



Primary Care Asthma Program (PCAP)

SPIROMETRY MANUAL

Version 2021

Ontario 

Primary Care Asthma Program

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Introduction/Background

The Primary Care Asthma Program (PCAP) is an evidence-based asthma and COPD program intended to provide primary care providers with decision aids to support best practice regarding asthma and COPD assessment, diagnosis and management. The Ministry of Health currently supports and funds PCAP as part of Ontario's Asthma and COPD Program.

Currently, PCAP is delivered within a multi disciplinary team of primary care providers with the support of a Certified Asthma/Respiratory Educator (CAE/CRE). The CAE/CRE assists with program implementation, mentoring, education of patients and staff and ensuring the ongoing sustainability of the program. The program is modeled on fostering patient and family self-management.

Key to the success of this primary care program is the expertise of the educator who provides current evidence-based knowledge and assists with on-site objective measurements via spirometry (please see policy and procedures in the manual for who can conduct spirometry and who can interpret spirometry). Spirometry, in accordance with American Thoracic Society/ European Respiratory Society (ATS/ERS) Standards, will be used as the primary objective measure for the confirmation of the diagnosis of asthma and as the objective measure for the monitoring of clients who are capable of performing this test.

This Spirometry Manual was developed by the PCAP coordinator group for health care providers in the primary care setting. The purpose of the manual is to promote quality spirometry in primary care.

Section 2: Policy and Procedure

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2.1 Primary Care Asthma Program (PCAP) Spirometry Policy and Procedures

Purpose:

To assist “**PCAP**” primary care providers with policies and procedures for performing spirometry testing in accordance with current American Thoracic Society/European Respiratory Society (ATS/ERS) Standardization of Lung Function Testing (1,14) as well as the Canadian Thoracic Society (CTS) guidelines for Spirometry in Primary Care (2).

Policy:

Spirometry is a non-invasive, diagnostic test that measures ventilatory capacity as a function of time, reflecting the flow resistive properties of the airways. Spirometry, pre- and post-bronchodilator, in accordance with ATS/ERS standards, will be used as the primary objective measure for clients who are able to perform the test for the confirmation of the diagnosis of asthma and COPD and as an objective measure of lung function for the monitoring of asthma and COPD clients. Refer to PCAP Generic Program Standards (GPS) # 5. (3)

Procedure:

Instrumentation, calibration, hygiene, infection control, performance of the test to meet criteria for acceptability and repeatability, reporting results for interpretation, and spirometry training recommendations are essential elements of performing spirometry that can have a significant impact on the quality/accuracy of the test and the appropriate interpretation of the results.

2.1.1 Instrumentation

Spirometer equipment recommendations apply to all spirometers and are minimal requirements.

Instrumentation recommendations should be followed to provide accurate data and information that is comparable from laboratory to laboratory and from one time period to another. The accuracy of a spirometry system depends on the characteristics of the entire system, from the volume or flow transducer and the use of an in-line filter, to the recorder, display or processor. An in-line bacterial/viral filter that connects to the flow sensor is recommended to ensure protection from microorganisms. Changes in any aspect of the equipment or errors at any step in the process can affect the accuracy of the results. All spirometry should be reported at BTPS (Body Temperature and Pressure Saturated) by any method (measuring temperature and barometric pressure). When a subject performs an FVC maneuver into a spirometer, the air leaving the lungs is approximately 33°C-35°C and saturated with water vapour. If the expired gas is assumed to be at BTPS, an error of ~1% will occur. Most volume-type spirometers assume instant cooling of the gas but this is not always the case. If the flow sensor is located further from the mouth, such as adding an in-line filter, more cooling will occur allowing for more errors. For example, if the BTPS correction factor is wrong, an accurately measured FVC will be incorrectly reported (1).

Flow-Sensing Spirometers – currently the most widely used instruments

- ☐ Utilizes a sensor that measures flow as the primary signal and calculates volume by electronic (analog) or numerical (digital) integration of the flow signal producing a **FLOW-VOLUME** curve
- ☐ Most commonly used flow sensors detect and measure flow from: the pressure drop across a resistance (pneumotach); cooling of a heated wire; or by electronically counting the rotation of a turbine blade

General Considerations (2,14):

- ☐ All spirometers must meet ISO 26782 standards, with a maximum permissible error of +/-2.5% for accuracy, linearity and repeatability when tested with a 3L calibration syringe.
- ☐ Exhalation-only spirometers are not recommended (e.g. Spirometers where the patient inhales to maximal lung volume, then while holding their breath, places mouth on mouthpiece and does a forced exhalation into the spirometer). This is because it requires more coordination from the patient and can

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cause inaccurate measurement due to leakage that occurs between the time when the patient reaches maximal lung volume and when the patient places their mouth on the mouthpiece. It is recommended that the spirometer chosen allows the patient to take tidal breaths with their mouth on the mouthpiece prior to the FVC maneuver. This allows for the person conducting the test to evaluate a proper seal around the mouthpiece and the nose clip is functioning properly. Any leakage that occurs at maximal lung volume will be captured and will be used to determine whether the test meets ATS/ERS standards.

Display (2):

- ☐ The Display must show both the flow-volume loop and the volume-time curve real time with sufficient resolution so that the person conducting the testing can determine whether test results have met the ATS/ERS standards (see page 6 of this Policy and Procedure)
- ☐ It should be possible for the person conducting the spirometry testing be able to observe both the display and the patient effort allowing for instant coaching and for the person conducting the spirometry testing to terminate the test early if the test is unacceptable
- ☐ The spirometer should be able to analyze each maneuver to determine whether each effort meets ATS/ERS standards (acceptability and repeatability) and provide “warning messages” to indicate if the maneuver was not acceptable (e.g. “end of test criteria not met – blow out longer”) This should be recognized by the person conducting the spirometry testing and an effort will be repeated even if the computerized system has accepted the test. Note: Most of the ATS/ERS standards are based on the adult population and many children can meet requirements with submaximal efforts and poor quality tests. Information about special considerations in children are available at the end of this document.

2.1.2 Calibration

Attention to equipment quality control and calibration is an important part of good laboratory practice, necessary for valid reliable results. At a minimum, the requirements are as follows:

(Refer to Appendix 1: PCAP Spirometry Operator Checklist)

- ☐ A Spirometer should have a Calibrating syringe. ATS/ERS standards specify that a 3L syringe be used for checking and calibrating a spirometer daily.
- ☐ A simple leak test (to test if there is a leak in the calibration syringe) using a stopper in the calibration syringe should be done monthly by pushing or pulling the syringe (2)
- ☐ Spirometers using pre-calibrated inserts must still be checked daily for accuracy using a 3L calibration syringe. (2)
- ☐ Daily calibration log should be maintained for all equipment requiring calibration;
- ☐ Room temperature, Barometric Pressure and Relative Humidity should be measured, not estimated. If a barometer is unavailable, pressure reported from a nearby weather station can be accessed from the Environment Canada website: http://weather.gc.ca/canada_e.html and must be corrected for altitude: http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html (3)
- ☐ Calibration should be conducted with mouthpiece/filter in-line with the calibration syringe;
- ☐ Monthly normal biological tests (e.g. perform spirometry on a staff member (with no underlying lung condition) on all spirometers in the clinic on a monthly basis for comparison (must be within 150mL of each other)
- ☐ Documentation of repairs or other alterations which return the equipment to acceptable operation; & preventative maintenance, corrective actions;
- ☐ Dates of computer software and hardware updates or changes; and
- ☐ If equipment is changed or relocated (e.g. industrial surveys), calibration checks and quality-control procedures must be repeated before further testing begins.

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Follow manufacturer's manual for complete calibration procedures. While manufacturers are responsible for demonstrating the accuracy and reliability of the systems that they sell, it is the user who is responsible for ensuring that the equipment's measurements remain accurate (1).

2.1.3 Hygiene and Infection Control

Each site is responsible to follow their site specific infection control policy. Each site will establish specific responsibilities and guidelines related to spirometry for their site safety and the prevention of infectious disease transmission. The goal of infection control is to prevent the transmission of infection to patients and staff during spirometry testing. Indirect transmission of aerosol droplets generated by the patient blowing into the pneumotach can be blown into the atmosphere. It is recommended that the operator follow local public health and infectious disease recommendations for testing (e.g., appropriate PPE, hand hygiene, ventilation, etc.). Please note that these recommendations can change to respond to local/regional policies and should be reviewed regularly. For more detailed guidance on resuming spirometry during a pandemic, please refer to our Recommendations for Conducting Spirometry Testing and Nebulized Treatment in the Primary Care Setting during the COVID-19 Pandemic. We recommend that all policies and protocols should be reviewed and approved by your local public health authority.

2.1.4 Performing the Spirometry Test - Who Can Conduct Spirometry?

- ☐ By a trained and qualified personnel in a setting with a regular quality assurance program (e.g. Trained health care professionals who are Registered Respiratory Therapist (RRT) or Registered Cardio-pulmonary Technologist, RCPT(P) or purchase (2)
- ☐ other regulated health care professionals who received formal training which included studies in anatomy and physiology of the cardiorespiratory system and who successfully completed a recognized spirometry training course, and other trained health care technologists who successfully completed a recognized spirometry training course (please refer to section 2.1.8 of this document for training programs) (2).

Reference Values:

Performing the test not only includes attention to the instrumentation, calibration and infection control but also to how the test is performed and attention to the quality of the measurements produced. All measurements are expressed as litres (L) or litres/second (L/s) and as % predicted, with the predicted values being derived from standardized data sets. Predicted values should reflect the patient population of your clinic. The current CTS guidelines recommend the use of Lower Limit of Normal (LLN). The Lower Limit of Normal (LLN) is defined as the 5th percentile (i.e. the value that marks the lower 5th percentile of the normal population). The 5th percentile is considered the threshold below which a value is considered to be abnormal. The Global Lung Function Initiative (GLI) recommends the all-age spirometry values developed by Quanjer et al. be used as reference values (age 3.5 - 90yrs). Most major spirometers have committed to implementing the Quanjer et al. reference values. Another choice of reference equations is the National Health and Nutrition Examination Survey (NHANES III) for Caucasian, African-American and Hispanics between 8-80 years of age. These equations should not be used outside this age range. This set is contained in almost all current spirometry systems. There are no reference equations for the Canadian Aboriginal population and therefore, spirometry tests involving this population should be interpreted with caution using the Caucasian reference values (2). More recently, the Canadian Health Measurement Survey (CHMS) provides reference values for the Canadian Caucasian population from 6 to 79 years of age and guidelines to approximate correction for other ethnic groups (12). Clinics may want to align with labs in their geographical region using the same reference sets understanding that if different reference sets are used only the patient's absolute values can be compared between tests. Predicted values take into account height, age, gender, ethnic origin. Weight is normally recorded for monitoring but is not in the equation for predicted spirometry values. The height should not be estimated but measured using a measuring tape (attached to the wall) with the patient standing without shoes with his/her back flat against the wall with a right angle device making contact with the top of the head and the measuring tape. When height cannot be measured using this method (e.g. chest wall deformities) arm span (middle finger tip to middle finger tip) can be used as an approximate (2).

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- ☐ The spirometer selected must have specific sets of normal reference values, both adult and pediatric, pre-programmed into its software. If it does not, insist that they be installed prior to purchase (2)
- ☐ Reference values must be appropriate for the age and ethnicity of the population and be able to provide the Lower Limit of Normal (LLN) (2). It is recommended that you inquire about a software update to obtain the LLN with your spirometer equipment if not already available.
- ☐ The interpretation of spirometry tests should be based on the LLN (2)

Indications for Spirometry (14):

Diagnosis
<ul style="list-style-type: none"> To evaluate symptoms, signs, or abnormal laboratory results To measure physiologic effect of disease or disorder To screen individuals at risk or having pulmonary disease To assess preoperative risk To assess prognosis
Monitoring
<ul style="list-style-type: none"> To assess response to therapeutic intervention To monitor disease progression To monitor patients for exacerbations or disease and recovery from exacerbations To monitor people for adverse reactions to drugs with known pulmonary toxicity
Disability/impairment evaluations
<ul style="list-style-type: none"> To assess patients as part of a rehabilitation program To assess risks as part of an insurance evaluation To assess individuals for legal reasons
Other
<ul style="list-style-type: none"> Research and clinical trials Epidemiological surveys Derivation of reference equations Pre-employment and lung health monitoring for at-risk occupations To assess health status before beginning at-risk physical activities

Table 1: Terminology and Definitions

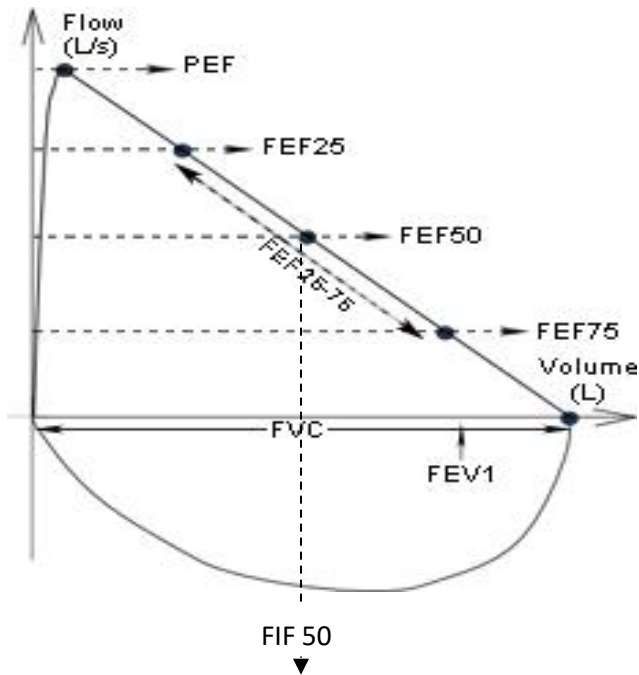
Measurement	Abbreviation	Definition
Forced Vital Capacity (L)	FVC	Maximum volume of air that can be expired as forcefully, quickly and completely as possible following a complete inspiration
Forced Expiratory Volume in 1 second (L/sec)	FEV1	Volume of air expired in the first second of the FVC - Used to assess airflow
Ratio of FEV1 to FVC %	FEV1/FVC	Used for the assessment of airflow obstruction
Peak Expiratory Flow (L/sec)	PEF	The maximum flow rate at the onset of the FVC maneuver – judges max effort
Forced Expiratory Flow 25-75% (L/Sec)	FEF 25-75	The average flow rate during the middle half of the FVC maneuver – reflects airflow

*FEF50/FIF50 = The ratio of flow at 50% of expiration and flow at 50% inspiration (Maximum flow at 50% that can be inspired as forcefully, quickly and completely as possible following a complete exhalation). Recognizing that the inspiratory loop is not always done in primary care, this loop might be useful in evaluating any upper airway obstruction (UAO). FEF50/FIF50 = 1 in fixed UAO, FEF50/FIF50 > 1 in variable extrathoracic UAO and FEF50/FIF50 < 0.3 in variable intrathoracic UAO (13)

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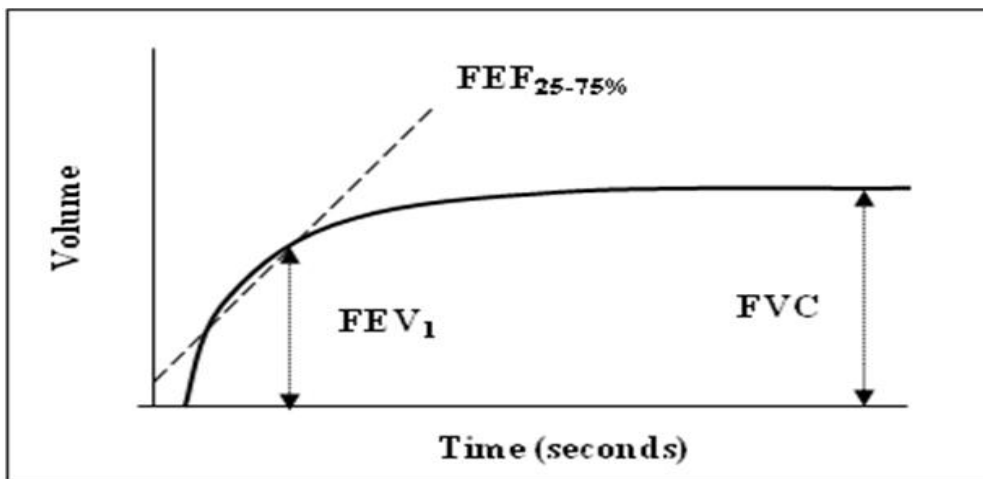
There are two types of graphs that are commonly displayed for Spirometry: the Flow Volume loop and the Volume Time curve. Your spirometer may be formatted to print out both curves.

Figure 1: Flow Volume loop - This is a record of how fast the air flows in/out (Flow) versus the amount (Volume) of air exhaled or inhaled within a certain time (8).



Flow (Y) versus Volume (X)

Figure 2: Volume time curve - This is a record of the expired volume in relation to time (8).



Volume (Y) versus Time (X)

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Table 2: Test Procedures for the Forced Vital Capacity maneuver (Flow-Volume loop) (2,14)

Preparation
<ul style="list-style-type: none">❖ Ensure the spirometer has daily calibration performed❖ Contraindications should be listed on the spirometry order requisition form or checklist form❖ Activities that should preferably be avoided prior to lung function testing<ul style="list-style-type: none"><input type="checkbox"/> Smoking and/or vaping and/or water pipe use within at least 1 h of testing (to avoid acute bronchoconstriction due to smoke inhalation)<input type="checkbox"/> Consuming intoxicants within 8 h of testing (to avoid problems in coordination, comprehension and physical ability)<input type="checkbox"/> Performing vigorous exercise within 1h of testing (to avoid potential exercise-induced bronchoconstriction)<input type="checkbox"/> Wearing clothing that substantially restricts full chest and abdominal expansion (to avoid external restrictions on lung function)<input type="checkbox"/> Eating a large meal within 2 h of testing<input type="checkbox"/> Inhaler Medication (Refer to Medication Section: Post Bronchodilator Testing to withhold prior to spirometry testing)❖ Wash hands (or use an approved hand sanitizer)❖ Prepare the patient<ul style="list-style-type: none"><input type="checkbox"/> Dispense hand sanitizer for patient<input type="checkbox"/> Confirm patient identification, age, birth sex, ethnicity, etc.<input type="checkbox"/> Measure weight and height without shoes<input type="checkbox"/> Ask the patient about:<ul style="list-style-type: none">○ Smoking/vaping○ Recent illness○ Inhaler/ medication use❖ Instruct and demonstrate the test to the subject<ul style="list-style-type: none"><input type="checkbox"/> Position the mouthpiece and nose clip<input type="checkbox"/> correct posture and head slightly elevated<input type="checkbox"/> Inspire rapidly until completely full<input type="checkbox"/> Expire with maximal effort until completely empty<input type="checkbox"/> Inspire with maximal effort until completely full<input type="checkbox"/> Confirm that the patient understands the instructions and is willing to comply
Test Performance
<ul style="list-style-type: none">❖ Perform maneuver<ul style="list-style-type: none"><input type="checkbox"/> Have subject assume the correct seated posture (a chair without wheels, feet flat on the ground)<input type="checkbox"/> Attach nose clip*, place mouthpiece in mouth and close lips around the mouthpiece, perform 2-4 tidal breaths<input type="checkbox"/> Inhale completely and rapidly with a pause of ≤ 2 s at TLC<input type="checkbox"/> Exhale forcefully and rapidly until no more air can be expelled while maintaining upright posture<input type="checkbox"/> Repeat instructions as necessary<input type="checkbox"/> Repeat for a minimum of three maneuver, usually no more than eight for adults<input type="checkbox"/> Check FEV1 and FVC repeatability and perform more maneuvers as necessary

*Recommendation is to use Nose Clips or manual occlusion of the nares, to avoid leaks, especially for nose breathers. People must mouth breathe during the procedure

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Post Bronchodilator Spirometry/Flow-volume loop (for bronchodilator responsiveness testing):

Spirometry testing and the administration of bronchodilators, requires a signed requisition from the Physician or a verbal or standing order as per site specific Medical Directives and provincial regulations that should indicate whether post bronchodilator testing is requested, and which bronchodilator is to be administered for the testing and how much bronchodilator should be given for testing.

Medication to withhold prior to spirometry testing

The decision to avoid bronchodilators before testing is dependent on the reason for the test. If post bronchodilator testing is to be performed to diagnose an underlying lung condition, the patient may/should withhold the following medication prior to spirometry testing:

Note: It is important to tell the patient that if they need to use their rescue inhaler for symptoms, they can do so and not withhold it for the test.

Inhaled bronchodilators (14)

Medication	Withholding time prior to Spirometry Testing
Short-Acting Beta2 Agonist (SABA) e.g., albuterol or salbutamol	4 - 6 Hours
Short-Acting Muscarinic Antagonist (SAMA) e.g., ipratropium bromide	12 Hours
Long-Acting Beta2 Agonist (LABA) e.g., formoterol or salmeterol	24 hours
Ultra-long acting beta2 agonist (ultra-LABA) e.g., indacaterol, vilanterol or olodaterol	36 hours
Long-Acting Muscarinic Antagonist (LAMA) e.g., tiotropium, umeclidinium, aclidinium or glycopyrronium	36-48 hours

- Other medications to withhold: Theophylline: 48 hours (7), LTRA 24 hours (2)
- Antihistamines and steroids (oral and inhaled) do not need to be withheld

Note: if the test is to determine the response to a medication, then the referring physician may choose not to withhold the medication prior to testing. The spirometry requisition order form should indicate whether to withhold a medication before testing and specify which medication to withhold

To standardize bronchodilator reversibility testing:

- ☐ Short Acting Beta Adrenergic (SABD) medications are the most commonly used bronchodilator, other drugs can be used (e.g. Short-Acting Muscarinic Antagonist (SAMA) such as Ipratropium Bromide)
 - If patients do not tolerate the use of salbutamol or have a history of allergic reaction, can use SAMA
- ☐ After the pre-bronchodilator test, administer SABA –
 - 4 separate doses* of 100mcg each, Total of 400 mcg salbutamol, or
 - 8 separate doses (puffs)* of 20mcg each, Total of 160mcg of Ipratropium Bromide
 - *Inhale separate doses from a valved holding chamber device 30 seconds apart (7)
- ☐ Perform post-bronchodilator testing 15 minutes post for SABA and 30 minutes post for SAMA

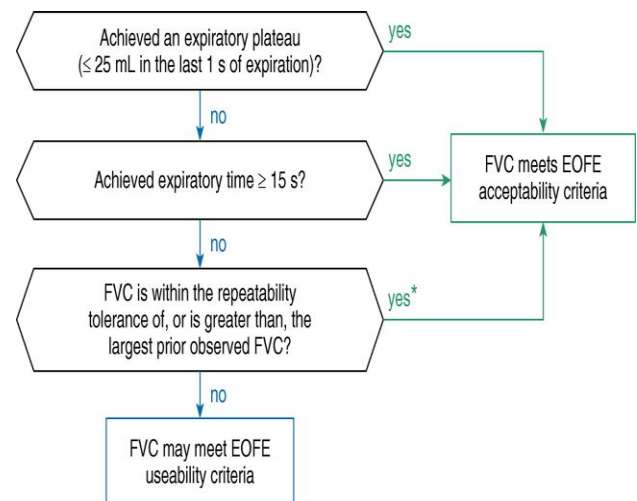
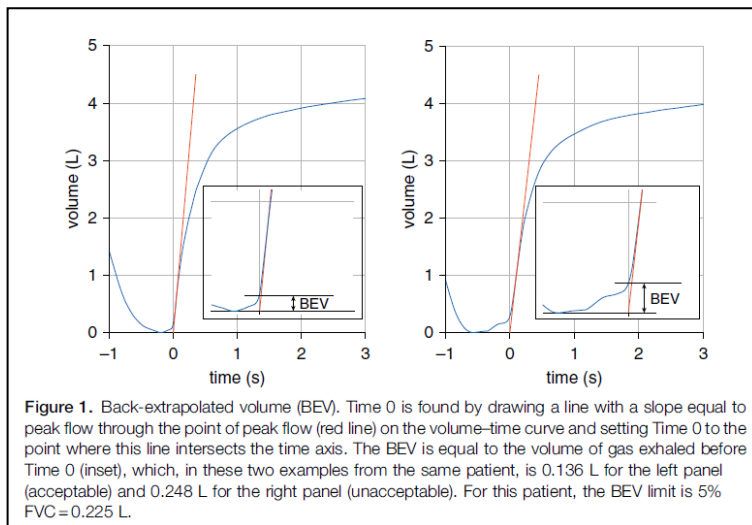
Note: ATS does not currently specify any recommendations for the pediatric population.

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2.1.5 Acceptability and Repeatability Test Criteria (14)

Acceptability criteria:

- ☐ Previously, the term “end of test (EOT) criteria” was used to denote the end of forced expiration. Now the standards stress the importance of maximal inspiration following the forced expiration. Therefore, EOT criteria terminology has changed to End of Forced Expiration (EOFE)
- ☐ There is no longer a minimum expiratory time (previously 6 seconds was the threshold for adults)
 - ☐ Must have BEV $\leq 5\%$ of FVC or 100mL, whichever is greater
 - ☐ Must have no evidence of a faulty zero-flow setting
 - ☐ Must have no cough in the first second of expiration*
 - ☐ Must have no glottis closure within the first sec of expiration*
 - ☐ Must have no glottis closure after 1 sec of expiration
 - ☐ Must achieve one of these three EOFE indicators;
 1. Expiratory plateau ($\leq 0.025\text{L}$ in the last 1 sec of expiration)
 2. Expiratory time ≥ 15 sec
 3. FVC within repeatability tolerance of or is greater than the largest prior observed FVC
 - ☐ Must have no evidence of obstructed mouthpiece or spirometer
 - ☐ Must have no evidence of a leak
 - ☐ If the maximal inspiration after EOFE is greater than FVC, then FIVC – FVC must be $\leq 100\text{mL}$ or 5% of FVC, whichever is greater



*For children <6 years of age, must have at least 0.75 sec of expiration without glottis closure or cough

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Repeatability:

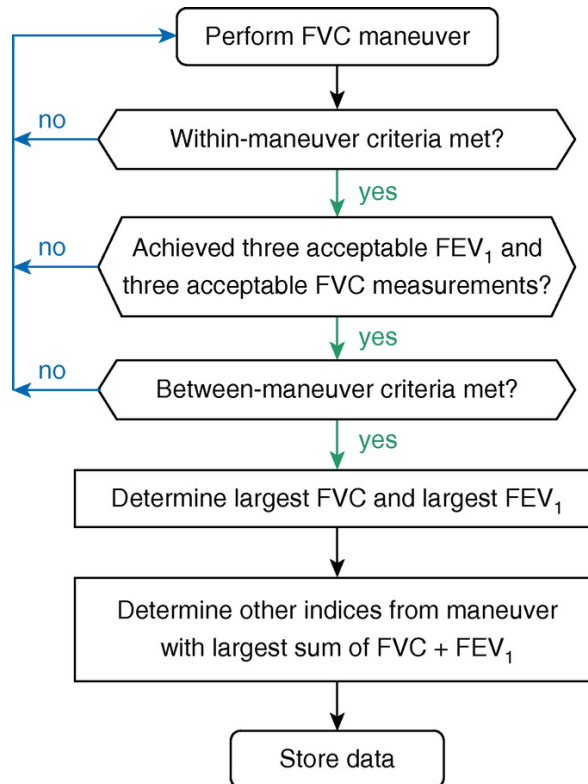
Age >6 years

- The difference between the two largest FVC values must be $\leq 150\text{mL}$, and the difference between the two largest FEV₁ values must be $\leq 150\text{mL}$

Age ≤ 6 years

- The difference between the two largest FVC values must be $\leq 100\text{mL}$ or 10% of the highest value, whichever is greater, and the difference between the two largest FEV₁ values must be $\leq 100\text{mL}$ or 10% of the highest value, whichever is greater

Figure 3: Flow chart on application of Acceptability & Repeatability criteria (14)



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2.1.6 Reporting Results (3)

- ☐ When considering a spirometer, consider whether it is compatible with your Electronic Medical Record (EMR)
- ☐ Flow and volume measures are reported at body temperature and pressure saturated with water vapor (BTPS)
- ☐ The largest FVC and FEV1 from acceptable maneuvers is reported, even though the values may not come from the same maneuver
- ☐ Largest PEF is reported
- ☐ All other flows i.e. FEF25-75% are reported from the “best curve” (defined as the maneuver with the largest sum of FVC and FEV1)
- ☐ Final reports should include the technologist’s comments regarding the patient performance, recent use of bronchodilators, quality of testing and whether or not the results were acceptable and reproducible (e.g. Patient had good effort, results reproducible, unable to perform reproducible curves, unable to attain residual volume, etc.)

Note: Please refer to Appendix A in this spirometry manual for what a sample report (2) should look like.

Who Can Interpret Spirometry?

- ☐ Primary Care physicians and Nurse Practitioners who interpret spirometry should have completed a spirometry interpretation course or specific training in spirometry interpretation (2). Please refer to Page 11 of this policy and procedure for recommended courses.

2.1.7 Technical Support (2):

- ☐ A spirometer must be sufficiently robust to be unaffected by drops or bumps. If a spirometer is dropped, a calibration check is recommended before continuing testing
- ☐ Ensure the vendor who provided you with the spirometer provide sufficient training initially in the use of a spirometer. They should also be able to provide technical support for addressing problems with the operation of the spirometer. If your spirometer needs to be checked, request a loaner device. There should be regular notification of any software upgrades and the spirometer should be thoroughly checked on a regular basis for any upgrades.

2.1.8 Training Recommendations for Performing Spirometry

Purpose:

This policy will provide guidelines on the minimum criteria and core components of training based on the ATS/ERS/CPSO guidelines for personnel with regards to performing spirometry.

Policy:

The following minimum criteria are recommended by ATS/ERS to establish competency in spirometry testing:

- ☐ Knowledge of theory and practical aspect of applied techniques, measurements, calibrations, hygiene, quality control, basic background in lung physiology and pathology;
- ☐ Introduction to the standards of spirometry, review of spirometry role in the diagnosis, management of asthma and assess contraindications;
- ☐ Test performance: Proper technique for performing spirometry including how to coach for best results (practical workshop or hands on training);
- ☐ Discuss predicted values and actual/absolute values;
- ☐ Review reporting process.

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Spirometry training can be attained through an accredited Institution. Recommended institutions:

Certification in conducting spirometry:

- ☐ “SpiroTrec” (Lung Association of Saskatchewan National program: <http://www.resptrec.org/>)

Additional Supports:

- ☐ The Lung Health Foundation Spirometry Interpretation workshop and e-modules
Workshops: <https://hcp.lunghealth.ca/workshops/>
e-modules: <https://hcp.lunghealth.ca/e-modules/>
- ☐ Job shadowing with a local/regional expert can enhance practical training objectives. This can be available but limited according to resources. Please contact PCAP Provincial Coordinator for more information <https://hcp.lunghealth.ca/clinical-programs/>

***Please Note:**

Permission and proper acknowledgement is required in any modification of the PCAP tools as per the PCAP process

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APPENDIX 1: PCAP SPIROMETRY OPERATOR CHECKLIST (Page 1)

<input type="checkbox"/> Barometric Pressure, Relative Humidity and Temperature updated daily
<input type="checkbox"/> Daily calibration performed according to manufacturer's and ATS/ERS Standards
<input type="checkbox"/> Relative Contraindications (Refer to the list on the reverse side of this page)
<input type="checkbox"/> Minimum of three acceptable FVC performed, with two repeatable maneuvers, maximum eight performed (ATS/ERS 2005)
<input type="checkbox"/> Assess Patient Performance: (Acceptability) <ul style="list-style-type: none">○ Maximum peak effort○ Must have BEV $\leq 5\%$ of FVC or 100mL, whichever is greater○ Must have no evidence of a faulty zero-flow setting○ Must have no cough in the first second of expiration*○ Must have no glottis closure within 1 sec of expiration*○ Must have no glottis closure after 1 sec of expiration○ Must achieve one of these three EOFE indicators;○ Expiratory plateau ($\leq 0.025L$ in the last 1 sec of expiration)○ Expiratory time ≥ 15 sec○ FVC within repeatability tolerance of or is greater than the largest prior observed FVC○ Must have no evidence of obstructed mouthpiece or spirometer○ Must have no evidence of a leak○ If the maximal inspiration after EOFE is greater than FVC, then FIVC – FVC must be $\leq 100mL$ or 5% of FVC, whichever is greater
<input type="checkbox"/> Assess Measurements: (Repeatability) <ul style="list-style-type: none">Age > 6 years<ul style="list-style-type: none">○ The difference between the two largest FVC values must be $\leq 150mL$, and the difference between the two largest FEV1 values must be $\leq 150mL$Age ≤ 6 years<ul style="list-style-type: none">○ The difference between the two largest FVC values must be $\leq 100mL$ or 10% of the highest value, whichever is greater, and the difference between the two largest FEV1 values must be $\leq 100mL$ or 10% of the highest value, whichever is greater
<input type="checkbox"/> Technical comments recorded on spirometry report

Primary Care Asthma Program **SPIROMETRY MANUAL**

APPENDIX 1: PCAP SPIROMETRY OPERATOR CHECKLIST (Page 2)

Relative Contraindications for Spirometry (14)*

Due to increases in myocardial demand or changes in blood pressure
<ul style="list-style-type: none">• Acute myocardial infarction within 1 week• Systemic hypotension or severe hypertension• Significant atrial/ventricular arrhythmia• Noncompensated heart failure• Uncontrolled pulmonary hypertension• Acute cor pulmonale• Clinically unstable pulmonary embolism• History of syncope related to forced expiration/cough
Due to increases in intracranial/intraocular pressure
<ul style="list-style-type: none">• Cerebral aneurysm• Brain surgery within 4 weeks• Recent concussion with continuing symptoms• Eye surgery within 1 week
Due to increases in sinus and middle ear pressures
<ul style="list-style-type: none">• Sinus surgery or middle ear surgery or infection within 1 week
Due to increases in intrathoracic and intraabdominal pressure
<ul style="list-style-type: none">• Presence of pneumothorax• Thoracic surgery within 4 weeks• Abdominal surgery within 4 weeks• Late-term pregnancy
Infection control issues
<ul style="list-style-type: none">• Active or suspected transmissible respiratory or systemic infection, including tuberculosis• Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding

*It is recommended that the decision to conduct spirometry testing should be made on a case by case basis in consultation with the primary care provider

Please note:

Permission & Proper acknowledgement is required in any modification of the PCAP Tools as per PCAP process.

Primary Care Asthma Program **SPIROMETRY MANUAL**

References

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<http://www.thoracic.org/statements/>
2. Coates AL et al. Spirometry in Primary Care. Can Respir J 2013; 20(1): 13-20.
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http://www.publichealthontario.ca/en/eRepository/IPAC_Clinical_Office_Practice_2013.pdf
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10. NIOSH, ***Spirometry Training Guide 2003*** <http://www.cdc.gov/niosh/docs/2004-154c/>
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14. American Thoracic Society: *Standardization of Spirometry 2019 Update*. Am J Respir Crit Care Med Vol 200, Iss 8, pp e70-e88, Oct 15, 2019

[NAME OF PRIMARY CARE SITE]
Medical Directive: Administration of Salbutamol Sulfate
Beta-2 Agonist during the Spirometry Pre and Post
Testing Procedure

Approval Date: _____

Review Date: _____

Background Information

The Primary Care Asthma Program (PCAP) is an evidence-based asthma and COPD program intended to provide primary care providers with decision aids to support best practice regarding asthma and COPD assessment, diagnosis and management.

Spirometry is part of PCAP offered at [site name]. Although it is not a controlled act, it is practice to include spirometry within the directive of administering an inhaled substance during the post testing spirometry procedure.

Spirometry, when indicated for the diagnosis and monitoring of respiratory conditions, requires the administration of a beta-2 agonist bronchodilator, followed by post spirometry testing. This post testing is performed both on initial visits to assist with confirming a diagnosis and also during follow up visits to assist in monitoring the clients respiratory status. If the client does not tolerate the use of salbutamol, ipratropium bromide can be used for post-bronchodilator testing. It is recommended that 8 puffs of ipratropium bromide 20 mcg be given for a total of 160 mcg.

Setting where medical directive to be Implemented:

In house spirometry testing at _____ [site name].

Professional Staff covered by the Directive: Authorized staff that have been observed and trained to perform spirometry according to American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines under _____ [site name] quality assurance and quality control policies for spirometry testing and that the undersigned presently holds the designation and college certification in good standing as within their respective regulated health colleges.

Indications:

To perform pre and post-spirometry testing which involves administration of a beta-2 agonist to primary care clients during the initial and follow-up visits with the PCAP program to determine whether there is any reversible lung function and to monitor respiratory status.

Contraindications:

Relative Contraindications for administering salbutamol sulfate beta-2 agonist:

- Hypersensitivity to any component of the medication being administered
- History of any adverse effects to the medication being administered

Relative Contraindications for spirometry:

Due to increases in myocardial demand or changes in blood pressure
<ul style="list-style-type: none">• Acute myocardial infarction within 1 week• Systemic hypotension or severe hypertension• Significant atrial/ventricular arrhythmia• Non-compensated heart failure• Uncontrolled pulmonary hypertension• Acute cor pulmonale• Clinically unstable pulmonary embolism• History of syncope related to forced expiration/cough
Due to increases in intracranial/intraocular pressure
<ul style="list-style-type: none">• Cerebral aneurysm• Brain surgery within 4 weeks• Recent concussion with continuing symptoms• Eye surgery within 1 week
Due to increases in sinus and middle ear pressures
<ul style="list-style-type: none">• Sinus surgery or middle ear surgery or infection within 1 week
Due to increases in intrathoracic and intraabdominal pressure
<ul style="list-style-type: none">• Presence of pneumothorax• Thoracic surgery within 4 weeks• Abdominal surgery within 4 weeks• Late-term pregnancy
Infection control issues
<ul style="list-style-type: none">• Active or suspected transmissible respiratory or systemic infection, including tuberculosis• Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding

Clinical Criteria:

1. The client must be rostered with [site name] with a documented referral for pre/post spirometry. A physician or NP must be on site during the conducting of a spirometry test in case of a medical emergency arising from the test.
2. Informed verbal consent for the test is obtained from the client or the legal guardian.
3. A list of medication to be put on hold prior to testing is provided to the patient in advance of testing
4. No contraindication for testing.

Process:

1. Review chart to confirm spirometry order
2. Explain the purpose of spirometry, how the test will be performed, contraindications, and obtain client's consent.
3. Inform client of the following potential side effects of the beta-2 agonist that will be administered:
 - a. Increased heart rate (palpitations)
 - b. Tremors of extremities lasting approximately 30 minutes
 - c. Headaches
4. If the client has an allergy to salbutamol sulfate or refuses to take salbutamol sulfate then the PCAP staff must stop the procedure and refer back to the primary care provider for an alternative bronchodilator.
5. Perform spirometry correctly as per the latest ATS/ERS/CTS guidelines
6. If any of the above side effects are noted, stop any further administration of the beta-2 agonist and do not perform post spirometry testing. Document the side effects in the EMR and notify the client's primary care provider.
7. Administer salbutamol sulfate HFA (100mcg) via metered dose inhaler and spacer:
 - a. Adult: 4 puffs
 - b. Pediatric: >6 years: 4 puffs

Documentation and Communication

The performance of spirometry by the PCAP educators through this medical directive will be documented in the EMR in accordance with the College of "_____" of Ontario Documentation Standards. The PCAP educator will ensure the following is documented in the EMR:

1. Verbal consent was obtained from the client or legal guardian
2. Side effects of the beta-2 agonist were reviewed with the client or legal guardian.
3. The number of doses given to client of the beta-2 agonist, the method of delivery and if the medication was delivered properly to the client.
4. Document in the EMR, any side effects the client may have experienced, if the test was stopped and that the primary care provider was notified.

Review and Quality Monitoring

1. All delegators and implementers will maintain their professional competence with their regulatory college.
2. All delegators and implementers will participate in educational opportunities to maintain/update their knowledge on any new beta-2 medications and the skill of delivering these medications.
3. All delegators and implementers will participate in peer evaluations and chart audit practices.
4. All delegators and implementers will document the performance and results of all spirometry that they have performed and will document any client concerns in the EMR.
5. All delegators and implementers agree to consult with and communicate any significant changes in the client's condition with the client's primary care provider as soon as possible.

Signatures:

The physician(s) and nurse practitioners indicated below delegate the order to perform pre and post spirometry and administer beta-2 agonist to the PCAP educator who is working at [site name] when all conditions are met.

Physician/NP authorizing delegation for _____ [Site name] :

Date: _____

Executive Director:

Date: _____

List of Authorized Staff for the Medical Directive Ordering and performing pre/post bronchodilator Spirometry Testing

Name	Date Certified	Review Date

References:

1. Coates AL et al. Spirometry in Primary Care. Can Respir J 2013; 20(1): 13-20.
2. American Thoracic Society: Standardization of Spirometry 2019 Update. Am J Respir Crit Care Med Vol 200, Iss 8, pp e70-e88, Oct 15, 2019

Sample Spirometry Requisition Form

Requisition for Spirometry Primary Care Clinic 123 Main St Anytown, Prov Z1Z 1Z1 Tel (987) 321-6540 Fax (987) 321-1234	Patient Name: _____ Patient ID#: _____ Referring Primary Care provider: _____ Primary care Provider Signature: _____ Date: _____ Tel: _____
---	--

Reason for Test

<input type="checkbox"/> Diagnosis _____ <input type="checkbox"/> Follow-up _____ <input type="checkbox"/> Other _____
Previous Test at this clinic? Yes <input type="checkbox"/> No <input type="checkbox"/>

Clinical Diagnosis: _____

 Smoking History: Current smoker ☐ Former smoker ☐ Never smoker ☐
 No. of pack years: _____
Spirometry requested

<input type="checkbox"/> Pre-bronchodilator	<input type="checkbox"/> Post-bronchodilator (400mcg salbutamol)
---	--

Relative Contraindications:

<input type="checkbox"/> Acute myocardial infarction within 1 week <input type="checkbox"/> Systemic hypotension or severe hypertension <input type="checkbox"/> Significant atrial/ventricular arrhythmia <input type="checkbox"/> Non-compensated heart failure <input type="checkbox"/> Uncontrolled pulmonary hypertension <input type="checkbox"/> Acute cor pulmonale <input type="checkbox"/> Clinically unstable pulmonary embolism <input type="checkbox"/> History of syncope related to forced expiration/cough <input type="checkbox"/> Cerebral aneurysm <input type="checkbox"/> Brain surgery within 4 weeks	<input type="checkbox"/> Recent concussion with continuing symptoms <input type="checkbox"/> Eye surgery within 1 week <input type="checkbox"/> Sinus surgery or middle ear surgery or infection within 1 week <input type="checkbox"/> Presence of pneumothorax <input type="checkbox"/> Thoracic surgery within 4 weeks <input type="checkbox"/> Abdominal surgery within 4 weeks <input type="checkbox"/> Late-term pregnancy <input type="checkbox"/> Active or suspected transmissible respiratory or systemic infection, including tuberculosis <input type="checkbox"/> Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding
--	---

Respiratory Medications: _____

Appointment Date: _____ Time: _____

Instructions to Provide to the Patient:

Depending on the reason for doing the test, the patient should be instructed whether or not medications are to be withheld prior to testing, and if so, precisely which medications be withheld and for how long. It is important to instruct any patient withholding medications that, if needed for symptom relief, a rescue inhaler should be used and the time of use noted so that it can be reported to the technologist conducting the test. Follow local public health guidelines regarding infection control policies and follow the instructions provided by the spirometry clinic prior to test.

Withhold medications? Yes ☐ No ☐

List medications to withhold:

Short-Acting Beta2 Agonist (SABA) e.g., albuterol or salbutamol	4 - 6 Hours
Short-Acting Muscarinic Antagonist (SAMA) e.g., ipratropium bromide	12 Hours
Long-Acting Beta2 Agonist (LABA) e.g., formoterol or salmeterol	24 hours
Ultra-long acting beta2 agonist (ultra-LABA) e.g., indacaterol, vilanterol or olodaterol	36 hours
Long-Acting Muscarinic Antagonist (LAMA) e.g., tiotropium, umeclidinium, aclidinium or glycopyrronium	36-48 hours

The patient should be instructed to avoid the following prior to testing:

- Smoking and/or vaping and/or water pipe use within at least 1 h of testing (to avoid acute bronchoconstriction due to smoke inhalation)
- Consuming intoxicants within 8 h of testing
- Performing vigorous exercise within 1h of testing
- Wearing clothing that substantially restricts full chest and abdominal expansion
- Eating a large meal within 2 h of testing

APPENDIX B: Sample spirometry report form

Family Physicians Clinic

123 Main St

Anytown, Prov, Z1Z 1Z1

987-321-6540

Age: **62 yr** **Male**

Ht: **186 cm** Race: **Caucasian**

Wt: **84 kg** BMI: **24.3 kg/m²**

Nonsmoker - pack-yr: **0**

Reason for test: **Chronic cough**

Name: **XXXXXXXX, XXXX**

ID#: **333222111**

Date of birth: **1949-Dec-31**

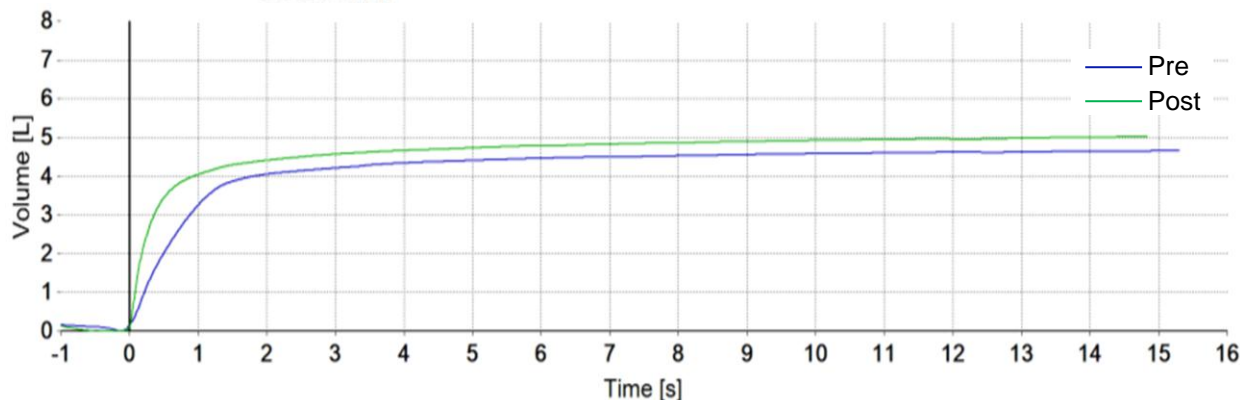
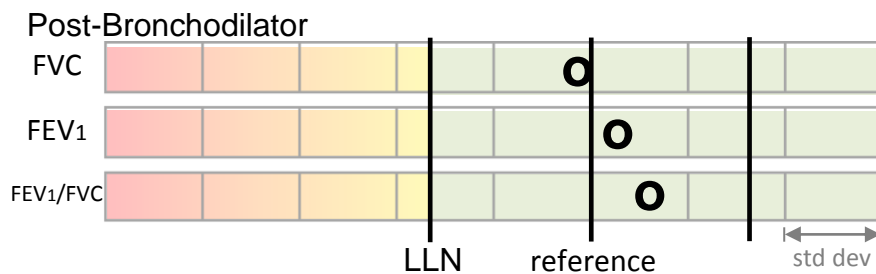
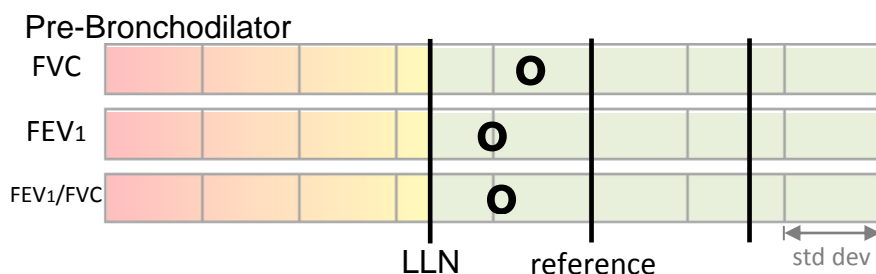
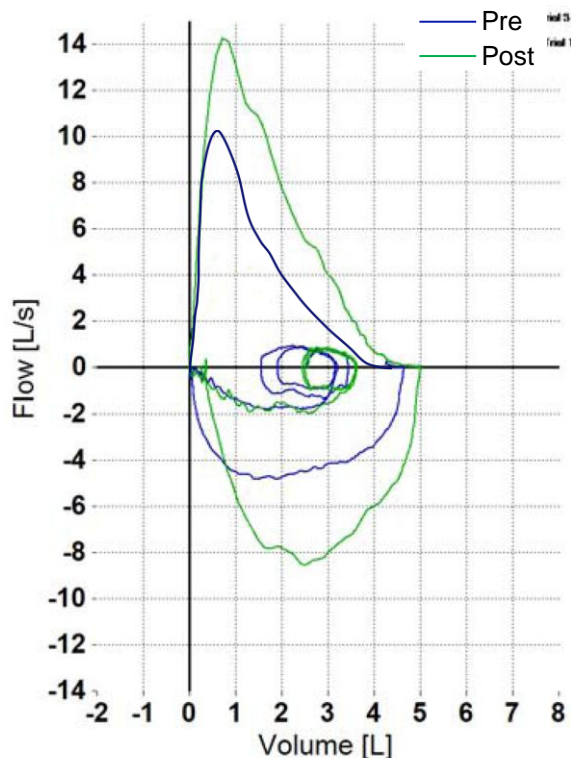
Date of test: **14:20, 2012-Jan-02**

Spirometry	Pre-Bronchodilator			Post-Bronchodilator			
	Best	LLN	%Ref	Best	%Ref	Change	%Chg
FVC (L)	4.65	3.86	91%	5.01	94%	360 mL	8%
FEV ₁ (L)	3.26	2.91	84%	4.04	100%	780 mL	24%
FEV ₁ /FVC	0.70	0.64		0.81			
PEF (L/s)	10.2			14.3			
FET (s)	15.3			14.8			
Test quality	B			A			
Reference values: Quanjer 2012 [Caucasian]							

Technologist comments:

3 acceptable blows with 2 repeatable for both Pre- and Post- tests.

No bronchodilators taken in previous 24 hrs.

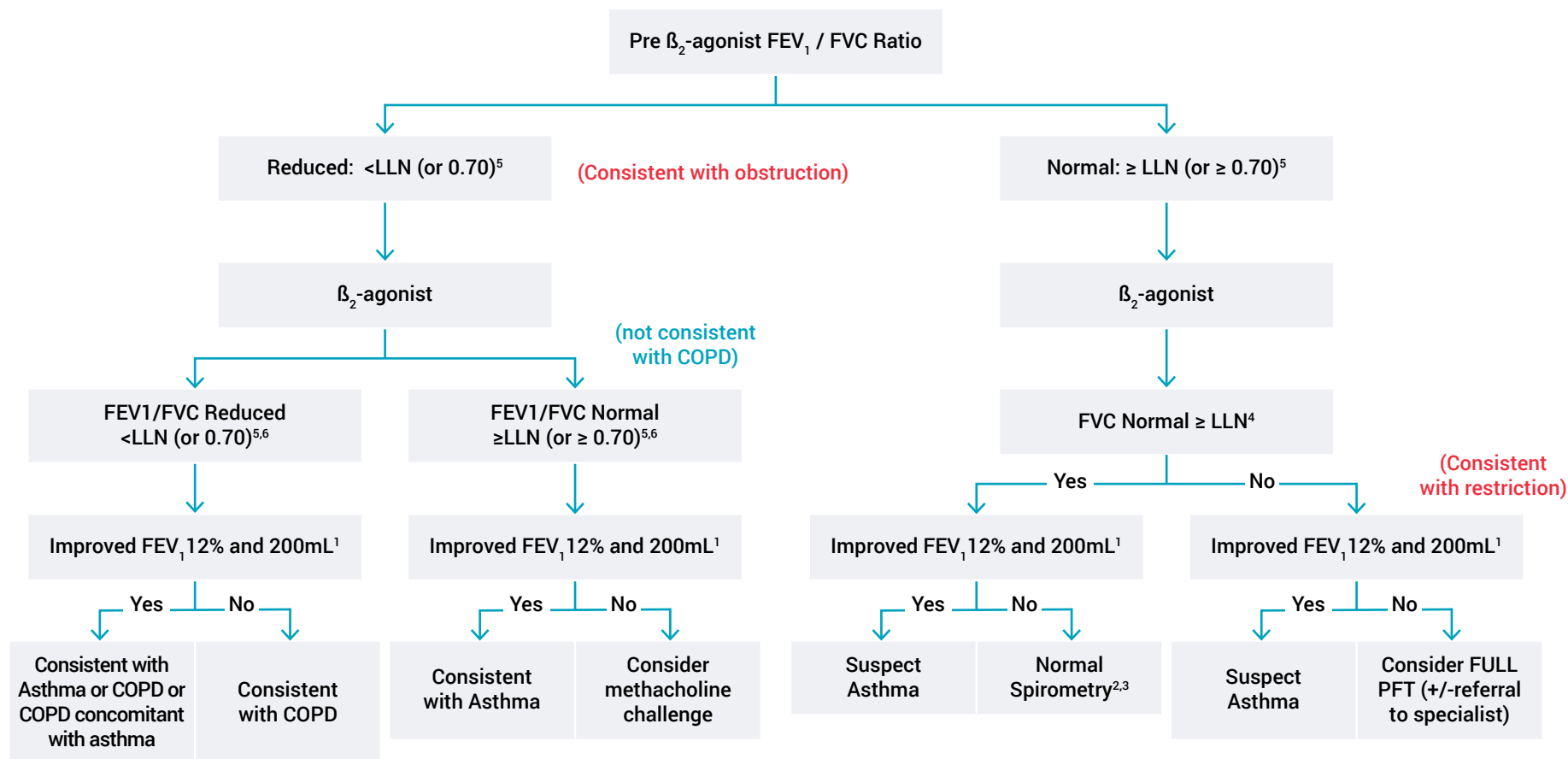


Interpretation: Pre-bronchodilator spirometry is in the normal range. There is a significant response to bronchodilators.

Section 3: Spirometry Practicum

Spirometry Interpretation Guide

Consider patient history and full clinical assessment in all decision making



- 200mL criteria only necessary for adults (18 yrs of age and over)
- Reversibility criteria not met. May occur with chronic asthma -consider methacholine challenge or referral
- Normal Spirometry: in the context of persistent symptoms consider further clinical testing i.e. methacholine challenge
- LLN may not be available on outdated systems –use 80% predicted
- Evidence supports the use of the fixed ratio (0.70) vs. LLN as more appropriate to identify individuals at risk for clinically significant COPD. However, the use of the fixed ratio may underestimate the presence of airflow obstruction in younger individuals and overestimate in older populations.
- If FVC < LLN (or < 80%) predicted, consider hyperinflation/gas trapping. If post-BD FVC remains < LLN (or < 80%) predicted, consider combined obstructive and restrictive defect and full PFT.

Note: Recommended reference equations: GLI-Global

Adapted and revised with permission from Primary Care Respiratory Alliance of Canada (PCRAC)

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Ontario Lung Association is a registered charity operating as the Lung Health Foundation
<http://lunghealth.ca/clinical-tools>

Primary Care Asthma Program Spirometry Operator's Checklist

PCAP SPIROMETRY OPERATOR CHECKLIST (Page 1)

<input type="checkbox"/> Barometric Pressure, Relative Humidity and Temperature updated daily
<input type="checkbox"/> Daily calibration performed according to manufacturer's and ATS/ERS Standards
<input type="checkbox"/> Relative Contraindications (Refer to the list on the reverse side of this page)
<input type="checkbox"/> Minimum of three acceptable FVC performed, with two repeatable maneuvers, maximum eight performed (ATS/ERS 2005)
<input type="checkbox"/> Assess Patient Performance: (Acceptability) <ul style="list-style-type: none">○ Maximum peak effort○ Must have BEV $\leq 5\%$ of FVC or 100mL, whichever is greater○ Must have no evidence of a faulty zero-flow setting○ Must have no cough in the first second of expiration*○ Must have no glottis closure within 1 sec of expiration*○ Must have no glottis closure after 1 sec of expiration○ Must achieve one of these three EOFE indicators;○ Expiratory plateau ($\leq 0.025L$ in the last 1 sec of expiration)○ Expiratory time ≥ 15 sec○ FVC within repeatability tolerance of or is greater than the largest prior observed FVC○ Must have no evidence of obstructed mouthpiece or spirometer○ Must have no evidence of a leak○ If the maximal inspiration after EOFE is greater than FVC, then FIVC – FVC must be $\leq 100mL$ or 5% of FVC, whichever is greater
<input type="checkbox"/> Assess Measurements: (Repeatability) <ul style="list-style-type: none">Age >6 years<ul style="list-style-type: none">○ The difference between the two largest FVC values must be $\leq 150mL$, and the difference between the two largest FEV1 values must be $\leq 150mL$Age ≤ 6 years<ul style="list-style-type: none">○ The difference between the two largest FVC values must be $\leq 100mL$ or 10% of the highest value, whichever is greater, and the difference between the two largest FEV1 values must be $\leq 100mL$ or 10% of the highest value, whichever is greater
<input type="checkbox"/> Technical comments recorded on spirometry report

Primary Care Asthma Program Spirometry Operator's Checklist

PCAP SPIROMETRY OPERATOR CHECKLIST (Page 2)

Relative Contraindications for Spirometry*

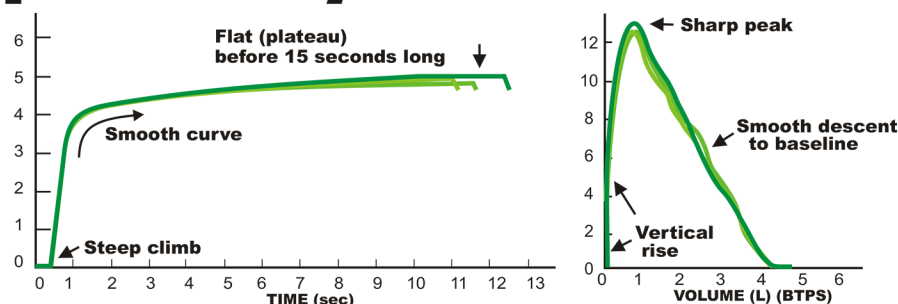
Due to increases in myocardial demand or changes in blood pressure
<ul style="list-style-type: none">• Acute myocardial infarction within 1 week• Systemic hypotension or severe hypertension• Significant atrial/ventricular arrhythmia• Noncompensated heart failure• Uncontrolled pulmonary hypertension• Acute cor pulmonale• Clinically unstable pulmonary embolism• History of syncope related to forced expiration/cough
Due to increases in intracranial/intraocular pressure
<ul style="list-style-type: none">• Cerebral aneurysm• Brain surgery within 4 weeks• Recent concussion with continuing symptoms• Eye surgery within 1 week
Due to increases in sinus and middle ear pressures
<ul style="list-style-type: none">• Sinus surgery or middle ear surgery or infection within 1 week
Due to increases in intrathoracic and intraabdominal pressure
<ul style="list-style-type: none">• Presence of pneumothorax• Thoracic surgery within 4 weeks• Abdominal surgery within 4 weeks• Late-term pregnancy
Infection control issues
<ul style="list-style-type: none">• Active or suspected transmissible respiratory or systemic infection, including tuberculosis• Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding

*It is recommended that the decision to conduct spirometry testing should be made on a case by case basis in consultation with the primary care provider

Get Valid Spirometry Results EVERY Time

**A Valid Test has:
3 or More Good Curves
and Repeatable FVC and FEV1 ***

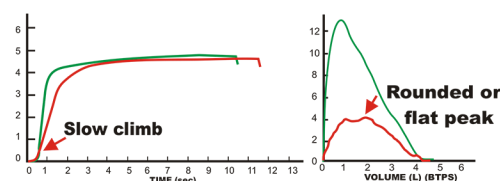
*Use most current American Thoracic Society/
European Respiratory Society (ATS/ERS) standards



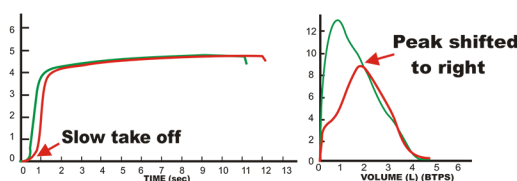
KEY
Green = Good Curve
Red = Error

HOW TO CORRECT TEST ERRORS

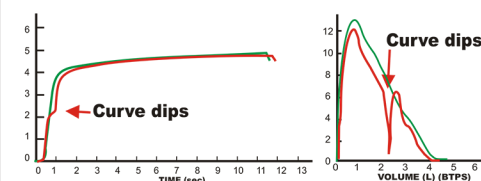
Poor Initial Blast
Coach: Blast air out HARDER



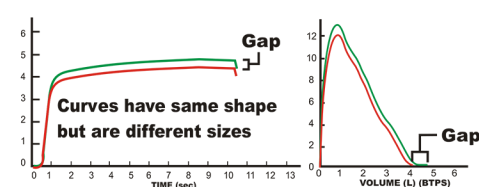
Hesitation; Slow Start; Large Extrapolated Volume
Delete Curve; Coach: Blast FASTER



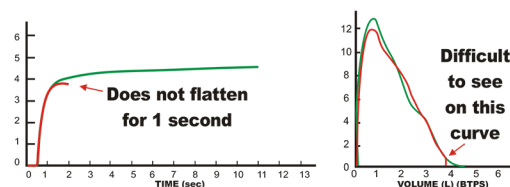
Cough in First Second
Delete Curve; Correction: Try a drink of water



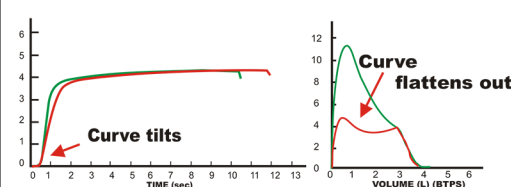
Incomplete Inhalation
Coach: Take a DEEPER breath



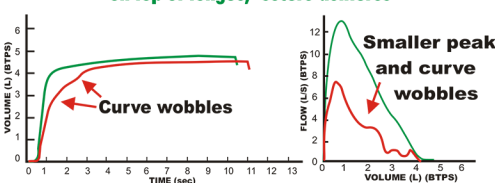
No Plateau Before 15 Seconds
Coach: Keep blowing until told to stop



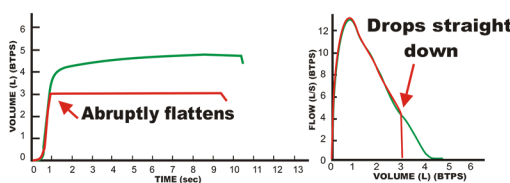
Inconsistent Effort
Coach: One continuous blast and keep blowing



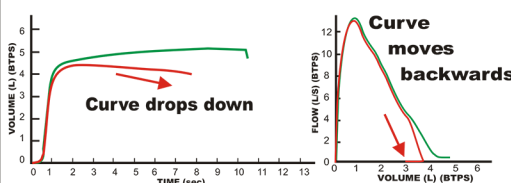
Partially Blocked Mouthpiece
Coach: Position mouthpiece between teeth and on top of tongue; secure dentures



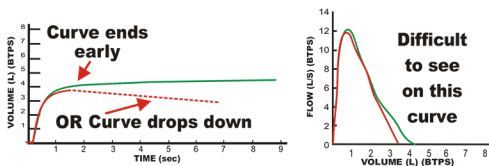
Glottis Closure or Breath Holding
Coach: Initial BIG BLAST then RELAX and keep blowing



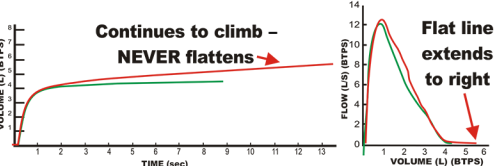
Leak
Correction: Check equipment and connections



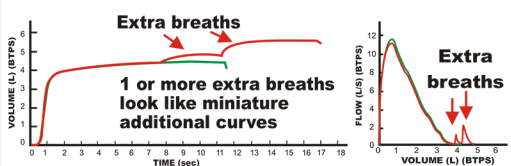
Negative Zero Flow Error
Correction: No airflow through sensor when spirometer zeroing
Hold sensor upright during test



Positive Zero Flow Error
Correction: No airflow through sensor when spirometer zeroing
Hold sensor upright during test



Extra Breaths
Correction: DELETE CURVE; Use nose clips and lips tightly sealed



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For a monthly update on news at NIOSH, subscribe to NIOSH eNews by visiting www.cdc.gov/niosh/eNews. For more information about NIOSH-Approved Spirometry Training go to <http://www.cdc.gov/niosh/topics/spirometry/training.html>

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Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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DHHS (NIOSH) Publication No. 2011-135



NIOSH

Section 4:

Standards/References

Standardization of Spirometry 2019 Update

An Official American Thoracic Society and European Respiratory Society Technical Statement

8 Brian L. Graham, Irene Steenbruggen, Martin R. Miller, Igor Z. Barjaktarevic, Brendan G. Cooper, Graham L. Hall, Teal S. Hallstrand, David A. Kaminsky, Kevin McCarthy, Meredith C. McCormack, Cristine E. Oropez, Margaret Rosenfeld, Sanja Stanojevic, Maureen P. Swanney[†], and Bruce R. Thompson; on behalf of the American Thoracic Society and the European Respiratory Society

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Background: Spirometry is the most common pulmonary function test. It is widely used in the assessment of lung function to provide objective information used in the diagnosis of lung diseases and monitoring lung health. In 2005, the American Thoracic Society and the European Respiratory Society jointly adopted technical standards for conducting spirometry. Improvements in instrumentation and computational capabilities, together with new research studies and enhanced quality assurance approaches, have led to the need to update the 2005 technical standards for spirometry to take full advantage of current technical capabilities.

Methods: This spirometry technical standards document was developed by an international joint task force, appointed by the American Thoracic Society and the European Respiratory Society, with expertise in conducting and analyzing pulmonary function tests, laboratory quality assurance, and developing international standards.

A comprehensive review of published evidence was performed. A patient survey was developed to capture patients' experiences.

Results: Revisions to the 2005 technical standards for spirometry were made, including the addition of factors that were not previously considered. Evidence to support the revisions was cited when applicable. The experience and expertise of task force members were used to develop recommended best practices.

Conclusions: Standards and consensus recommendations are presented for manufacturers, clinicians, operators, and researchers with the aims of increasing the accuracy, precision, and quality of spirometric measurements and improving the patient experience. A comprehensive guide to aid in the implementation of these standards was developed as an online supplement.

Keywords: spirometry; spirometer; pulmonary function; technical standards

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Hygiene and Infection Control Equipment Display BTPS Adjustment Device Quality Assurance Operator Details Patient Details Patient Preparation	FEV₁ and FVC Maneuver Test Procedure Within-Maneuver Evaluation Between-Maneuver Evaluation Maximum Number of Maneuvers Bronchodilator Responsiveness Testing Test Procedure	Reported Values Other Derived Indices Grading the Quality of the Test Session VC and Inspiratory Capacity Maneuver Equipment Test Procedure Further Studies Other Potential Analyses
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Overview

This document is an update of the 2005 American Thoracic Society (ATS) and European Respiratory Society (ERS) standardization of spirometry (1), which in turn built on a wealth of previous work (2–6). Additional standards have been developed for occupational surveillance (7) and for preschool children (8). Improvements in instrumentation and computational capabilities, together with new research studies and enhanced quality assurance approaches, have led to the need to update the 2005 technical standards for spirometry to take full advantage of current technical capabilities and evolving best practices. This technical report covers definitions, equipment specifications, patient-related procedures, quality control, and data reporting. A comprehensive guide to aid in the implementation of these standards was developed as an online supplement. A summary of the primary changes in this update is provided in Table E1 in the online supplement.

Key Updates

- A new list of relative contraindications was added.
- Spirometers are now required to meet International Organization for Standardization (ISO) 26782 standards, but with a maximum permissible accuracy error of $\pm 2.5\%$.
- Device quality assurance procedures were updated.
- Operator training as well as attainment and maintenance of competency were addressed.
- The list of activities that patients should avoid before testing was updated.
- There is a focus on the use of devices that measure both expiration and inspiration.
- Maneuver acceptability and repeatability criteria were updated. The end of forced expiration (EOFE) was redefined.

- Requirements for spirometry systems to provide uniform cues and feedback to the operator were added.
- New withholding times for bronchodilators before bronchodilator responsiveness testing were developed.
- A new grading system for assessment of spirometry quality was developed.
- Standardized operator feedback options that promote synoptic reporting were developed.
- Preliminary findings derived from an international patient survey were presented.

Introduction

Spirometry is a physiological test that measures the maximal volume of air that an individual can inspire and expire with maximal effort. The primary signal measured in spirometry is either volume or flow as a function of time. The most relevant measurements discussed in this document are the FVC, which is the volume delivered during an expiration made as forcefully and completely as possible starting from full inspiration, and the FEV₁, which is the expiratory volume in the first second of an FVC maneuver. These standards also apply to measurements of FEV₁ in airway responsiveness testing and exercise testing. Other spirometric variables derived from the FVC maneuver are also addressed, as well as the measurement of VC from a slow maneuver.

In this document, the “operator” is the person conducting the test; the term “patient” is used for the person being tested, recognizing that not all persons will be patients; and “maneuver” is the term used for the inspiratory and expiratory VC excursions. The term “must” is used to indicate a requirement for meeting the standards, and “should” is used to indicate actions that may not be mandatory but are considered to be best practices.

These standards are the minimum criteria that must be met for clinical spirometry, which may not be sufficient for all

settings, such as research or occupational surveillance (7). The spirometry facility manager is also responsible for following local regulations, which may have additional requirements. As manufacturers continue to improve spirometric instrumentation and as new technology is implemented, it is expected that new systems will meet and, in many cases, exceed these new standards. Standards that are developed and updated from time to time should not limit the quest for continual improvement in the quality of lung function measurements and innovation in applying new technology (9).

This revision also includes updates of applicable sections of the 2005 ATS/ERS general considerations for lung function testing document (10). Although these standards apply in primary care, some studies have shown that standards are often not met in primary care (11, 12). However, in studies of patients with asthma and/or chronic obstructive pulmonary disease (COPD), office spirometry was accurate and reliable when compared with laboratory-based spirometry (13–15), demonstrating that competent operators using equipment that meets ATS/ERS standards can meet the spirometry acceptability criteria in the primary care setting.

Methods

An application was submitted for a joint ATS and ERS task force to update the 2005 spirometry standards (1). The task force membership and co-chairs were approved by the ATS and the ERS. Task force members were scientists and physicians with experience in international guidelines and standards; clinical experience in routine lung function testing; and specialist knowledge of spirometry, including research publications. All potential conflicts of interest were disclosed and managed according to the rules and procedures of the ATS and the ERS. A search in the

MEDLINE database (using PubMed) for publications containing various terms related to spirometry published from 2004 to 2018 yielded 23,368 citations (search terms listed in Section E3). Task force members reviewed the abstracts and identified 190 as directly relevant to the project and a further 382 as potentially relevant. New publications were monitored after the initial search, and twelve 2018 and 2019 references are included. All manufacturers of spirometry equipment were sent a survey requesting equipment specifications. The task force also reviewed equipment specifications published on the manufacturers' websites. An international survey of patients was conducted through the European Lung Foundation to elicit their experience in spirometry testing. Using the 2005 standards as the base document, revisions and additions were made on a consensus basis. The recommendations in this document represent a consensus of task force members in regard to the evidence available for various aspects of spirometric measurement (as cited in the document) and otherwise reflects the expert opinion of the task force members for areas in which peer-reviewed evidence was either not available or incomplete. Constraints on the development of these standards are listed in Section E12.

The Patient Experience

To gather information regarding patients' experiences and to identify problems faced by patients who have performed spirometry, an online survey completed by 1,760 spirometry patients from 52 countries was conducted in August and September 2018 by the European Lung Foundation. Patients reported the need for more information about spirometry before the test, including medication withholding. Eighty percent of respondents found the degree of difficulty to be mostly acceptable or completely acceptable. Even so, 31% considered the statement "To keep blowing even though you do not feel anything is coming out" to describe a moderate or serious issue. This could be addressed by having an analog or digital display of flow in ml/s on the screen to give patients feedback on their expiratory rate during the maneuver. Key messages from the survey are provided in Section E4. Full results of

the survey will be forthcoming in a future publication.

Indications

Spirometry is fundamental in the assessment of general respiratory health. Spirometry enables measuring the effect of a disease on lung function, assessing airway responsiveness, monitoring disease course or the result of therapeutic interventions, assessing preoperative risk, and determining a prognosis for many pulmonary conditions. Spirometry is a valuable tool that provides important information to clinicians which is used together with other physical findings, symptoms, and history to reach a diagnosis. Common indications for spirometry are given in Table 1.

Relative Contraindications

Performing spirometry can be physically demanding. The forced expiratory maneuver used in spirometry increases intrathoracic, intraabdominal, and intracranial pressures (16–20). Potential risks of spirometry are primarily related to maximal pressures generated in the thorax and their impact on abdominal and thoracic organs, venous return and systemic blood pressure, and expansion of the chest wall and lung. The physical effort required can increase myocardial demand. Caution must be used for patients with medical conditions that could be adversely affected by these physiological consequences (Table 2). Although such risks are likely to be minimal for spirometry in most patients (21), the potential risks associated with testing should always be weighed against the benefit of obtaining information about lung function (16, 17, 22). Spirometry should be discontinued if the patient experiences pain during the maneuver. Patients with potential contraindications that would prevent testing in the primary care setting may be tested in a pulmonary function laboratory where operators are more experienced and there may be access to emergency care if needed. Furthermore, because spirometry requires the active participation of the patient, inability to understand directions or unwillingness to follow the directions of the operator will usually lead to submaximal test results.

A 20-year review of 186,000 pulmonary function tests in a tertiary institution found that patient safety incidents occurred in 5 of every 10,000 routine pulmonary function tests (excluding exercise and provocation tests) with generally low risk of harm (21). Cardiopulmonary incidents, primarily syncope, were the most common finding. A study found that 10% of patients having maximal cardiopulmonary exercise tests had simple, self-limited arrhythmias induced by spirometry (23). No adverse effects were reported in spirometry conducted in studies of 56 and 230 (24, 25) patients with abdominal aortic aneurysms from 5 to 13 cm in size and in 519 patients with thoracic aortic aneurysms from 5 to 8 cm in size (26).

Laboratory Details

Ambient temperature, barometric pressure, and time of day must be recorded. Temperature is an important variable in most pulmonary function tests and is sometimes measured directly by the instrument. The way in which it is measured and used may vary from instrument to instrument (e.g., a simple thermometer or an internal thermistor). Regardless of the method used, the operator should confirm the accuracy of temperature measurements, and the manufacturer should describe or provide a clear mechanism for checking the accuracy of instrument temperature measurements. Spirometers that require a barometric pressure measurement should have a barometric pressure sensor or the ability to calculate mean barometric pressure using altitude above sea level (27).

Testing should preferably occur in a quiet and comfortable environment that is separated from the waiting room and other patients being tested. Drinking water should be available. Tissues or paper towels should be offered to help patients deal with secretions. The patient should be seated erect, with shoulders slightly back and chin slightly elevated. A chair with arms (to prevent falling sideways should syncope occur), without wheels, and with a height adjustment so that the feet are flat on the floor should be used. A smaller chair or a raised footstool should be provided for children and small adults. For the maneuvers described below, a noseclip or manual occlusion of the nostrils should be used. If testing is undertaken with the

Table 1. Indications for Spirometry**Diagnosis**

- To evaluate symptoms, signs, or abnormal laboratory test results
- To measure the physiologic effect of disease or disorder
- To screen individuals at risk of having pulmonary disease
- To assess preoperative risk
- To assess prognosis

Monitoring

- To assess response to therapeutic intervention
- To monitor disease progression
- To monitor patients for exacerbations of disease and recovery from exacerbations
- To monitor people for adverse effects of exposure to injurious agents
- To watch for adverse reactions to drugs with known pulmonary toxicity

Disability/impairment evaluations

- To assess patients as part of a rehabilitation program
- To assess risks as part of an insurance evaluation
- To assess individuals for legal reasons

Other

- Research and clinical trials
- Epidemiological surveys
- Derivation of reference equations
- Preemployment and lung health monitoring for at-risk occupations
- To assess health status before beginning at-risk physical activities

patient in another position, this must be documented in the report. Tests done while standing are similar to sitting in studies of adults (28), obesity (29), and children (30). Fowler's position (elevated head and torso) yields higher values than supine or Crook's position (knees raised) (31). In most studies involving healthy subjects or patients with lung, heart, neuromuscular disease, or obesity, FEV₁ and FVC were higher in more erect positions, whereas for subjects with tetraplegic spinal cord injury, FVC and FEV₁ were higher in supine than while sitting (32).

Hygiene and Infection Control

The goal of infection control is to prevent the transmission of infection to patients and staff during pulmonary function testing (33, 34). The number of documented cases of infection transmission is very small, but the potential is real. Infection can be transmitted by direct contact with surfaces such as mouthpieces, noseclips, handheld spirometers, chair arms, and immediate proximal surfaces of valves or tubing. Indirect transmission occurs by aerosol droplets generated by the patient blowing into the equipment but also expelled into the air of the testing room between maneuvers.

The operator must wash her or his hands or use an approved hand sanitizer before contact with each new patient (35). Additional steps may be required by local infection control policies. Using disposable gloves does not eliminate the need for hand washing or sanitizing, but if gloves are used, a new pair is required for each patient. The patient should be given an approved hand disinfectant gel or wipe upon first entry into the testing station, because patients will be touching various surfaces, and many spirometers are handheld.

The use of disposable, in-line filters for spirometers has become standard practice in most facilities. Furthermore, the mouthpiece is usually an integral part of the filter and will reduce contamination of the spirometer. All disposable items, including filters, mouthpieces, noseclips, and gloves, must be disposed of at the end of the testing session.

To avoid operator exposure and cross-contamination, hands must be washed immediately after direct handling of mouthpieces, tubing, breathing valves, or interior spirometer surfaces. Gloves should be worn when handling potentially contaminated equipment and/or if the operator has any open cuts or sores on his or her hands.

Manufacturers must explicitly describe acceptable methods of cleaning and disinfecting their equipment, including recommended chemicals and

concentrations, as well as safety precautions for the operator. Local infection control requirements, especially for at-risk populations such as patients with cystic fibrosis (36), may supersede both manufacturers' recommendations and those in this document.

Extra precautions should be taken for patients with, or suspected of having, tuberculosis, hemoptysis, oral lesions, or other known transmissible infectious diseases. Possible precautions include reserving equipment for the sole purpose of testing infected patients or testing such patients at the end of the workday to allow time for spirometer disassembly and disinfection and/or testing patients in their own rooms with adequate ventilation and appropriate protection for the operator. Hygiene processes are described in more detail in the *ATS Pulmonary Function Laboratory Management and Procedure Manual* (37).

Equipment

Manufacturers must ensure that all spirometers meet the standards contained in the current update of ISO 26782 (38). The current update is ISO 26782:2009, last reviewed in 2016 and scheduled to be reviewed next in 2021. Although not explicitly stated in ISO 26782, it is not permissible to recalibrate a spirometer between the individual test profiles of Annex C of ISO 26782. Notwithstanding the ISO 26782, Section 7, performance requirements of being within $\pm 3.0\%$ for accuracy, linearity, and repeatability, spirometric equipment must have a maximum permissible error of $\pm 2.5\%$ when tested with a 3-L calibration syringe and when using the test profiles of ISO 26782, Section 7, Annex C. If future ISO 26782 revisions specify a maximum permissible error less than $\pm 2.5\%$, then the lower value must be used. A 2018 survey of spirometer manufacturers worldwide found that 17 of 19 respondents reported that the accuracy of their products was within $\pm 2\%$. A study of 7,497 calibration verifications of volume spirometers demonstrated the need for more stringent standards (39). Thirteen of 19 manufacturers responding to the survey were compliant with ISO 26782:2009. A study has questioned whether the previously recommended ATS standard waveforms were sufficient (40). For

Table 2. Relative Contraindications for Spirometry

Due to increases in myocardial demand or changes in blood pressure
Acute myocardial infarction within 1 wk
Systemic hypotension or severe hypertension
Significant atrial/ventricular arrhythmia
Noncompensated heart failure
Uncontrolled pulmonary hypertension
Acute cor pulmonale
Clinically unstable pulmonary embolism
History of syncope related to forced expiration/cough
Due to increases in intracranial/intraocular pressure
Cerebral aneurysm
Brain surgery within 4 wk
Recent concussion with continuing symptoms
Eye surgery within 1 wk
Due to increases in sinus and middle ear pressures
Sinus surgery or middle ear surgery or infection within 1 wk
Due to increases in intrathoracic and intraabdominal pressure
Presence of pneumothorax
Thoracic surgery within 4 wk
Abdominal surgery within 4 wk
Late-term pregnancy
Infection control issues
Active or suspected transmissible respiratory or systemic infection, including tuberculosis
Physical conditions predisposing to transmission of infections, such as hemoptysis, significant secretions, or oral lesions or oral bleeding

Spirometry should be discontinued if the patient experiences pain during the maneuver. Relative contraindications do not preclude spirometry but should be considered when ordering spirometry. The decision to conduct spirometry is determined by the ordering healthcare professional on the basis of their evaluation of the risks and benefits of spirometry for the particular patient. Potential contraindications should be included in the request form for spirometry.

digitization of the flow or volume signal, the sampling rate must be ≥ 100 Hz (41) with a minimum resolution of 12 bits. The ERS/ATS standards for diffusing capacity (42) specify a volume accuracy of $\pm 2\%$, but the flow range required for the diffusing capacity maneuver is smaller than that for spirometry, and the systems measuring diffusing capacity primarily use higher-grade instrumentation. Therefore, laboratories using such equipment are expected to exceed accuracy requirements for spirometry.

Display

For optimal quality control, both volume–time and flow–volume real-time displays are required, and operators must visually inspect the performance of each maneuver for quality assurance before proceeding with another maneuver. For the flow–volume graph, expiratory flow must be plotted upward, and expiratory volume must be plotted toward the right. A 2:1 aspect ratio must be maintained between the flow and volume scales; that

is, 2 L/s of flow and 1 L of volume must be the same distance on their respective axes.

Displays of flow versus volume provide more detail than volume–time graphs for the first 1 second of the FVC maneuver. Because this portion of the maneuver, particularly the peak expiratory flow (PEF), is correlated with the pleural pressure during the maneuver, the flow–volume graph is useful to assess the magnitude of effort during the initial portions of the maneuver. The ability to overlay a series of flow–volume graphs registered at the point of maximal inspiration may be helpful in evaluating repeatability and detecting submaximal efforts. However, if the point of maximal inspiration varies between maneuvers, then the interpretation of these results is difficult because the flows at identical measured volumes are being achieved at different absolute lung volumes. In contrast, display of the FVC maneuver as a volume–time graph provides more detail for the latter part of the maneuver. In a display of multiple trials, the sequencing of

the maneuvers should be apparent to the operator.

For the start of test display, the volume–time graph must begin at the point of maximum inspiration or 1 second before Time 0 (defined below), whichever occurs first. The display of the maneuver should continue to the end of the plateau (defined below) or the beginning of inspiration.

BTPS Adjustment

All spirometry outcomes must be reported at BTPS (body temperature, ambient barometric pressure, saturated with water vapor). The ambient temperature must always be recorded with an accuracy of $\pm 1^\circ\text{C}$. In situations when the ambient air temperature is changing rapidly ($>3^\circ\text{C}$ in <30 min), continuous temperature corrections may be necessary (Section E5). Operators should be aware of potential problems with tests performed outside the range of ambient temperatures and barometric pressures specified by the manufacturer for their particular spirometer.

Changes in spirometer or flow sensor temperature can be a source of variability (43). Spirometer temperature should be measured and not assumed to be constant, even over the course of one testing session. For volume spirometers, errors up to 6% in FEV₁ and FVC can occur if ambient temperature is used instead of internal temperature of volume spirometers (44). Therefore, when using volume spirometers, the temperature inside the spirometer should be measured for each breathing maneuver.

Device Quality Assurance

Attention to equipment quality assurance and calibration is an important part of good laboratory practice. The minimum requirements are as follows: 1) maintenance of a log of calibration results, 2) documentation of repairs or other alterations that return the equipment to acceptable operation, 3) recording of dates of computer software and hardware updates or changes, and 4) recording the dates equipment is changed or relocated (e.g., industrial surveys). Calibration verifications and quality control procedures must be repeated after any such changes before further testing begins. Key aspects of

equipment quality assurance are summarized in Table 3.

A calibration procedure determines the relationship between flow or volume transducer signals measured by the sensor and the actual flow or volume. In contrast, a calibration verification is the procedure used to validate that the device is within calibration limits (i.e., $\pm 3\%$ [accuracy tolerance, $\pm 2.5\%$ for spirometers plus $\pm 0.5\%$ for calibration syringes]). Spirometry systems must include a calibration verification option using room air at ambient conditions. If a device fails its calibration verification (Table 4), then a new calibration procedure or equipment maintenance is required. Manufacturers must provide an alert if the new calibration factor either varies by more than ± 2 SDs from the mean calibration factor or changes by more than 6% from the previous calibration factor, because this may indicate that the spirometer requires cleaning, maintenance, and/or repair. Calibration verifications must be undertaken daily, or more frequently if specified by the manufacturer. Precalibrated spirometers cannot be recalibrated by the operator but must still undergo a calibration verification. Manufacturers must specify the action to be taken if a precalibrated device fails the calibration verification. Spirometry software must include the ability to generate a report of calibrations that includes the results of all verifications, the number of failed calibration verifications in each session, and the changes in calibration factors. A warning should be issued if the calibration verification error differs from the historical mean calibration verification error by more than ± 2 SDs (37, 39, 45, 46).

The spirometry system must determine the zero-flow level with the spirometer blocked before calibration, calibration verifications, and patient tests. If variable flow is detected during the zero-flow setting procedure or if the zero level has changed significantly, the zero-flow setting procedure must be repeated.

A 3-L syringe used to both recalibrate and verify the volume calibration of spirometers must have an accuracy of ± 0.015 L or $\pm 0.5\%$ of the full scale, and the manufacturer must provide recommendations concerning appropriate intervals between checks of the syringe accuracy. The syringe must be kept at room temperature. Holding the syringe body to

steady the syringe during a calibration verification can raise its temperature and contribute to measurement error. Operators should be aware that a syringe with an adjustable or variable stop may be out of calibration if the stop is reset or accidentally moved. Calibration syringes must have a monthly leak test at more than one volume up to their maximum; this can be done by attempting to empty or fill them with the outlet corked (47). A dropped or damaged syringe should be considered out of calibration until it is checked.

Calibration verifications must be undertaken at least daily using a 3-L syringe cycled at least three times to give a range of flows varying between 0.5 and 12 L/s (with 3-L injection times between 0.5 and 6 s). If an in-line filter is used in spirometry testing, then it must also be used during recalibrations and verifications. The measured volume at each flow must meet the accuracy requirement of $\pm 3\%$ for both inspiration and expiration (or for expiration only for volume-based spirometers). For devices using disposable flow sensors, a new sensor from the supply used for patient tests must be tested each day.

The *ATS Pulmonary Function Laboratory Management and Procedure Manual* (37) includes the option for a biological control: a healthy, nonsmoking individual capable of performing very repeatable spirometry. A biological control is not a substitute for the use of a calibration syringe. However, operators are encouraged to know their own usual FEV₁ and FVC, which allows them to conduct a quick, rough check if they suspect a problem. In some jurisdictions, including a biological control in quality control reporting may constitute a breach of employee privacy protection.

Operator Details

As Ruppel and Enright observed, “There are 3 key elements to obtain high quality pulmonary function data: accurate and precise instrumentation, a patient/subject capable of performing acceptable and repeatable measurements, and a motivated technologist to elicit maximum performance from the patient. In the realm of standardization, the technologist has received the least attention” (48). The importance of the operator was also a key message derived from the patient experience survey.

It is the responsibility of the operator to observe and engage with the patient to achieve optimal results, which requires a combination of training and experience. Training courses for conducting quality spirometry testing are available in many countries, which has led to operators following ATS/ERS standards (14, 15, 49–51), but short-term follow-up and supplementary training are important to maintain quality (52, 53). Operator training and attainment and maintenance of competency must be integrated in any spirometry testing service (54).

Patient Details

The patient’s age, height, and weight (wearing indoor clothes and without shoes) are recorded. It is preferable to calculate age using the date of birth and the date of the test, including in jurisdictions where birth dates may only be recorded to the nearest month. Age must be reported in years to one decimal place. Height in centimeters to one decimal place (55) and weight to the nearest 0.5 kg must be recorded; these may also be expressed in inches and pounds on reports in jurisdictions still using those measures. Body mass index should be calculated as kg/m². The height must be measured without shoes, with the feet together, standing as tall as possible with the eyes level and looking straight ahead, and the back flush against a wall or stadiometer. For patients unable to stand erect, height may be estimated using ulna length (preferred for children) (56) or arm span (57) (*see* Section E6), recognizing that there are sex, age, and ethnic differences in such estimates. Ulna length should be measured with calipers to avoid error introduced using a tape measure. In persons aged 25 years or older, for whom a reliable height measurement has been made previously in the same facility, remeasuring height at subsequent visits within 1 year may not be necessary.

Birth sex and ethnicity should be included in the patient information on the spirometry request. Otherwise, the operator will ask the patient to provide this information. When requesting birth sex data, patients should be given the opportunity to provide their gender identity as well and should be informed that although their gender identity is respected, it is birth sex and not gender that is the

Table 3. Equipment Quality Assurance (for Both Volume- and Flow-based Sensors)**Spirometer**

- Daily calibration verification at low, medium, and high flow: If the calibration verification fails, check for and remediate problems (Table 4) and repeat calibration verification
- If an in-line filter is used in spirometry testing, then it must also be used during recalibrations and verifications
- Recalibrate the spirometer both after failed calibration verification and at intervals specified by the manufacturer
- If the change in calibration factor is $\geq 6\%$ or varies by more than ± 2 SD from the mean, inspect and, if necessary, clean the spirometer according to the manufacturer's instructions; check for errors (Table 4) and recalibrate the spirometer
- Perform routine checks and maintenance at intervals specified by the manufacturer

3-L calibration syringe

- Daily inspection for displacement of the piston stop
- Daily check for smooth operation of the syringe with no sticking or catching
- Accuracy of ± 0.015 L verified by manufacturer on delivery and at intervals recommended by the manufacturer
- Monthly syringe leak test

Documentation

- A log of all quality control findings, repairs and adjustments, and hardware and software updates
- Verification of reference value calculations after software updates

determinant of predicted lung size. Inaccurate entry of birth sex may lead to incorrect diagnosis and treatment. Similarly, patients should be informed of the need for reporting ethnicity (58). Ethnicity categories for the Global Lung Function Initiative (GLI) reference values (59) are white (i.e., European ancestry), African American, Northeast Asian, Southeast Asian, and other/mixed (Section E7). If birth sex and/or ethnicity data are not disclosed, the operator notes must alert the interpreter of this omission and state what default values were used for calculating predicted values.

Patient Preparation

Patients should avoid the activities listed in Table 5 before testing, and these requirements should be given to the patient

at the time of making the appointment. On arrival, all of these points must be checked, and any deviations from them must be recorded.

Patients should be as relaxed as possible before and during the tests. Patients should be asked to loosen tight-fitting clothing. Well-fitting dentures are usually left in place. A 2001 study found that spirometry results are generally better with dentures in place (60), but a larger 2018 study found that FVC was an average of 0.080 L higher when dentures were removed (61).

The decision to withhold long- and short-acting bronchodilators before testing is a clinical one determined by the referring healthcare professional. If the study is performed to diagnose an underlying lung condition, then withholding bronchodilators

before testing is useful (see BRONCHODILATOR RESPONSIVENESS TESTING). For studies to determine a response to an existing therapeutic regimen, bronchodilator medications are generally not withheld.

Instructions on withholding medications should be given to the patient at the time of making the appointment. The operator must record the type and dosage of any inspired, oral, or injected medication that may alter lung function and when the drugs were last administered. The operator should record observed signs or symptoms such as cough, wheeze, dyspnea, or cyanosis.

FEV₁ and FVC Maneuver**Test Procedure**

For spirometers that measure inspiration and expiration, there are four distinct phases of the FVC maneuver: 1) maximal inspiration, 2) a "blast" of expiration, 3) continued complete expiration for a maximum of 15 seconds, and 4) inspiration at maximal flow back to maximum lung volume. Most of the variability in results obtained from spirometry relates to inadequate and variable inspiration to TLC, ending the expiration prematurely, and variable effort.

The operator must demonstrate the appropriate technique and follow the procedure described in Table 6. Once the zero-flow level has been determined, the patient should insert the mouthpiece and be instructed to breathe normally or easily. The operator checks that the patient has the proper posture, the noseclip is in place, and the lips are sealed around the mouthpiece. Patients unable to use a mouthpiece may be able to use a face mask (62). In some circumstances, such as patients with tracheostomy or nasal resection, noninvasive adjustments such as a sealing face mask, tubing connectors, or occlusion valves can be applied at the discretion of the operator and must be recorded in the operator notes.

Maximal inspiration. Patients should be informed that maximal inflation is unnatural; they may not have achieved it before, and it may seem somewhat uncomfortable. Reductions in PEF and FEV₁ have been shown when inspiration is slow and/or there is a 4- to 6-second pause at TLC before beginning expiration (63, 64). It is therefore important that the preceding inspiration be rapid and any pause at full inspiration be minimal (≤ 2 s).

Table 4. Potential Reasons for Calibration Verification Failure

- A slight change in spirometer function that requires a subsequent recalibration procedure to adjust the calibration factor
- A leak in the connection of the spirometer to the calibration syringe
- Air flow through the spirometer during the zero-flow setting procedure
- Failure to fully fill and empty the calibration syringe in one smooth action
- Calibration syringe malfunction (e.g., piston leak or displacement of the piston stop or syringe damaged by dropping)
- Spirometer blockage either by debris in the spirometer sensor or by the operator's hand while holding the spirometer in place
- Improper assembly of the sensor, mouthpiece, filter, and/or breathing tube
- Differences between room temperature and calibration syringe temperature
- Data entry errors in the ambient temperature and/or pressure

Table 5. Activities That Should Be Avoided before Lung Function Testing

- Smoking and/or vaping and/or water pipe use within 1 h before testing (to avoid acute bronchoconstriction due to smoke inhalation)
- Consuming intoxicants within 8 h before testing (to avoid problems in coordination, comprehension, and physical ability)
- Performing vigorous exercise within 1 h before testing (to avoid potential exercise-induced bronchoconstriction)
- Wearing clothing that substantially restricts full chest and abdominal expansion (to avoid external restrictions on lung function)

The operator should be in a position to view the patient and the display of the testing device, but the major sign that the subject has achieved full inflation will come from the patient. The patient's head and face should be observed while the command to "inspire as deeply as possible" (not just "take in a deep breath") is given. During the inspiration, the operator should coach the patient using phrases such as "more, more, more." Indicators of maximal inspiration include eyebrows raising or eyes widening, and sometimes the head begins to quiver. A patient who looks comfortable is not likely to be at full inflation.

Maximal expiration. At full inflation, without hesitation, the patient should be prompted to "blast," not just "blow," the air from their lungs, and then he or she should be encouraged to fully expire. Continuous and enthusiastic coaching of the patient is required throughout the maneuver, using appropriate body language and phrases such as "keep going." The operator simultaneously observes the patient and the computer display during the test to help ensure maximal effort. The spirometry system must signal the operator when a plateau has been reached or forced expiratory time (FET) reaches 15 seconds. Having an audio cue for end expiration permits the operator to observe the patient more closely. The patient survey indicated that many were concerned by being asked to keep blowing when they felt nothing more was coming out. If the patient is able to see a volume-time trace still moving as they blow and/or a numeric or analog display of flow in mL/s, this might help motivate them to keep blowing. Children may benefit from incentive displays. If the patient shows signs of syncope, the maneuver should be stopped. Reducing the effort partway through the maneuver (after 4 s) (65, 66) may give a higher expiratory volume in some patients and may prevent glottic closure and avoid syncope, but then

it is no longer a true maximally forced expiration. Some patients with restrictive lung disease and young patients with high elastic recoil can empty their lungs quickly and may not be able to hold an expiratory plateau for 1 second. The operator needs to recognize the convex pattern of the flow-volume graph in such patients and distinguish it from an early termination of expiration (Figure E2).

Maximal inspiration after forced expiration. Upon completing the forced expiration, the patient should remain on the mouthpiece, and the operator should again coach the patient to rapidly inspire to full inflation. This will provide a measure of forced inspiratory VC (FIVC). It is a maximal effort to return to TLC to complete the flow-volume loop. Comparison of the FIVC with the FVC will provide feedback to the operator on whether the patient began the forced expiration from full inflation (67). It is important that the inspiration to full inflation before and after the forced expiration be coached with equal vigor so that a valid comparison can be made.

With appropriate coaching, children as young as 2.5 years old with normal cognitive and neuromotor function are able to perform acceptable spirometry (8, 59). The operators who are involved in the pulmonary function testing of young children should be specifically trained and competent to work with this population. A child-friendly environment is important for successful testing. Encouragement, detailed but simple instructions, lack of intimidation, and visual feedback in the teaching are important in helping children to perform the maneuver (8, 68). Even if unsuccessful at the first session, children will learn to be less intimidated, and their performance may improve in subsequent sessions. Testing children in "adult" laboratories requires extra time and effort to cater to the specific needs of the younger

patient (69). Other techniques such as raised volume rapid thoracic compression technique that are used for infants (70) are not included in this document.

For spirometers measuring expiration only, the procedure is modified as follows. The patient first inspires rapidly to maximal lung volume and then within 2 seconds inserts the mouthpiece, seals his or her lips around the mouthpiece, and initiates maximal expiration. Keeping the mouth open until the mouthpiece is in place can help minimize air loss before sealing the lips. The mouthpiece is removed at EOF. Regarding expiration-only maneuvers, a study found that the use of noseclips did not affect group mean performance (71).

Within-Maneuver Evaluation

The following criteria were developed as objective measures to determine whether a maximal effort was achieved and acceptable FEV₁ and/or FVC measurements were obtained. However, in some cases, maneuvers that do not meet all of the criteria may be the best that the patient is able to do on that occasion, and although the FEV₁ and/or FVC measurements are not technically acceptable, they may be clinically useful (i.e., "usable") (Table 7).

The start of forced expiration, for the purpose of timing, is determined by the back-extrapolation method (Figure 1) (1, 38). At the point of PEF on the volume-time graph, a tangent is drawn with a slope equal to PEF, and its intersection on the abscissa defines Time 0, which becomes the start for all timed measurements. The back-extrapolated volume (BEV) is the volume of gas that has already been expired from maximal lung volume to Time 0 and is included in the FEV₁ and FVC measurements. To ensure that the FEV₁ comes from a maximal effort, the BEV must be <5% of the FVC or 0.100 L, whichever is greater (72, 73). The 0.100-L tolerance is a reduction from the 0.150-L tolerance in the 2005 standards (1). The hesitation time, defined as the time from the point of maximal inspiration to Time 0, should be 2 seconds or less (Figure E13). FEV₁ and FVC measurements from a maneuver with BEV exceeding the limit are neither acceptable nor usable. A large BEV will usually result in an erroneously high FEV₁ (74). Patients with upper airway obstruction or neuromuscular disease are often unable to initiate a rapid increase in flow, and the BEV limit may be exceeded.

Table 6. Procedures for FVC Maneuvers

Wash hands* (or use an approved hand sanitizer)

Prepare the patient

- Dispense hand sanitizer for the patient
- Confirm patient identification, age, birth sex, ethnicity, etc.
- Measure weight and height without shoes
- Ask about activities listed in Table 5, medication use, and any relative contraindications flagged on the requisition; note respiratory symptoms

Instruct and demonstrate the test

- Position of the mouthpiece and noseclip
- Correct posture with head slightly elevated
- Inspire rapidly until completely full
- Expire with maximal effort until completely empty
- Inspire with maximal effort until completely full
- Confirm that patient understands the instructions and is willing to comply

Perform maneuver

- Have patient assume the correct posture
- Attach noseclip, place mouthpiece in mouth, and close lips around the mouthpiece
- Breathe normally
- Inspire completely and rapidly with a pause of ≤ 2 s at TLC
- Expire with maximal effort until no more air can be expelled while maintaining an upright posture
- Inspire with maximal effort until completely full
- Repeat instructions as necessary, coaching vigorously
- Repeat for a minimum of three maneuvers, usually no more than eight for adults
- Check FEV₁ and FVC repeatability and perform more maneuvers as necessary

Perform maneuver (expiration-only devices)

- Have patient assume the correct posture
- Attach noseclip
- Inspire completely and rapidly with a pause of ≤ 2 s at TLC
- Place mouthpiece in mouth and close lips around the mouthpiece
- Expire with maximal effort until no more air can be expelled while maintaining an upright posture
- Repeat instructions as necessary, coaching vigorously
- Repeat for a minimum of three maneuvers, usually no more than eight for adults
- Check FEV₁ and FVC repeatability and perform more maneuvers as necessary

*Additional steps may be required by local infection control policies. Using disposable gloves does not eliminate the need for hand washing or sanitizing, but if gloves are used, a new pair is required for each patient.

The operator must have the ability to override the BEV acceptability designation for such patients.

The volume–time graph must include 1 second before the start of forced expiration (Time 0) or begin before the point of maximum inspiration, whichever occurs first. The system should display the BEV value. Inspection of the flow–volume graph may be added as a measure of the satisfactory start of a test. PEF should be achieved with a sharp rise and occur close to Time 0 as measured by the rise time from 10% to 90% of peak flow (75), which should be ≤ 150 ms but may be greater than this in a maneuver in a patient with upper airway obstruction.

End of forced expiration. Previous standards used the term “end of test” and

the abbreviation “EOT” to denote end of forced expiration (EOFE). These standards stress the importance of a maximal inspiration after the forced expiration. As such, the end of forced expiration is not the end of the maneuver, and hence the term EOFE is used.

Recognizing a satisfactory EOFE is important to ensure that a true FVC has been achieved. Achieving one of the following three recommended indicators of EOFE is required (Figure 2):

1. There is less than a 0.025-L change in volume for at least 1 second (a “plateau”). This is the most reliable indicator of complete expiration. The system must provide both an indicator on the real-time display and an audio alert—a single beep—when this criterion

has been reached. Note that a closure of the glottis may prematurely terminate a maneuver, hence rendering it unacceptable for FVC, even when the apparent duration of expiration is much longer.

OR

2. The patient has achieved an FET of 15 seconds. The system must provide both an indicator on the real-time display and an audio alert—a double beep—when this criterion has been reached. For patients with airway obstruction or older patients, longer FETs are frequently achieved; however, FETs >15 seconds will rarely change clinical decisions (1, 4). The 1994 ATS spirometry standards used “forced exhalation is of reasonable duration” as an indicator of EOFE and suggested that 12–15 seconds was sufficient (4). A study of adults (mean age, 67 yr) found that more than 95% of obstructed patients had an FET of <15 seconds and that $>95\%$ of normal subjects had an FET of <11 seconds (76). Multiple prolonged expirations are seldom justified and may cause light-headedness, syncope, undue fatigue, and unnecessary discomfort.

OR

3. The patient cannot expire long enough to achieve a plateau (e.g., children with high elastic recoil or patients with restrictive lung disease). In this case, the measure of whether EOFE has been reached is for the patient to repeatedly achieve the same FVC. For within-maneuver acceptability, the FVC must be greater than, or within the repeatability tolerance (*see below*) of, the largest FVC observed before this maneuver in the current testing set. If the first maneuver of either the prebronchodilator testing set or the post-bronchodilator testing set does not have a plateau and FET <15 seconds, it provisionally meets this EOFE criterion for acceptability, subject to comparison with the FVC from subsequent maneuvers. It becomes acceptable if it is within the repeatability tolerance of, or is greater than, a subsequent FVC. Hence, for the prebronchodilator and post-bronchodilator testing sets analyzed separately, all FVC values from maneuvers without a plateau and FET <15 seconds that are within the repeatability tolerance of the maximum FVC in that set are judged to have met

Table 7. Summary of Acceptability, Usability, and Repeatability Criteria for FEV₁ and FVC

Acceptability and Usability Criterion	Required for Acceptability		Required for Usability	
	FEV ₁	FVC	FEV ₁	FVC
Must have BEV ≤5% of FVC or 0.100 L, whichever is greater	Yes	Yes	Yes	Yes
Must have no evidence of a faulty zero-flow setting	Yes	Yes	Yes	Yes
Must have no cough in the first second of expiration*	Yes	No	Yes	No
Must have no glottic closure in the first second of expiration*	Yes	Yes	Yes	Yes
Must have no glottic closure after 1 s of expiration	No	Yes	No	No
Must achieve one of these three EOFE indicators:	No	Yes	No	No
1. Expiratory plateau (≤0.025 L in the last 1 s of expiration)				
2. Expiratory time ≥15 s				
3. FVC is within the repeatability tolerance of or is greater than the largest prior observed FVC [†]				
Must have no evidence of obstructed mouthpiece or spirometer	Yes	Yes	No	No
Must have no evidence of a leak	Yes	Yes	No	No
If the maximal inspiration after EOFE is greater than FVC, then FVC – FVC must be ≤0.100 L or 5% of FVC, whichever is greater [‡]	Yes	Yes	No	No

Repeatability criteria (applied to acceptable FVC and FEV₁ values)

Age >6 yr: The difference between the two largest FVC values must be ≤0.150 L, and the difference between the two largest FEV₁ values must be ≤0.150 L

Age ≤6 yr: The difference between the two largest FVC values must be ≤0.100 L or 10% of the highest value, whichever is greater, and the difference between the two largest FEV₁ values must be ≤0.100 L or 10% of the highest value, whichever is greater

Definition of abbreviations: BEV = back-extrapolated volume; EOFE = end of forced expiration; FEV_{0.75} = forced expiratory volume in the first 0.75 seconds; FIVC = forced inspiratory VC.

The grading system (Table 10) will inform the interpreter if values are reported from usable maneuvers not meeting all acceptability criteria.

*For children aged 6 years or younger, must have at least 0.75 seconds of expiration without glottic closure or cough for acceptable or usable measurement of FEV_{0.75}.

[†]Occurs when the patient cannot expire long enough to achieve a plateau (e.g., children with high elastic recoil or patients with restrictive lung disease) or when the patient inspires or comes off the mouthpiece before a plateau. For within-maneuver acceptability, the FVC must be greater than or within the repeatability tolerance of the largest FVC observed before this maneuver within the current prebronchodilator or the current post-bronchodilator testing set.

[‡]Although the performance of a maximal forced inspiration is strongly recommended, its absence does not preclude a maneuver from being judged acceptable, unless extrathoracic obstruction is specifically being investigated.

the EOFE acceptability criterion.

Although patients should be strongly encouraged to achieve their maximal effort, the operator should be alert to any indication that the patient is experiencing discomfort and should terminate the maneuver if a patient is significantly uncomfortable or is approaching syncope.

Maneuvers that do not meet any of the EOFE acceptability criteria will not provide acceptable FVC measures. However, an acceptable FEV₁ measurement may be obtained from a maneuver with early termination after 1 second. For children aged 6 years or younger, an acceptable FEV_{0.75} (the forced expiratory volume in the first 0.75 s) may be obtained from a maneuver with early termination after 0.75 seconds.

Note that there is no requirement for a minimum FET. Studies have shown that patients with airflow obstruction and elderly patients may have difficulty meeting the

2005 ATS/ERS requirement of achieving a plateau (77–79), and the criterion results in the exclusion of too many patients while having minimal impact on predicted values (80). A large occupational health study in an older population (mean age, 63 yr) found that 53% of spirometry maneuvers failed to reach a plateau despite encouragement by trained operators and long FETs (72). However, in another study, 90% of patients with severe lung function impairment were able to meet the criteria (81). Other large adult population studies found that more than 95% of subjects who expired for longer than 6 seconds achieved a plateau (82, 83). A large clinical trial using well-trained, supervised operators found that 94% of patients with COPD were able to meet the 1994 ATS spirometry standards plateau criteria (4, 84).

The 2005 ATS/ERS requirement of a minimum FET (1) resulted in some valid maneuvers being classified as inadequate (77, 78, 85). In a study of 1,631 healthy children aged 10–18 years, only 18% met

the 2005 minimum FET in maneuvers that were visually judged to be acceptable (73). However, because the requirement for a minimum FET has been eliminated, increased vigilance by the operator and the interpreter is required in the assessment of whether expiration was complete or there was early termination.

If the volume of the maximal inspiration (i.e., FIVC) after EOFE is greater than FVC, then the patient did not start the maneuver from TLC. FEV₁ and FVC measurements from a maneuver with FIVC – FVC > 0.100 L or 5% of FVC, whichever is greater, are not acceptable.

A cough during the first second of the maneuver can affect the measured FEV₁ value, and the FEV₁ from such a maneuver is neither acceptable nor usable. However, the FVC may be acceptable.

Glottic closure or early termination, such as inspiration or coming off the mouthpiece, renders FVC unacceptable and, if it occurs in the first 1 second, renders FEV₁ unacceptable and unusable. A similar

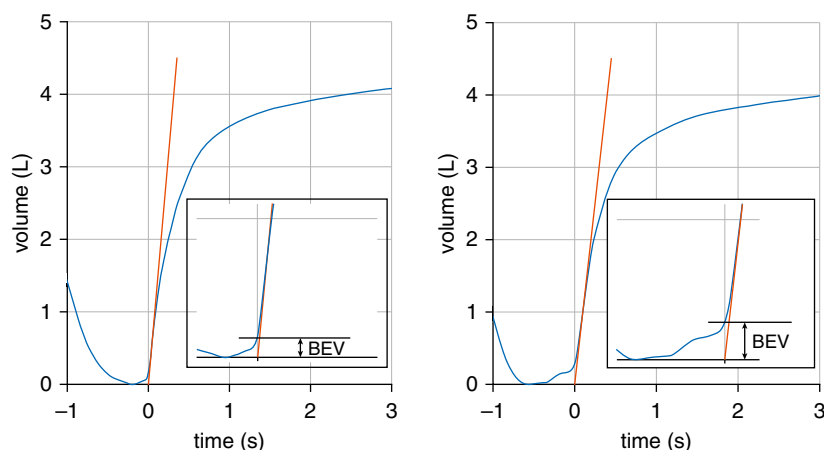


Figure 1. Back-extrapolated volume (BEV). Time 0 is found by drawing a line with a slope equal to peak flow through the point of peak flow (red line) on the volume–time curve and setting Time 0 to the point where this line intersects the time axis. The BEV is equal to the volume of gas exhaled before Time 0 (inset), which, in these two examples from the same patient, is 0.136 L for the left panel (acceptable) and 0.248 L for the right panel (unacceptable). For this patient, the BEV limit is 5% FVC = 0.225 L.

termination in the first 0.75 seconds renders $FEV_{0.75}$ unacceptable and unusable.

There must be no leak at the mouth (4). Patients with difficulty making a seal around the mouthpiece may require a flange-type mouthpiece or assistance from the operator to guarantee an adequate seal.

Obstruction of the mouthpiece (e.g., by the tongue being placed in front of the mouthpiece, by teeth in front of the mouthpiece, or by distortion from biting) may affect the performance of either the device or the patient. Errors also occur because of obstruction of a handheld spirometer by improper hand placement.

Maneuvers conducted with an erroneous zero-flow level will either under- or overestimate FEV_1 and FVC. Figure E13 shows the effects of a faulty zero-flow set procedure that renders both FEV_1 and FVC neither acceptable nor usable.

Operator feedback. The spirometry system software must provide explicit feedback to the operator indicating FEV_1 and FVC acceptability at the completion of each maneuver. Sample warning messages and suggested corrections are provided in Section E8. The operator must have the ability to override the acceptability designation, because the operator may note

a leak, a cough, inadequate inspiration or expiration, or a faulty zero-flow level that was not detected by the software.

Records of all maneuvers with FEV_1 and/or FVC that are acceptable or usable must be retained because, for some patients, their best performance may yield only usable data that does not meet acceptability criteria. Examples of acceptable and unacceptable volume–time curves and corresponding flow–volume curves are provided in Figures E1–E12.

Between-Maneuver Evaluation

The goal of each prebronchodilator testing set and post-bronchodilator testing set is to achieve a minimum of three acceptable FEV_1 and three acceptable FVC measurements. Note that acceptable FEV_1 and acceptable FVC measurements are not necessarily from the same maneuver. The operator must ensure that sufficient time is allowed between maneuvers for the patient to sufficiently recover and agree to perform another maximal maneuver. FVC repeatability is achieved when the difference between the largest and the next largest FVC is ≤ 0.150 L for patients older than 6 years of age (86) and ≤ 0.100 L or 10% of largest FVC, whichever is greater, for those aged 6 years or younger (8, 87). For FEV_1 repeatability, the difference between the largest and the next largest FEV_1 is ≤ 0.150 L for those older than 6 years of age and ≤ 0.100 L or 10% of the largest FEV_1 , whichever is greater, for those aged 6 years or younger. If these criteria are not met in three maneuvers, additional trials must be attempted, up to eight maneuvers in adults, although more may be done in children (Figure 3).

Achieving repeatable results is the best indicator that the patient performed the maximal FEV_1 and FVC that she or he was capable of doing. The degree of repeatability, which is quantified in the grading system (see GRADING THE QUALITY OF THE TEST SESSION), guides the confidence level in the interpretation of the results. The repeatability criteria are used to determine when more maneuvers are needed. In many cases, patients can and will achieve closer repeatability than these criteria. Studies have found that most adults are able to achieve FVC and FEV_1 repeatability to within 0.150 L (82, 88) and that children are able to achieve repeatability within 0.150 or 0.100 L (89).

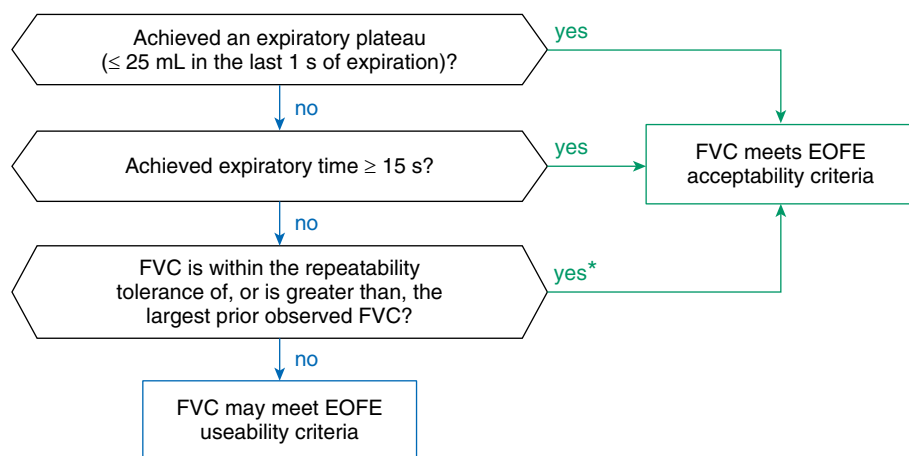


Figure 2. Flowchart outlining the end of forced expiration (EOFE) acceptability criteria for FVC. *If there are no prior observed FVC values in the current pre- or post-bronchodilator testing set, then the FVC provisionally meets EOFE acceptability criteria.

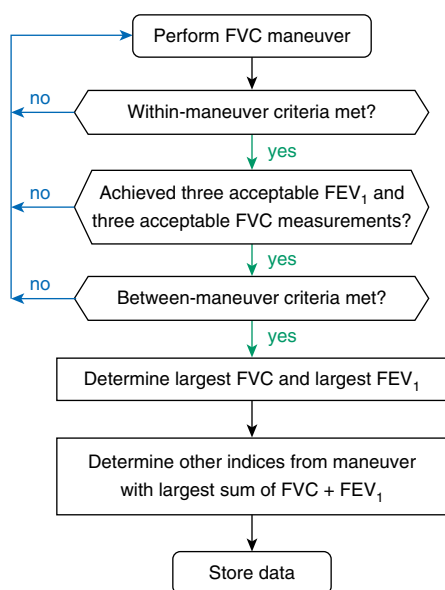


Figure 3. Flowchart outlining application of acceptability and repeatability criteria.

Maximum Number of Maneuvers

Although there may be some circumstances in which more than eight consecutive FVC maneuvers may be needed, eight is generally a practical upper limit for most adults (90, 91). After several forced expiratory maneuvers, fatigue can begin to take its toll on patients, and additional maneuvers would be of little added value. In rare circumstances, patients may show a progressive reduction in FEV₁ or FVC with each subsequent maneuver. If the FEV₁ from an acceptable test drops below 80% of the start value, the test procedure should be terminated in the interest of patient safety. When testing children, more than eight attempts may be required because each attempt may not be a full maneuver. Children may benefit from practicing the different phases of the maneuver before attempting a full maneuver. Operators should be aware of the child's enthusiasm and effort to avoid exhausting or discouraging the child from future testing.

Bronchodilator Responsiveness Testing

Previously, the term "reversibility testing" has been used, but the term "bronchodilator responsiveness testing" is used in these standards to avoid the unwarranted inference that "reversibility"

implies the complete elimination of airway obstruction (92). Bronchodilator responsiveness testing is a determination of the degree of improvement of airflow in response to bronchodilator administration as measured by changes in FEV₁ and FVC. It is commonly undertaken as part of spirometry testing. The choice of bronchodilator, dose, and mode of delivery is a clinical decision depending on what the referring clinician wishes to learn from the test.

If the aim of the test is to determine whether the patient's spirometric lung function can be improved with therapy in addition to their regular treatment, then the patient may continue with his or her regular medication before the test. If the test is used for diagnosis or to determine whether there is any change in spirometric lung function in response to bronchodilators, then the clinician ordering spirometry will instruct the patient to withhold bronchodilators before baseline testing. Table 8 lists suggested withholding times for various bronchodilators. The withholding times are based on studies of the lasting bronchodilator effects of the various agents (93, 94). Inhaled corticosteroids and leukotriene modifiers need not be withheld. It is important to notify and remind the patient about withholding medications before the test and confirm withholding at the time of the test (95).

Because normal baseline spirometry does not rule out a bronchodilator response, all initial spirometry done for diagnostic reasons should be performed before and after bronchodilator administration. Thereafter the clinician may choose to perform spirometry without bronchodilator responsiveness testing, but it is important to consider baseline variability in lung function when making this decision. Monitoring lung function by serial spirometry, especially in patients with obstructive lung disease, may be more useful by following post-bronchodilator values (96).

Test Procedure

The patient first performs prebronchodilator spirometry to achieve three acceptable FEV₁ and FVC measurements as described previously. Next, the bronchodilator is administered in the dose and by the method specified in the protocol for the spirometry facility (Section E9). Three or more additional post-bronchodilator acceptable FEV₁

and FVC measurements are then obtained after the wait time specified in the facility protocol. Every facility conducting bronchodilator responsiveness testing must have a written protocol for the test.

It is not uncommon for a post-bronchodilator maneuver to be erroneously coded as prebronchodilator, or the converse. The spirometry system must permit the operator to change the designation of the maneuver from pre- to post-bronchodilator, and vice versa, so that a good maneuver is not lost and the patient is not required to perform an additional unwarranted maneuver. When the first post-bronchodilator maneuver is initiated by the operator, the system must display the time elapsed since the last prebronchodilator maneuver. If the elapsed time is less than the wait time for the bronchodilator effect, then the system must provide a warning message to the operator.

Reported Values

The following measurements are reported separately for the sets of prebronchodilator and post-bronchodilator maneuvers (Table 9). The largest FVC and the largest FEV₁ observed from all of the acceptable values are reported (or largest usable values if none are acceptable). Their ratio is used for FEV₁/FVC, even though the largest FVC and the largest FEV₁ may not necessarily come from the same maneuver. If a bronchodilator is administered, both the percentage change and the absolute change in FEV₁ and FVC compared with prebronchodilator values are reported. Recent studies showed that reporting the change in FEV₁ as a percentage of the predicted FEV₁ or as z-scores avoids sex and height bias in assessing bronchodilator responsiveness (97, 98).

FIVC is the largest inspiratory volume immediately after forced expiration from all of the maneuvers. PEF is the highest flow achieved from a maximum forced expiratory maneuver started without hesitation from a position of maximal lung inflation. The largest value from maneuvers meeting the acceptability criteria for FEV₁ in Table 7 is reported.

FET is the time in seconds measured from Time 0 to the end of the expiratory plateau or the beginning of inspiration after maximal forced expiration, or the time that the patient comes off the mouthpiece,

Table 8. Bronchodilator Withholding Times

Bronchodilator Medication	Withholding Time
SABA (e.g., albuterol or salbutamol)	4–6 h
SAMA (e.g., ipratropium bromide)	12 h
LABA (e.g., formoterol or salmeterol)	24 h
Ultra-LABA (e.g., indacaterol, vilanterol, or olodaterol)	36 h
LAMA (e.g., tiotropium, umeclidinium, aclidinium, or glycopyrronium)	36–48 h

Definition of abbreviations: LABA = long-acting β_2 -agonist; LAMA = long-acting muscarinic antagonist; SABA = short-acting β_2 -agonist; SAMA = short-acting muscarinic antagonist.

Note: Withholding times for post-bronchodilator testing are shorter than those for methacholine challenge testing (147) because the bronchoprotection provided by these agents lasts longer than their bronchodilation effects. In the case of dual bronchodilators, the withholding time for the longer-acting bronchodilator is used.

whichever is shortest. The FET does not include any period of zero flow at the end of expiration. The FET from the maneuver with the largest FVC is reported. For patients with airflow obstruction, the FVC may depend on FET. The interpreter must be aware that an apparent change in FVC after bronchodilator administration may be due to a change in FET.

FEV_t is the maximal volume expired by Time t seconds from Time 0 of a forced expiratory maneuver. Children aged 6 years or younger have relatively large airways compared with their lung volume and may complete expiration in <1 second. Therefore, $FEV_{0.75}$ and $FEV_{0.5}$ have been used. In children aged 6 years or younger, $FEV_{0.75}$ was found to provide information similar to that of FEV_1 (99, 100). The

ATS/ERS statement on pulmonary function testing in preschool children states that $FEV_{0.75}$ and $FEV_{0.5}$ should be reported (8). However, because GLI reference values for $FEV_{0.75}$ (but not for $FEV_{0.5}$) are available for ages 3–7 years (59), $FEV_{0.75}$ should be reported for children aged 6 years or younger, and if FET is >1 second, then FEV_1 should also be reported.

The mean forced expiratory flow, midexpiratory phase (FEF_{25-75}), may be reported from the maneuver with the largest sum of FEV_1 and FVC. It should be noted that FEF_{25-75} is highly dependent on the validity of the FVC measurement and the degree of expiratory effort. A volume adjustment may be required when comparing pre- and post-bronchodilator FEF_{25-75} values (101).

Table 9. Measured Variables (Reported Separately for Pre- and Post-bronchodilator Tests)

Variable	Units
FVC	Liters
FEV_1	Liters
FEV_1/FVC	Decimal fraction to two decimal places
PEF	Liters per second
FET	Seconds
FIVC	Liters
For children ≤ 6 yr	
$FEV_{0.75}$	Liters
$FEV_{0.75}/FVC$	Decimal fraction to two decimal places

Definition of abbreviations: FET = forced expiratory time; $FEV_{0.75}$ = forced expiratory volume in the first 0.75 seconds; FIVC = forced inspiratory VC; PEF = peak expiratory flow.

Volumes in liters and PEF in L/s are reported to two decimal places at BTPS (body temperature, ambient barometric pressure, and saturated with water vapor). Spirometry systems must be capable of measuring these variables and reporting them as recommended in the American Thoracic Society standardized format (114). Although FEV_1 , FVC, and FEV_1/FVC are obligatory, the facility manager must have the ability to configure the report to include the other optional variables, such as FEV_6 , FEV_1/FEV_6 , $FEV_{0.5}$, and mean forced expiratory flow, midexpiratory phase (forced expiratory flow between 25% and 75% of the FVC).

Other Derived Indices

FEV_1/FEV_6 has been shown to be useful in the diagnosis of airflow obstruction in adults (102, 103). Recording FEV_6 has the advantages of being more reproducible than FVC, being less physically demanding for patients, reducing the risk of syncope, and providing a more explicit EOF (104–107). Appropriate reference values for FEV_6 must be used (108–111). The ratio of FEF at 50% VC to forced inspiratory flow at 50% VC (FEF_{50}/FIF_{50}) is sometimes used as an indicator of upper airway obstruction (112, 113). A table of all of the measurements required to be available and stored is provided in the online supplement (Section E10).

The ATS standardized report form (114) should be the default report form for spirometry systems. The default set of reference values for all ages should be the GLI reference equations (59), although other options may be provided. In addition to summary reports, the interpreter should have access to a report of all maneuvers within a testing session. The flow and/or volume data from each test session must be available for export with adequate information for the facility manager to extract results and plot volume–time and flow–volume graphs of each maneuver (Section E10). The system should also have the capability to export data to electronic medical records, both as .pdf file copies of the printed report and as discrete data, using the Clinical Document Architecture Release 2 standard of HL7 International (115) or Fast Healthcare Interoperability Resources. Logical Observation Identifiers Names and Codes should be used to identify test data so that data captured in the electronic health record can be accessed and understood universally. A workshop at the ATS 2019 International Conference began the process of developing an interoperability roadmap to integrate pulmonary function data in electronic health records.

The date and time for each maneuver must be recorded. Diurnal variations of 3% in FEV_1 and 6% in PEF have been reported (116), with lower values noted in patients with COPD in the afternoon compared with the morning (117). In addition, the time data are useful for verifying pre- and post-bronchodilator maneuvers.

Operator comments are a key part of the report. The system must permit the operator to enter comments from a

Table 10. Grading System for FEV₁ and FVC (Graded Separately)

Grade	Number of Measurements	Repeatability: Age >6 yr	Repeatability: Age ≤6 yr*
A	≥3 acceptable	Within 0.150 L	Within 0.100 L*
B	2 acceptable	Within 0.150 L	Within 0.100 L*
C	≥2 acceptable	Within 0.200 L	Within 0.150 L*
D	≥2 acceptable	Within 0.250 L	Within 0.200 L*
E	≥2 acceptable OR 1 acceptable	>0.250 L N/A	>0.200 L* N/A
U	0 acceptable AND ≥1 usable	N/A	N/A
F	0 acceptable and 0 usable	N/A	N/A

Definition of abbreviation: N/A = not applicable.

The repeatability grade is determined for the set of prebronchodilator maneuvers and the set of post-bronchodilator maneuvers separately. The repeatability criteria are applied to the differences between the two largest FVC values and the two largest FEV₁ values. Grade U indicates that only usable but not acceptable measurements were obtained. *Although some maneuvers may be acceptable or usable at grading levels lower than A, the overriding goal of the operator must be to always achieve the best possible testing quality for each patient.* Adapted from Reference 114.

*Or 10% of the highest value, whichever is greater; applies for age 6 years or younger only.

dropdown menu as well as free text. The facility manager should have the ability to edit the list of menu options. A list of standard operator comments is given in Section E11.

Grading the Quality of the Test Session

Technical standards are designed to help attain the best result possible for each patient. Spirometry results are very dependent on patient cooperation. Maneuvers done at maximal lung volume with maximal effort are more repeatable than maneuvers that are done at submaximal lung volumes or with submaximal effort. Although there may be other indicators of submaximal spirometry, in general, the acceptability and repeatability criteria provided in this document are validated and objective (1, 86, 114, 118).

The grading system that is recommended by the ATS for spirometry reporting (114), which is a modified version of the system developed by Hankinson and colleagues (80) and expanded to include young children, should be used (Table 10). Grade “U” was added to denote “usable” values. FEV₁ and FVC are graded separately. The grading applies to the set of prebronchodilator maneuvers as a whole rather than individual maneuvers and is determined separately for the set of post-bronchodilator maneuvers.

This grading system informs the interpreter about the level of confidence that the spirometry results represent the best that the patient was able to do at the time of the

test and the probability that an equivalent value would be achieved if the test were to be repeated. Some patients may not be able to meet the criteria for acceptability and repeatability that are necessary for grade A, but nevertheless, their results may be clinically useful. For example, the spirometry maneuver may trigger the cough reflex, and after the first one or two attempts, the patient may not be able to do another acceptable maneuver. In cases in which grades less than A are the best that can be achieved within the test session, the clinical judgment of the interpreter becomes a more important factor in the interpretation of the results. *Although some maneuvers may be acceptable or usable at grade levels lower than A, the overriding goal of the operator must be to always achieve the best possible testing quality for each patient.*

Patients who see the grade assigned to their values might erroneously assume that the grade applies to the health of their lungs. The operator should inform the patient that the grade refers to the consistency of their blows.

VC and Inspiratory Capacity Maneuver

The VC is the volume change between TLC and residual volume (RV). The slow VC can be derived in two ways. The expiratory VC (EVC) is the volume of gas slowly expired from TLC to RV. The inspiratory VC (IVC) is the volume of gas slowly inspired from RV to TLC (Figure 4). These maneuvers are unforced, except at the point of reaching

RV or TLC, respectively, when extra effort is required (119).

Inspiratory capacity (IC) is the volume change recorded at the mouth when taking a slow full inspiration with no hesitation, inspiring from a position of passive end-tidal expiration (i.e., FRC) to a position of maximum inspiration (i.e., TLC). IC is an indirect estimate of the degree of lung hyperinflation at rest and is useful to assess changes in FRC with pharmacological interventions and physical exercise (120–123).

Equipment

For measurements of VC and IC, the spirometer must comply with the requirements for FVC maneuvers above. VC can be measured using conventional spirometers or equipment used to measure static lung volumes and their subdivisions (124). Both inspiratory and expiratory maneuvers must be included in the display of the VC maneuver. Regardless of whether the inspiratory or expiratory maneuver is used for deriving measurements, a display of the entire recorded VC maneuver must be provided to determine whether the patient obtained a plateau in the expiratory effort.

Test Procedure

For a slow VC, a maximum of eight maneuvers is a practical upper limit. It is preferable that VC maneuvers be performed before FVC maneuvers because of the potential for muscular fatigue and volume history effects, whereby, after maximal inspiratory efforts, some patients with severe airway obstruction return to a falsely

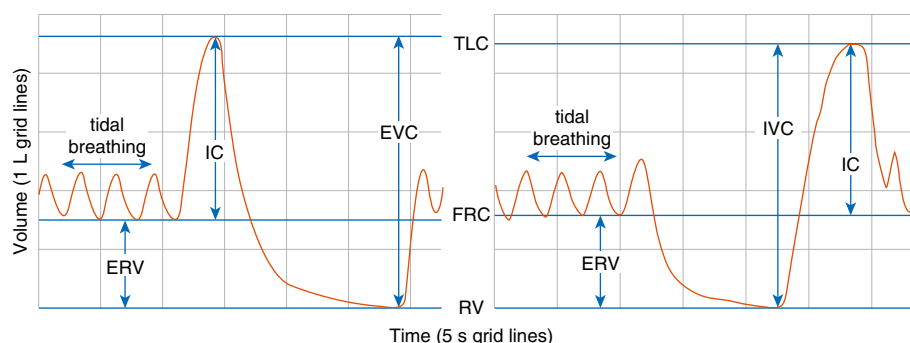


Figure 4. Measurement of VC and IC. VC may be measured either as EVC (left panel) or IVC (right panel). In these examples, divisions on the volume axis are 1 L, and those on the time axis are 5 seconds. ERV = expiratory reserve volume; EVC = expiratory VC; IC = inspiratory capacity; IVC = inspiratory VC; RV = residual volume.

high level of FRC or RV as a result of gas trapping or stress relaxation (4). The VC maneuver may measure either IVC or EVC (Figure 4). Important differences between IVC and EVC maneuvers may be observed in patients with airway obstruction (125–127).

Patients should be relaxed, seated erect with a noseclip in place, and asked to breathe normally until the end-expiratory lung volume is stable. Stability is defined as having at least three tidal breaths with end-expiratory lung volume within 15% of the V_T . If this is not achieved within 10 breaths, the VC part of the maneuver may begin, but the IC will not be reliable. The patient is then urged either 1) to take a deep breath to TLC with no hesitation and expire to RV or 2) to breathe all the way out to RV and then take a deep breath in to TLC, and then breathe normally (Figure 4).

The maneuver is not forced but is performed in a relaxed manner, except near end inspiration and end expiration. The operator should encourage the patient to reach maximal inspiratory and expiratory volumes with a relatively constant flow. In healthy patients, adequate maximal inspiratory and expiratory levels are achieved within 5–6 seconds. Patients with airway obstruction will take longer, but expiration should be terminated after 15 seconds. The expiration should not be excessively slow, because this can lead to underestimation of VC. Operators should observe the patient carefully to ensure that his or her lips are sealed around the mouthpiece, nothing obstructs the mouthpiece, the noseclip is in place with no leaks, and TLC and RV are reached. The system must provide both a visual and an audible signal (single beep) when a stable end-expiratory tidal lung volume is detected

or there have been 10 tidal breaths and, for expiration to RV in either IVC or EVC maneuvers, a double beep when a plateau is reached (<0.025 L in the last second) or the expiration time reaches 15 seconds.

For within-maneuver evaluation, there must be no leak at the mouth or nose and no obstruction of the mouthpiece. The IC may be underestimated if the inspiratory maneuver is too slow because of poor effort or hesitation or if there is premature closure of the glottis.

For between-maneuver evaluation, as with forced maneuvers, a minimum of three acceptable VC maneuvers must be obtained. If the difference in VC between the largest and next largest maneuver is >0.150 L or 10% VC, whichever is smaller, for patients older than 6 years of age or >0.100 L or 10% VC, whichever is smaller, for those aged 6 years or younger, then additional trials should be undertaken. Meeting repeatability criteria may require performing up to eight maneuvers, with sufficient rest time between the maneuvers so that the operator and patient agree that the next maneuver may begin. Large variability in this test is often due to incomplete inspiration. For VC, the largest value from at least three acceptable maneuvers should be reported. For maneuvers in which stable end-expiratory tidal lung volume was not attained, IC is not reported. For IC, the average value from the acceptable maneuvers should be reported.

Further Studies

An analysis of BEV measures from both children and adults is needed to develop evidence-based criteria for acceptable BEV

limits. An analysis of FETs in patients with airflow obstruction is needed to determine better criteria for maneuver acceptability and the impact of shorter FETs in these patients on their diagnosis. Research is needed to validate the EOFE plateau criterion (≤ 0.025 L in 1 s), which is based on expert opinion dating back to 1979 (2). Other unknowns include the optimal resting time between maneuvers and the effect of mouthpiece shape (round, oval, and flared). Updated standards are required for unattended home monitoring spirometry (128–130) and peak flow monitoring. A grading system for the slow VC needs to be developed and evaluated. Studies have shown that ongoing supervised training using a telemedicine system is effective and valid for assessing and monitoring the quality of the spirometry tests performed in primary health centers in a public health system (131, 132).

Other Potential Analyses

Although FEV_1 and FVC are the primary variables measured in spirometry, there is far more information contained in the flow and volume data. Continuing research on innovative analyses that may improve diagnoses or lead to earlier diagnosis in at-risk persons is important, and new methods of measuring volume and flow are strongly encouraged.

Measures of curve shape using flow and volume signal analyses have good agreement with expert impression of expiratory flow–volume curve concavity, which is useful in assessing asthma and cystic fibrosis in children (133). The slope ratio may be useful in mild COPD (134). The calculation of Time 0 may be improved by breakpoint methods using a recursive, segmented linear regression technique (135).

More advanced analyses of the flow and volume data have been proposed to assist in the automation of spirometry quality assessment (136–138) and to automatically detect errors in early termination, cough, extra breaths, and variable flow (139). A system developed using machine learning techniques demonstrated a credible potential to differentiate acceptable maneuvers from ones with poor quality, with performance rates near the level of experts (140).

A study found that an isolated reduction of the FEV_3/FVC ratio is an

indicator of mild lung injury (141), and reductions in FEV₁/FEV₆ (142) or FEV₃/FEV₆ (143) may have higher sensitivity than FEV₁/FVC for detecting early airflow limitation. Lower limits of normal have been derived for FEV₁/FEV₆,

FEV₃/FEV₆, and FEV₃/FVC (109). Estimating FVC using data from the first 2–3 seconds of expiration might potentially either assist in determining whether EOFE was attained or provide a surrogate for FVC when EOFE is not

attained (144, 145). Imaging technology has the potential to monitor spirometry without a direct connection to the patient (146), permitting testing of patients unable or unwilling to use a mouthpiece. ■

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Primary Care Asthma Program **SPIROMETRY MANUAL**

Resource Links:

ATS:

ATS Standardization of Spirometry 2019 Update:

<https://www.atsjournals.org/doi/pdf/10.1164/rccm.201908-1590ST>

ATS/ERS Task Force Standardisation of Lung Function Testing: Standardisation of spirometry (2005): <https://www.thoracic.org/statements/resources/pft/PFT2.pdf>

ATS/ERS Task Force Standardisation of Lung Function Testing: General considerations for lung function testing (2005): <https://www.thoracic.org/statements/resources/pft/PFT1.pdf>

ATS/ERS Task Force Standardisation of Lung Function Testing: Interpretative strategies for lung function tests (2005): <https://www.thoracic.org/statements/resources/pft/pft5.pdf>

ATS/ERS Task Force Standardisation of Lung Function Testing: Standardisation of the measurement of lung volumes (2005): <https://www.thoracic.org/statements/resources/pft/pft3.pdf>

ATS/ERS Recommendations for a Standardized Pulmonary Function Report (2017): <https://www.thoracic.org/statements/resources/pft/standardized-pulmonary-function-report.pdf>

CPSO:

Independent Health Facilities: Assessment Protocol for Pulmonary Function Studies - Technologist Assessor <https://www.cpso.on.ca/CPSO/media/Documents/physician/your-practice/quality-in-practice/clinic-inspections-special-programs/ihf-general-assessment-tools/pulmonary-function/ihf-pulmonary-function-pft-checklist-tech.pdf>

Independent Health Facilities Clinical Practice Parameters and Facility Standards: Pulmonary Function Studies – <http://policyconsult.cpso.on.ca/wp-content/uploads/2014/04/Final-Draft-February-2014.pdf>

CTS:

Spirometry in Primary Care:

http://www.respiratoryguidelines.ca/sites/all/files/CTS_Spirometry_Primary_Care_2013.pdf

Statements on Resumption of Spirometry During a Pandemic: <https://cts-sct.ca/covid-19/pft/>

Practicum:

Lung Health Foundation Education Workshops, Events and E-Modules:

<https://hcp.lunghealth.ca/events/>

Resptrec Spirotrec course:

<https://www.resptrec.org/course/spirometry.php?&currMenu=Spirometry>