained during a slow, unforced expiration following maximal inspiration. Unlike FVC, which depends on patient effort and reflects flow dynamics under high intrathoracic pressure, SVC is performed without forceful exhalation, minimizing airway compression and premature closure. The difference between SVC and FVC provides valuable clinical insight: in healthy individuals, the two values are nearly identical, whereas in obstructive lung diseases—such as COPD or asthma—FVC tends to be lower than SVC due to dynamic airway collapse and air trapping during forced maneuvers. A markedly reduced FVC compared to SVC therefore supports the presence of airflow limitation and air trapping, even when the FEV_1/FVC ratio appears borderline or normal. Measuring SVC is particularly useful in patients unable to perform reliable forced efforts, or when obstructive physiology is suspected but not clearly demonstrated by conventional spirometry.

3. Indications for Spirometry

Static lung volumes = describe how much air the lungs can hold.
Dynamic lung volumes = describe how fast and how much air can be moved in a given time.

Spirometry has a wide range of diagnostic indications and is performed to confirm, characterize, or exclude respiratory disease. It is indicated whenever there is a need to detect, differentiate, or monitor obstructive and restrictive ventilatory defects, or to evaluate unexplained respiratory symptoms such as cough, wheeze, or dyspnea. The following list summarizes the major clinical indications for spirometry across diagnostic, monitoring, and screening contexts.[14,15]

1. Obstructive Lung Diseases

- **Asthma:** Detects reversible airflow obstruction (low FEV_1/FVC ratio that improves with bronchodilator). Useful for confirming diagnosis, assessing variability, and ruling out other causes of symptoms.
- **Chronic Obstructive Pulmonary Disease (COPD):** Identifies persistent, not fully reversible obstruction (FEV_1/FVC < LLN after bronchodilator). Help classify severity and stage disease progression.
- **Bronchiectasis / Chronic Bronchitis:** Provides evidence of obstruction and measures response to treatment.

2. Restrictive Lung Diseases

- Interstitial Lung Diseases (ILDs) such as pulmonary fibrosis: Reduced FVC with preserved or increased FEV_1/FVC ratio.
- Chest Wall or Neuromuscular Disorders (e.g., scoliosis, muscular dystrophy, myasthenia gravis): Spirometry shows reduced volumes reflecting restriction.

3. Mixed Patterns

- Detects coexistence of obstructive and restrictive features, e.g., COPD with pulmonary fibrosis.

4. Occupational Lung Diseases

- Pneumoconiosis (silicosis, asbestosis, coal workers' lung): Helps monitor progression.
- Exposure-related asthma or hypersensitivity pneumonitis: Detects obstruction or restriction early.

5. Pre- and Post-Intervention Assessment

- Bronchodilator testing: To assess reversibility in asthma vs. COPD.
- Pre-operative risk assessment: Especially in thoracic and upper abdominal surgery, where lung function affects perioperative risk.
- Pre- and post-therapy monitoring: For inhalers, steroids, immunomodulators, or rehabilitation.

6. Screening & Surveillance

- Smokers and high-risk populations – Early detection of COPD before symptoms appear.
- Occupational screening – For workers exposed to dust, fumes, and chemicals.
- Family history of respiratory disease – To detect early changes in high-risk groups.

7. Clarification of Symptoms

- Unexplained chronic cough, wheeze, or breathlessness.
- Distinguishing respiratory vs. cardiac causes of dyspnea.
- Assessing variability in symptoms suggestive of asthma.

4. Contraindications for Spirometry

Knowing when not to perform spirometry is just as important as knowing how to perform it. Contraindications are classified as either absolute, where the test must be avoided due to potential harm, or relative, where the risks should be weighed against the anticipated clinical benefit. Recognizing these situations ensures patient safety and preserves the accuracy of test results.[14,15]

Absolute Contraindications

Spirometry should be avoided in situations where forced breathing could cause serious harm:

- **Recent myocardial infarction** (within last 1 month)

Unstable angina

- **Thoracic, abdominal, or cerebral aneurysm** at risk of rupture
  Recent eye, chest, or abdominal surgery (e.g., cataract, neurosurgery, thoracotomy) where straining may disrupt healing

Current pneumothorax

- **Inability to follow instructions** (e.g., severe dementia, uncooperative patient)

Relative Contraindications

Spirometry may be performed with caution if the clinical benefit outweighs the risk:

- **Hemoptysis of unknown origin** (could worsen bleeding)
- **Recent respiratory infection** (may cause inaccurate results or discomfort)
- **History of syncope with forced exhalation** (risk of fainting)
- **Severe nausea, vomiting, or abdominal pain** (may worsen with forced maneuvers)
- **Uncontrolled hypertension** (forced expiration may cause blood pressure spikes)
- **Facial, oral, or dental pain/surgery** (mouthpiece use may be uncomfortable or harmful)
- **Pregnancy (late stage)** – only if essential, due to increased intra-abdominal pressure during forced maneuvers

5. Equipment Calibration and Quality Assurance

Absolute contraindications = serious risk if done (e.g., recent MI, aneurysm, pneumothorax).
Relative contraindications = proceed with caution if needed (e.g., recent infection, hemoptysis, uncontrolled hypertension).

Specifications of Spirometers:
Spirometers are precision instruments designed to measure lung volumes and airflow, and their specifications are critical to ensure accuracy, reliability, and reproducibility of results. At the core, a spirometer must be capable of measuring forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and the FEV_1/FVC ratio with high accuracy, as these are the key indices for diagnosing obstructive and restrictive lung diseases.[16,17]

Daily calibration and maintenance procedures:
Proper calibration and maintenance are essential to ensure spirometer accuracy, reliability, and patient safety. The ATS/ERS 2019 standards require that spirometers meet ISO 26782, with permissible errors of ±3.0% (or tighter if possible) for volume measurements when tested using a validated 3-L calibration syringe.[16] Daily calibration verification is recommended, using the 3-L syringe to flow at low, medium, and high rates (approx. 0.5-12 L/s), to ensure volumes remain within acceptable limits. If filters are used during patient testing, they should also be used during calibration.16 Maintenance steps include performing leak tests regularly (daily checks for leaks in the spirometer and calibration syringe), ensuring the calibration syringe itself is in good working order (no damage, smooth piston movement, etc.), and staying alert to environmental factors (temperature, barometric pressure) that can affect measurements. All calibration and maintenance activities should be documented in a log, including any repairs, software updates, hardware changes, and calibration outcomes, so that any deviations can be traced and corrected.[16,17,18]

Quality assurance and infection control:
Quality assurance (QA) and infection control are essential components in spirometry laboratories to ensure not only the accuracy and reliability of lung function tests but also the safety of both patients and staff. According to the ATS/ERS 2019 standards, QA involves regular calibration, documentation of device performance, operator training, and monitoring of acceptability and repeatability criteria to reduce measurement errors and inter-session variability.[17] On the infection control side, guidelines emphasize the risk of transmission via contaminated mouthpieces, tubing, valves, surfaces, and aerosols generated during forced exhalation. To mitigate this, best practices include use of disposable filters and mouthpieces, rigorous cleaning or disinfection of reusable components as per manufacturer's instructions, hand hygiene, use of personal protective equipment (PPE) where appropriate, and postponing tests in patients with active respiratory infection.[17] Together, robust QA procedures paired with strict infection control protocols maintain test integrity, prevent cross-infection, and build trust in spirometry results.

Criteria for repeatability and acceptability:

Repeatability and acceptability are the two key quality control standards in spirometry that ensure results are accurate and reliable (Figure 2, Table 1).

Acceptability criteria require each maneuver to begin with a sharp, rapid start which means that back-extrapolated volume is ≤150 mL or ≤5% of FVC. It should be free of artefacts such as cough, leaks or variable effort in the first second. Finally, the maneuver should continue with a smooth exhalation until a plateau is attained or at least for 6 seconds in adults (≥3 seconds in children).[16,17]

Repeatability criteria are met when the two largest FVC values and the two largest FEV_1 values are within 150 mL of each other; for children ≤6 years, the limit is within 100 mL or 10% of FVC. At least three acceptable blows must be achieved, and testing can continue up to eight attempts if repeatability is not met. These standards, as outlined in the ATS/ERS 2019 spirometry guidelines, are essential for ensuring test validity, reducing errors, and allowing correct interpretation of the FVC, FEV_1, and FEV_1/FVC ratio.[16,17]

Figure 2: Acceptability and repeatability criteria; schematic description

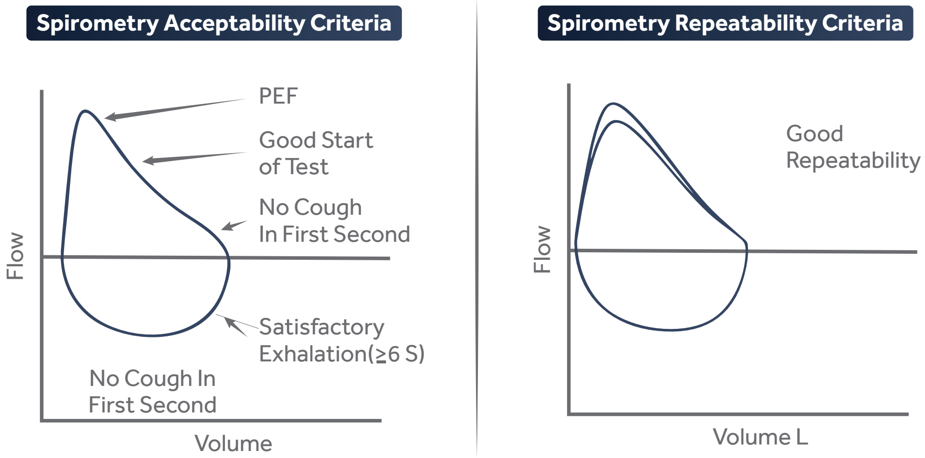


Table 1: Acceptability and Repeatability criteria for spirometry

Acceptability Criteria (per maneuver)	Repeatability Criteria (between maneuvers)
Rapid, forceful start: back-extrapolated volume ≤150 mL or ≤5% of FVC	At least 3 acceptable maneuvers must be obtained
No artefacts (no cough in 1st second, no leak, no false start, no variable effort)	Two highest FVC values within 150 mL (≤ 100 mL or 10% in children ≤6 yrs)

Exhalation continued until plateau (≤25 mL change in volume over 1 sec) OR ≥6 sec in adults (≥3 sec in children)	Two highest FEV_1 values within 150 mL (≤ 100 mL or 10% in children ≤6 yrs)
Flow-volume and volume-time curves are smooth and free of irregularities	Testing may continue up to 8 maneuvers if repeatability not met
Patient effort is maximal, with lips sealed tightly around mouthpiece	Final report should use the highest FVC and FEV_1, even if from different maneuvers

6. Patient Preparation

Instructions prior to tests (e.g., avoid smoking, bronchodilators, caffeine)

Before a spirometry test, specific patient preparations are important to avoid factors that can temporarily alter lung function and lead to misleading results.[16,17]

- Patients should **abstain from smoking for at least one hour** before testing, since smoking can acutely constrict airways.[19]
- **Withhold short-acting bronchodilators** (e.g. albuterol/salbutamol) for about **4–6 hours,** and **long-acting bronchodilators** for **12 hours or more, if** clinically safe, unless the test is specifically for drug response.[16]
- Caffeine (found in coffee, tea, chocolate, cola drinks) should be avoided on the day of the test, because it can act as a weak bronchodilator and possibly affect measurements.[17,19]
- Patients should also avoid vigorous exercise for at least 30 minutes to an hour before testing and not eat a large meal close to the test, because a full stomach can restrict chest expansion.[16,19]
- Additionally, any acute respiratory illness or infection should ideally be resolved at least 1-4 weeks prior to testing, as such conditions may affect baseline lung function.[16,19]

Table 2: List of instructions which should be given to patients before spirometry

Factor	Recommendation
Smoking	Avoid for ≥1 hour before test (preferably longer)
Short-acting bronchodilators (e.g. salbutamol, albuterol)	Withhold for 4–6 hours if clinically safe
Long-acting bronchodilators (e.g. salmeterol, formoterol)	Withhold for 12 hours

Long-acting muscarinic antagonists (LAMA)(e.g. tiotropium)	Withhold for 24 hours if possible
Caffeine (coffee, tea, energy drinks, chocolate)	Avoid on the day of the test
Vigorous exercise	Avoid for 30–60 minutes before test
Heavy meals	Avoid eating a large meal within 2 hours before test
Respiratory infection	Postpone test until 1–4 weeks after recovery

Positioning (seated upright, feet flat, nose clip usage)

- The patient should be seated upright in a stable, comfortable chair (without wheels) with arms supported and both feet flat on the floor. This posture provides safety (reducing risk of falls or syncope) while allowing full chest expansion and is the preferred position in most clinical settings.[16]
- Head and neck should be in a neutral to slightly elevated position; chin (jaw) level, shoulders relaxed, back straight. This helps maintain airway patency and avoids restrictions of airflow caused by flexion or slumping.[16]
- Use of a nose clip is recommended to prevent nasal air leakage and ensure all airflow is through the mouthpiece during forced expiratory and inspiratory maneuvers.[16]
- While the test can also be done in the standing posture, the seated position is usually preferred (especially for safety and consistency) unless there is a specific reason to stand. If standing is used, it should be documented, and preferably the same posture should be used for repeat tests to improve comparability.[16]
- For special patient populations (e.g. very small children, patients with neuromuscular disease or spinal cord injury), other positions (supine, semi-upright) may be considered for additional useful information (e.g. to assess diaphragmatic function) but these are exceptions and if used must be clearly documented.[20]

Explaining the procedure clearly to the patient

Explaining the spirometry procedure to the patient beforehand is crucial for ensuring valid, reproducible, and safe results. According to the ATS/ERS 2019 technical statement, patients should be informed of what the test involves, including the need for maximal inhalation, forceful exhalation, and continuing until no more air can be expelled (or until a plateau) so the operator and patient understand the effort required.16 Clear instruction reduces common sources of error such as hesitation at the start, early termination of exhalation, and variable effort between maneuvers.[16,17]

Proper description of the procedure to patients also helps reduce patient anxiety, which can impair performance, especially for those unfamiliar with forced breathing maneuvers or those who feel uncomfortable with the idea of blowing hard. Moreover, the patient needs to be aware ahead of time of any preparation (e.g., withholding bronchodilators, avoiding smoking, wearing loose clothes) so that none of these factors cause confounding of the results.[16] In summary, a well-explained procedure boosts cooperation, effort, safety, and ultimately the accuracy and clinical usefulness of the spirometry test.

7. Testing Procedure

Acceptable maneuvers: FVC, FEV1, FEV1/FVC ratio:

An acceptable maneuver in spirometry for measuring FVC, FEV_1, and calculating the FEV_1/FVC ratio must satisfy several technical criteria to ensure accurate and reproducible results.

- The maneuver should begin with a good start, meaning less than 150ms hesitation from the start of the forced exhalation and a back-extrapolated volume of ≤5% of FVC or ≤ 0.150L (whichever is greater).
- There should be maximal effort from full inspiration, no leak at the mouth, no obstruction of the mouthpiece (e.g. by tongue, teeth or biting).
- Coughing or other artefacts in the first second of exhalation (which would distort FEV_1) must be avoided.
- Exhalation must continue until a satisfactory end-of-test is achieved: either a plateau in the volume-time curve (where volume change is less than 25 mL over at least 1 second), or exhalation for at least 6 seconds in adults (or 3 seconds in children), whichever occurs earlier.

Acceptability also requires that the maneuver is smooth, without early termination, and that full effort is maintained. After obtaining at least three acceptable maneuvers, the best values for FVC and FEV_1 (not necessarily from the same blow) are used. These criteria are necessary so that the FEV_1/FVC ratio reflects true lung function rather than artefact or suboptimal effort.[17,21]

Number of efforts: Minimum 3, maximum 8

According to the ATS/ERS guidelines, a minimum of three acceptable maneuvers must be obtained to ensure reliability, with acceptability judged by criteria such as a good start, absence of artefacts, and adequate exhalation to a plateau. If repeatability criteria are not met, meaning the two largest FVC and FEV_1 values differ by more than 150 mL (or 100 mL or 10% of FVC in children under 6 years), additional efforts should be attempted, usually up to a maximum of eight maneuvers before the test is stopped to avoid fatigue.16 The best FEV_1 and FVC values, even if from different maneuvers, are then reported. This approach ensures that the final results reflect true lung function while protecting patients from excessive strain. Following are various steps which should be followed while performing the spirometry.

Step 1: Patient performs first maneuver. Check for acceptability (good start, no artefacts, full exhalation).
Step 2: Repeat until you have at least 3 acceptable maneuvers.
Step 3: Check repeatability:

- Two highest FEV_1 values within 150 mL (100 mL or 10% if <6 yrs).
- Two highest FVC values within 150 mL (100 mL or 10% if <6 yrs).

Step 4: If repeatability achieved, Test is complete. If repeatability is not achieved continue further testing.
Step 5: Allow up to a maximum of 8 maneuvers. Stop if patient becomes fatigued, dizzy, or unsafe to continue.
Step 6: Report the highest FEV_1 and FVC values, even if from different efforts.

8. Interpretation of Spirometry Results

Once a report is generated and sent to the clinician, interpretation of spirometry becomes a central and critical step in deriving clinical meaning from the test. This interpretation categorizes the patient's ventilatory function as normal, obstructive, restrictive, or mixed.

Beyond identifying these patterns, spirometry also contributes to grading the severity of functional impairment. However, a spirometry report alone has limited diagnostic value if interpreted without supporting clinical and radiological information. It is therefore recommended that spirometry results should never be interpreted in isolation but always integrated with the patient's history, examination findings, and complementary investigations such as imaging or diffusion studies.[22]

A valid interpretation of spirometry depends on accurate data acquisition, proper patient preparation, and adherence to quality assurance standards that ensure test acceptability and repeatability. Moreover, interpretation must employ appropriate reference equations that accurately represent the tested population. The traditional reliance on "percent predicted" values and fixed cut-offs (such as $FEV_1/FVC < 0.70$) has gradually evolved toward the use of Z-scores and the Lower Limit of Normal (LLN), which offer statistically robust, age- and population- adjusted definitions of abnormality. This approach has been strongly recommended in international standards and formally endorsed by the ATS/ERS 2019 Interpretive Strategies consensus statement.[16,17,22] We will briefly review both the traditional and LLN-based interpretive methods in the following section.

8.1 Traditional Method: Percent Predicted and Fixed Ratio

Historically, interpretation of spirometry was based on comparing measured values to predicted values, expressed as a percentage of the predicted value:

% Predicted = Measured value / Predicted value x 100

- FEV_1 ≥ 80% predicted
- FVC ≥ 80% predicted
- FEV_1/FVC ≥ 0.70

Values below these cutoffs were supposed to be indicative of airflow obstruction (FEV_1/FVC < 0.70). Although the traditional approach remains deeply embedded in routine spirometry interpretation due to its simplicity and long-standing use, it carries several important limitations. The fixed FEV_1/FVC ratio of 0.70 does not account for the physiological age-related decline in this ratio, resulting in over-diagnosis of obstruction among elderly individuals and under-diagnosis among younger adults. It has been found that it can lead to a 20% misdiagnosis.22 Furthermore, reliance on a uniform "percent predicted" threshold fails to reflect the natural biological and ethnic variability in lung function. For instance, an older man with an FEV_1/FVC of 0.68 may fall below the fixed cut-off yet still lie within the statistically normal range for his age and population. This limitation underscores the need for population-specific reference equations, and Z-score based interpretation.[16,22]

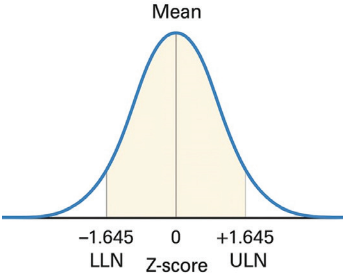
8.2: The Z-Score and Lower Limit of Normal (LLN) Approach

Modern international guidelines now recommend the use of Z-scores derived from population-based reference equations for spirometry interpretation. A Z-score indicates how many standard deviations a measured value lies above or below the predicted mean for an individual of the same age, sex, height, and ethnic background. This statistical approach provides a continuous measure of deviation from normal, minimizing misclassification across different age and demographic groups:[22]

$$z = (\text{Measured} - \text{Predicted Mean}) / \text{Standard Deviation}$$

A Z-score of zero represents the predicted mean; negative values indicate results below the mean, while positive values indicate results above it. A Z-score of –1.645 corresponds to the 5th percentile, defining the Lower Limit of Normal (LLN). A Z-score of +1.645 corresponds to the 95th percentile, defining the Upper Limit of Normal (ULN). Therefore, 90% of healthy individuals fall between these two boundaries (Figure 3).[16,19,24]

Figure 03:
Relationship Between Z-Score and Percentile Limits in Spirometry



Clinical interpretation:

- Values below the LLN (Z < –1.645) are considered abnormal.
- Values between –1.0 and –1.645 may be borderline and should be interpreted in clinical context.
- Expressing results as Z-scores avoids the bias introduced by age, sex, height, and ethnicity differences inherent in fixed percentage-predicted thresholds.

able 3: Classification of Severity (FEV_1 Z-scores)

Severity	Z-Score Range	Approximate % Predicted
Normal	≥ −1.64	≥ 80%
Mild	−1.65 to −2.50	70–79%
Moderate	−2.51 to −4.00	50–69%
Severe	< −4.00	< 50%

To exemplify this, a patient with an FEV_1 Z-score of −2.0 lies roughly at the 2.3rd percentile—meaning fewer than 3 in 100 healthy individuals would have such a low value—strongly supporting the presence of abnormal airflow limitation.

Advantages of Using Z-score based approach:
Studies based on large population datasets such as NHANES III and GLI 2012 demonstrate that applying the 80% rule misclassifies up to 20–25% of older adults as abnormal despite having values above the true LLN, while it fails to detect up to 10–15% of younger individuals whose results fall below the LLN but remain above 80% predicted. The Z-score– based interpretation, now endorsed by ATS/ERS (2022), eliminates these demographic biases and provides a statistically valid assessment of normality across all ages.[16,17,22] Z-score based approach thus offers clear advantages:

- Adjusts for the natural aging process and body size.
- Avoids arbitrary cutoffs and provides a continuous measure of abnormality.
- Reduces both false-positive and false-negative classifications.
- Allows uniform reporting across populations and laboratories.

8.2.1 Practical Examples on application of z-score

Example 1:
45-year-old male with longstanding history of smoking came for evaluation of his lung function tests. Spirometry shows: $FEV_1/FVC = 0.68$, $Z = -1.2$. What should be the interpretation of these findings?

- Explanation: She has normal lung function according to z-score (above LLN i.e. -1.64). On the other hand, if traditional fixed ratio cutoff i.e. 0.70, this would have been misclassified as obstruction.

Example 2:
70-year-old female presented with shortness of breath for last 4 months. She has no audible wheeze on auscultation. Her CXR was normal. She underwent spirometry which showed $FEV_1/FVC = 0.68$, $Z = -2.0$. What is the likely interpretation of her spirometry?

- Explanation: Using z-score method she has an obstructive pattern indicative of chronic airflow limitation. However, if you are using fixed ratio approach, her FEV1/FVC ratio would appear "borderline," missing true disease.

Example 3:
54-years-old female FVC = 68% predicted (Z = –2.2), FEV_1/FVC of 0.9 (Z = -1.34). What should be the interpretation of her spirometry?

- Explanation: Restrictive patterns likely due to reduced lung volume as Z-score for FVC is 2.2 which is below the lower limit of normal (-1.64).
- These examples are described to demonstrate how the Z-score method can affect diagnostic precision and avoid misleading conclusions.

8.3 Recognizing Spirometric Patterns:
Applying the LLN-based approach in clinical practice enhances the accuracy and consistency of spirometry interpretation. When reporting results, values should be expressed as both the absolute measurement and the corresponding Z-score, with reference to whether they fall below the LLN. Clinicians should interpret these findings alongside the pattern of abnormality (obstructive, restrictive, or mixed) and the degree of severity based on Z-scores for FEV_1. This method promotes uniform interpretation, minimizes age- or ethnicity-related bias, and aligns clinical decision-making with current ATS/ERS standards.[16,19] Various spirometric patterns are summarized in table below.

able 4: Classification of lung function impairment on spirometry (decreased or increased values indicative of lower and upper limits of normal)

Pattern / Interpretation	FEV_1			Approximate % Predicted
Obstructive impairment	↓ or Normal	↓ or Normal	↓	Characterized by reduced expiratory flow; confirm with bronchodilator response. Common in asthma and COPD.
Restrictive impairment	↓	↓	Normal or ↑	Suggests for reduced total lung capacity (TLC); confirm restriction with static lung volume measurement.
Non-specific pattern (PRISm)	↓	↓	Normal	TLC is usually normal. May represent preserved ratio impaired spirometry (PRISm), seen in some

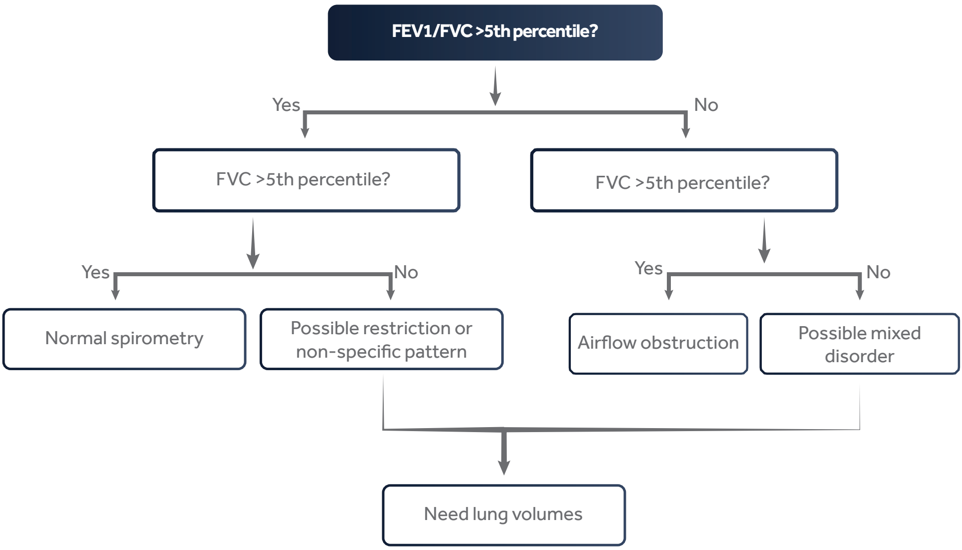
				smokers and early lung disease. Further testing (TLC, bronchodilator response, airway resistance) may help.
Muscle weakness	↓	↓	Normal	Both FEV_1 and FVC reduced with preserved ratio. Flow–volume curve shows blunted peak expiratory flow; assess for neuromuscular or chest wall causes.
Suboptimal effort	↓	↓	Normal	Incomplete exhalation or poor effort leads to falsely reduced FEV_1 and FVC; curve lacks sharp PEF and shows early termination. Repeat testing after coaching.
Mixed pattern	↓	↓	↓	Indicates coexistence of obstruction and restriction. Confirm with lung volumes (reduced TLC confirms mixed defect).
Dysanapsis (disproportionate airway-to-lung size)	Normal	Normal or ↑	↓	May represent physiological variation, especially in young or athletic individuals; not necessarily pathological.

8.3.1. Step-Wise approach to interpretation of spirometry:

Interpretation begins with evaluation of the FEV_1/FVC ratio, which determines whether airflow obstruction is present. A reduced ratio (below the 5th percentile or LLN) indicates obstructive impairment. Once obstruction is identified, the FVC should be assessed to differentiate between isolated obstruction and a possible mixed pattern. A normal FVC suggests pure obstruction, whereas a reduced FVC raises suspicion of a concomitant restrictive or non- specific process.

If the FEV_1/FVC ratio is within normal limits, obstruction is excluded, and interpretation proceeds by reviewing the FVC. When FVC is normal, spirometry is considered normal. A reduced FVC with a preserved ratio, however, indicates a possible restrictive or non-specific pattern. This finding may occur in individuals with early or mild obstruction, poor inspiratory or expiratory effort, or extrapulmonary causes such as chest wall or neuromuscular limitation.

Figure 4: A schematic approach to interpretation of spirometry (Adapted from ERS/ATS technical standards for routine lung function testing)



8.4. Flow–Volume and Volume–Time Loop Interpretation

Numerical values alone can never provide a complete picture of pulmonary function. The flow–volume and volume–time curves are essential graphical tools that enable visual assessment of both test quality and physiological patterns.[17] They assist in evaluating:

- **Test quality:** effort, hesitation, cough, or premature termination.
- **Pattern recognition:** obstructive, restrictive, or mixed ventilatory defects.
- **Upper airway abnormalities:** identification of fixed or variable intrathoracic and extra-thoracic obstruction.
- **Bronchodilator response:** direct visualization of post-bronchodilator changes in flow or volume.

These graphical displays are invaluable for both clinical interpretation and teaching, often revealing technical or physiological abnormalities even when numerical indices appear within acceptable ranges.[17]

8.4.1. Flow–Volume Loops:

The flow–volume loop displays airflow (L/s) on the y-axis and volume (L) on the x-axis, illustrating the relationship between flow and lung volume throughout the respiratory cycle. Expiration is represented above the baseline, while inspiration appears below it. The shape, size, and contour of the loop provide important visual information about respiratory mechanics, airway resistance, and lung compliance. Characteristic changes in the loop can help differentiate obstructive, restrictive, and upper airway flow abnormalities.[21]

Figure 05

Common Flow Volume Loop Abnormalities depicting normal, obstructive (loop shifts to left, FEV1 reduced but FVC increased), restrictive (loop shifts to right with preserved FEV1 but reduced FVC) patterns.

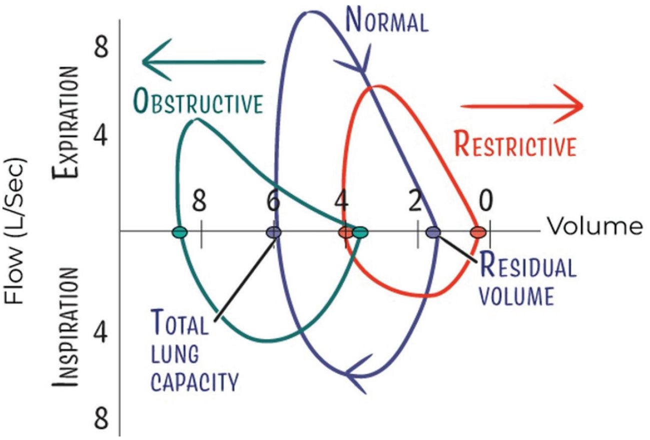
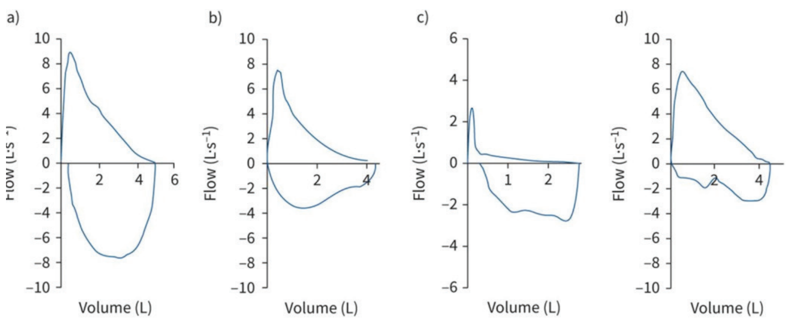
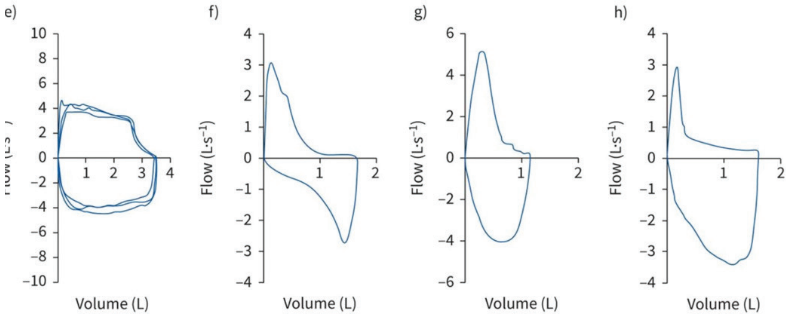


Figure 06

Representative flow–volume loop patterns illustrating: a) normal configuration, b) mild to moderate obstruction, c) severe obstruction, d) variable extra thoracic obstruction, e) fixed large or central airway obstruction, f) unilateral mainstem bronchial obstruction, g) restrictive pattern, and h) mixed ventilatory defect ((Adapted from ERS/ATS technical standards for routine lung function testing)



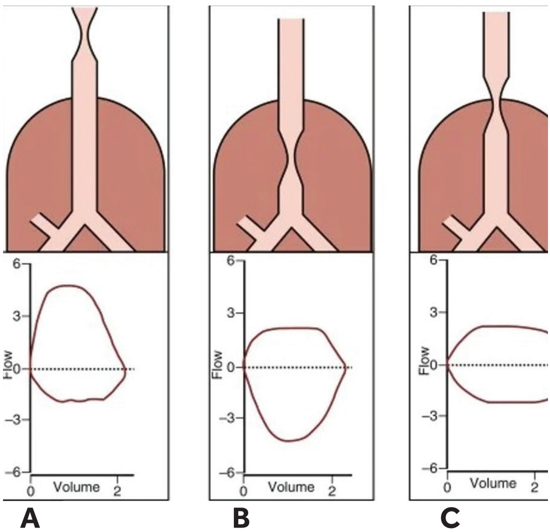


8.4.2. Flow–Volume Loop Patterns in Central/Upper Airway Obstruction

Examination of the expiratory flow–volume loop provides valuable clues to the presence and nature of upper airway obstruction. A consistent plateau of inspiratory flow with relatively preserved expiratory flow indicates a variable extra thoracic obstruction (figure 7A). Conversely, a plateau during expiration with a normal inspiratory contour suggests a variable intrathoracic obstruction (figure 7B). When both inspiratory and expiratory phases demonstrate plateaus, a fixed large or central airway obstruction should be suspected (figure 7C).

In unilateral mainstem bronchial obstruction, a rare finding, the inspiratory loop may show higher initial flow that declines toward the end of inspiration due to delayed gas filling (figure 6f). During forced expiration, an initial fall in flow followed by a mid-expiratory plateau reflects sequential emptying of rapidly and slowly ventilated lung regions.

Figure 7: Common patterns of central/upper airway obstruction. A: Variable extra-thoracic obstruction, B: Variable intra-thoracic obstruction, C: Fixed obstruction (intra or extra-thoracic)



Analysis of the flow–volume loop provides essential qualitative information that complements numerical spirometric indices. Characteristic loop shapes help identify specific patterns of ventilatory impairment and can reveal upper airway or large airway obstruction that may not be evident from FEV_1, FVC, or their ratio alone. A summary of various abnormalities which can be found in flow-volume loops is summarized in table 5.

Table 5: Characteristics of Various Flow-volume loops identifiable on spirometry

Pattern	Shape Description	Key Features	Example Clinical Interpretation
Normal	Rapid rise to peak expiratory flow, smooth convex expiratory limb, symmetrical inspiratory limb	Full loop, sharp PEF, smooth return to baseline	Healthy subject
Obstructive	"Scooped" or concave expiratory limb; may have reduced peak flow	↓Peak flow, prolonged expiration, normal/increased FVC	Asthma, COPD
Restrictive	Small, narrow loop maintaining shape	↓FVC and FEV_1, normal or high FEV_1/FVC ratio	Interstitial lung disease, obesity
Mixed	Small loop with concave expiratory limb	↓FEV_1/FVC and ↓FVC	COPD with fibrosis
Variable Extrathoracic Obstruction	Flattened inspiratory limb, normal expiratory limb	Flow limitation during inspiration	Vocal cord dysfunction, tracheal stenosis
Variable Intrathoracic Obstruction	Flattened expiratory limb, normal inspiration	Flow limitation during expiration	Tracheomalacia, intrathoracic mass
Fixed Large Airway Obstruction	Flattening of both inspiratory and expiratory limbs	Constant flow limitation	Subglottic stenosis, tracheal tumor
Poor Effort / Cough / Leak	Irregular, jagged, or early termination of loop	Unreliable test, must be repeated	Suboptimal patient performance

8.4.3: Volume–Time Curve

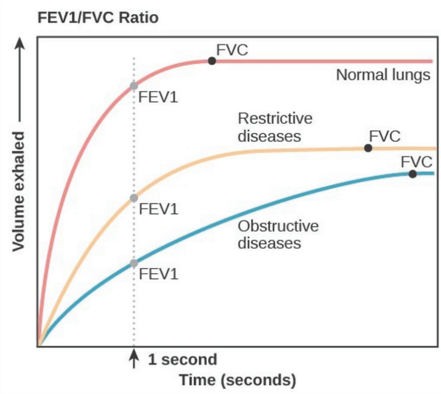
The volume–time curve plots the total exhaled volume against time and is especially valuable for assessing test validity and expiratory duration. It demonstrates how rapidly and completely a subject can exhale during a forced expiratory maneuver. The curve begins at zero, the start of exhalation, and rises progressively until it reaches a plateau, indicating that the forced vital capacity (FVC) has been achieved. From this curve, key spirometric indices such as FEV_1, FVC, and the FEV_1/FVC ratio are derived.[2,16,17]

Key features:

- The curve should reach a **plateau within 6 seconds** in adults and **3 seconds in children.**
- A **smooth, continuous ascent** indicates good effort and absence of cough or hesitation.
- Failure to reach a plateau suggests **premature termination, suboptimal effort, or air trapping.**
- The **initial steep rise** reflects the expiratory flow rate, while the **plateau** represents the total FVC achieved.

Proper evaluation of the volume–time curve is essential for confirming test acceptability, identifying technical errors, and ensuring accurate interpretation of the numerical results.[2]

Figure 08
FEV1 and FVC for normal lungs, restrictive and obstructive pulmonary diseases. Most pulmonary diseases result in reduced FEV1 and FVC values.



8.4.4 Difference between clinical utility of Volume-time versus Flow-volume loop

Both the volume–time curve and flow–volume loop provides complementary information in spirometry interpretation. The volume–time curve demonstrates how much and how fast air is exhaled, making it valuable for quantitative assessment and quality control. In contrast, the flow–volume loop illustrates how airflow behaves throughout the respiratory cycle, offering greater clinical utility for pattern recognition and anatomical localization of airway obstruction (e.g., fixed, variable intrathoracic, or variable extra thoracic).[16,19,21] The following table summarizes their comparative clinical features:

Table 6: Comparison of various differentiating features of Volume Time Curve and Flow-volume loops

Feature	Volume–Time Curve	Flow–Volume Loop
Main axis variable	Time	Flow
Key focusd	Volume change over time	Flow at each lung volume
Main parameters	FEV_1, FVC, FEV_1/FVC	PEF, loop shape, inspiratory vs expiratory pattern
Best for	Quantitative assessment (how much, how fast)	Qualitative pattern recognition (how the air moves)
Clinical use	Severity grading, completeness, effort check	Identifying site/type of obstruction, visual pattern

8.5: Bronchodilator Reversibility Testing

Bronchodilator reversibility testing is an integral component of spirometry interpretation that helps distinguish reversible airflow limitation (as seen in asthma) from fixed obstruction (as seen in COPD and other chronic airway diseases). The physiological rationale is to determine the extent to which airway narrowing can be relieved through smooth muscle relaxation following administration of a short-acting bronchodilator. Nebulization is performed with salbutamol 2.5 mg, then wait 10–15 minutes followed by repeat spirometry to obtain post-bronchodilator value.

Interpretation of bronchodilator response (BDR) has evolved with updated international recommendations. The 2005 ATS/ERS criteria defined a significant BDR as an increase of ≥ 12% and ≥200 mL in FEV_1 or FVC from baseline values. However, the 2022 ATS/ERS Technical Standard recommends expressing BDR as a change relative to the predicted value, which accounts for sex, height, and age differences and better reflects population variability. Based on pooled reference data, an increase of >10% of the predicted value in FEV_1 or FVC is now considered to exceed the normal physiological range. It is important to note that this threshold is not equivalent to a 10% change from baseline measurements. For continuity, both criteria may be reported during the transition to the newer standard.[16,17,22]

BDR = (Post – Pre bronchodilator value [L] × 100) / Predicted value

For example, a 50-year-old male, height 170 cm, has a pre-bronchodilator forced expiratory volume in 1 s (FEV1) of 2.0 L and a post-bronchodilator FEV1 of 2.4 L. The predicted FEV1 is 3.32 L (GLI 2012 "other" equation).

$$\textbf{Bronchodilator response} = \frac{(2.4 - 2.0) \times 100}{3.32} = 12.1\%$$

Therefore, their bronchodilator response is reported as an increase of 12.1% of their predicted FEV1 and classified as a significant response.

Interpretive patterns of bronchodilator response:

- **Complete reversibility:** FEV_1 or FVC returns to the normal range post-bronchodilator — typically consistent with an asthma phenotype.[16,17]
- **Partial reversibility:** Improvement is present, but values remain below LLN — may indicate asthma–COPD overlap (ACO) or partially reversible COPD.[16,17]
- **No reversibility:** Suggests fixed obstruction, commonly seen in COPD, bronchiectasis, or constrictive bronchiolitis.[16,17]

It is important to note that the absence of reversibility does not exclude asthma. Airway responsiveness may vary depending on disease activity, current treatment, or timing of bronchodilator administration.[17] Therefore, spirometric results must always be interpreted within the clinical context.

8.6: Common Errors and Artifacts in Spirometry

Accurate interpretation of spirometry depends on the technical quality of data acquisition. Recognition of common errors and artifacts is therefore essential to avoid misinterpretation and diagnostic inaccuracy. Visual inspection of the flow–volume and volume-time curves should always accompany numerical review to identify the following issues:[16,17,21]

A. Suboptimal effort or poor inspiration

- Incomplete inspiration results in underestimation of FVC and FEV_1.
- The flow–volume loop starts below the true maximal inspiratory level

B. Hesitation or slow start of exhalation

- Produces a rounded or "slurred" curve at the start of expiration.
- Underestimates FEV_1 and may mimic obstruction.

C. Early termination of exhalation

- Volume–time curve fails to reach a plateau within 6 seconds (adults).
- Leads to falsely low FVC and an artificially high FEV_1/FVC ratio, simulating restriction.

D. Cough during maneuver

- Causes spikes or interruptions in the curve, particularly early in expiration.
- Invalidates the measurement if occurring within the first second.

E. Variable effort between maneuvers

- Results in poor repeatability (difference in FVC or FEV_1 > 150 mL between best efforts).
- Repeat testing with clear coaching is required.

F. Glottic closure or leak

- Sudden cessation of flow or irregular "steps" in the loop.
- May falsely reduce FVC or distort the loop shape.

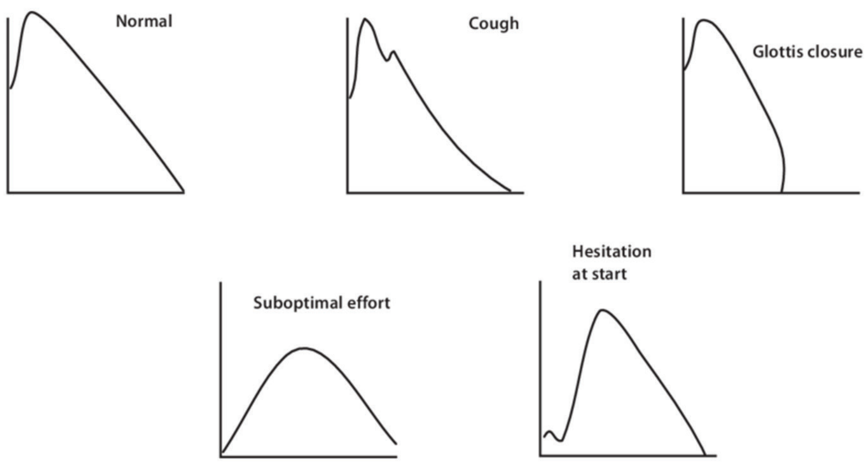
G. Equipment or calibration errors

- Incorrect zeroing or leaks in tubing may cause volume drift or inconsistent flow readings.
- Daily calibration and quality control checks are mandatory.

H. Artifact recognition

- Flattened loops due to software scaling, thermal drift, or improper display should be distinguished from true physiological abnormalities.

Figure 9: Various errors and artifacts encountered in spirometry



Continuous operator training and regular equipment maintenance are essential to minimize these errors and maintain the integrity of spirometry data.

Table 7: Various artifacts/errors during spirometry with their clinical implication

Artifact / Error	Curve Appearance / Finding	Interpretive Impact	Corrective Action
Suboptimal inspiration	Loop begins below true baseline; reduced volumes	Underestimates FVC and FEV_1; may simulate restriction	Reinstruct patient; ensure full inspiration before exhalation
Hesitant or slow start of exhalation	Rounded or "slurred" take-off at curve start	Underestimates FEV_1; may mimic obstruction	Emphasize sharp, immediate exhalation; repeat maneuver

Early termination of exhalation	Volume–time curve fails to plateau within 6 s (adults)	Falsely low FVC; artificially high FEV_1/FVC ratio	Encourage continued exhalation until plateau; verify duration
Cough during maneuver	Spikes or interruptions on flow–volume loop	Invalidates FEV_1 if within first second, distorts loop	Repeat after patient clears cough; exclude invalid blow
Variable effort between maneuvers	Inconsistent loop size/shape between trials	Poor repeatability; unreliable results	Provide coaching; accept best two with ≤150 mL difference
Glottic closure / leak	Sudden drop in flow or irregular "steps"	Underestimates FVC; distorted loop contour	Refit mouthpiece. check seal; repeat after rest
Mouth leak or tongue interference	Irregular oscillations or reduced flows	Erroneous low volumes; erratic loop	Reinstruct on mouthpiece seal. stabilize tongue
Equipment / calibration error	All curves shifted or inconsistent volumes	Systematic measurement bias	Recalibrate; perform leak test; check sensors
Software scaling / Display artifact	Flattened or distorted loop without physiologic basis	May be misread as fixed obstruction	Verify display settings, cross-check raw data

8.7: Reporting of Spirometry: Integrating Results into Clinical Context

While spirometry provides very important physiological information, **no test should be interpreted in isolation.** Correlation with clinical features such as symptoms, auscultatory findings, radiology, and diffusing capacity is essential to reach a conclusive diagnosis. For instance, an obstructive pattern in a smoker with wheeze supports COPD, while similar findings in a young patient with variability and bronchodilator reversibility may indicate asthma.

Therefore, the **interpretation report** should include:

- The test's quality grade (acceptable/repeatable).
- Numerical values with Z-scores and LLN.
- Flow-volume and volume-time curves.
- A concise interpretive comment (e.g., "Obstructive pattern, moderate severity; consistent with airflow limitation, clinical correlation advised")

8.8: Reference Equations and Local Adaptation

Accurate interpretation depends on selecting the correct reference equation. The Global Lung Initiative (GLI 2012) reference dataset provides equations for multi-ethnic populations aged 3–95 years and is now widely adopted as an international standard. However, regional or population-specific variations remain important. Studies in South Asian populations, including data from Karachi reference equations (Malik et al., 2021), show that GLI equations may overestimate predicted values, leading to higher rates of false abnormality.[25] For developing countries, including Pakistan, adopting these modern standards along with validation of local reference values is essential to ensure accurate diagnosis, avoid misclassification, and enhance patient care. Therefore, each laboratory should adopt or validate a reference equation that best reflects its local population. In Pakistan and South Asia, both GLI "South-East Asian" and locally derived equations should be compared to ensure fair representation.

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