TIRED? NO! YOU ARE LOOKING GOOD YOU CAN DO FAR BETTER LETS GO AGAIN.

SPIROMETRY

“LETS DO IT RIGHT EVERY TIME ALL THE TIME.”
QUALITY SPIROMETRY

1. Operator performing the test.
   • Performing The Spirometry Test

2. Patient Information.
7. Spirometry Protocol.
8. Lung Diseases.

This will be a hand on course as a lot have done previous training on spirometry but has not understood the total concept of spirometry because of the jargon they use.
1. **Operator Performing the test**

This is a vital part of all spirometry tests and the outcome of the tests.

- The operator must be familiar with the Spirometer.
- Use the Spirometer's Manual.
- Keep to the instructions laid out by the Manufacturer.
- The Operator should have basic knowledge of spirometry. (What is required by South African Thoracic Society)

**Performing the Spirometry test**

- The greatest potential source of error is the failure of the patient to perform the test properly.
- Spirometry must be performed correctly, because of the serious impact its results can have on a patient's life.

**What to explain to the Patient.**

- Before a lung function test avoid: Smoking, Testing direct after a meal, tight clothing, and if possible still on medication.
- Patient should sit or stand in an upright position during a test manoeuvre.
- Teeth must be over the mouthpiece.
- Lips must be tightly closed to prevent air leaks around the mouthpiece.
- Nose clips must be on the nose.
- Explain to the patient the test Procedure as short as possible e.g. "I am going to have you blow into the machine to see how big your lungs are and how fast the air comes out. " It doesn't hurt but your cooperation is required.
- Key points in your explanation to your patient:" Take a deep breath, blast out hard.
- NB!!! Give feedback about the performance, Encourage and describe what improvements can be made.

**Does the patient understand?**

- Take a deep breath.
- Blow the air out fast and keep on as long as you can. (Start Fast)
- Don't stop, don't cough.
- Try for 6 seconds or as long as you can.
What to observe during the test manoeuvre:

- Keep an eye on the patient and the test.
- Stop the test if it’s not acceptable.
- Explain to the patient what is wrong.
- Try again.
- Encourage the patient at all times during the test.
- When the test is completed, tell the patient the test was done correctly.

Source of error:

- Must get full co-operation of the patient.
- If the co-operation is poor, errors will be extremely visible.
- Technical variation related to the equipment.
- Technique.
- Operator.
- Interaction between the operator and the patient.

What can be done?

- Explain again to the patient. (Patience is needed)
- The results or the diagnoses will be affected by poor blowing.
- Show the patient again how to blow.

2. Patient Information:

- Correct height measurement is important.
- Gender, Age, Height and weight are needed to calculate the predicted values.
- In general, women have smaller lung volumes than men.
- Taller subjects have larger lung volumes, and African origin tend to have smaller lung volumes.

3. Safety precautions:

- Infection control is to prevent infection and cross-contamination to patients and equipment e.g. Against TB, HIV, and Hepatitis.
- It’s advisable to use disposable mouthpieces and bacterial filters.
- To avoid cross-contamination, wash hands, disinfect worktops, use gloves and sterilize equipment and consumables regularly.
- Flow-sensing turbine must be sterilized regularly according to manufacturer’s specifications.
- The next patient must be sure of a clean and infection-free environment.
Summary of ATS Recommendation
1994 Update

1. At least 3 acceptable trials should be performed, with a maximum of 8 trials.

2. Expired time should not be less than 6 seconds.

3. Reproducible tests of 3 acceptable curves:

   The largest FVC or FEV1 and the second largest FVC and FEV1 from acceptable curves should not vary by more than 200ml.

4. The best test selected is the largest sum of the FVC and FEV1. From this test the PEF and FEF 25% - 75% is recorded.

<table>
<thead>
<tr>
<th></th>
<th>Best</th>
<th>Pred</th>
<th>% B/P</th>
<th>Act 1</th>
<th>Act 2</th>
<th>Act 3</th>
<th>Act 4</th>
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<tbody>
<tr>
<td>FVC</td>
<td>5.45</td>
<td>4.42</td>
<td>123</td>
<td>5.46</td>
<td>5.45</td>
<td>5.32</td>
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<td>FEV1</td>
<td>4.44</td>
<td>3.61</td>
<td>123</td>
<td>4.35</td>
<td>4.44</td>
<td>4.33</td>
<td>4.45</td>
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<tr>
<td>FEV1/FVC%</td>
<td>82</td>
<td>82</td>
<td>100</td>
<td>80</td>
<td>82</td>
<td>81</td>
<td>82</td>
</tr>
</tbody>
</table>

References:
3. Manual Erich Jaeger
Characteristics of an acceptable flow-volume loop:

- After a full inspiration, an instantaneous start and exhalation.
- A rapid rise in flow to peak.
- Sharp peak showing maximal effort, close to a vertical line.
- Smooth continuous exhalation no coughs or glottal closure and not less than 6 seconds.
- Smooth continuous inspiration.
- Reproducible graphs over lapping indicating no variable air flow.
- Meet ATS recommendation.
Characteristics of an unacceptable flow volume loops:

- Poor slow start of exhalation and slow rise in flow to peak.
- Flat peak due to lack of optimal peak.
- Erratic exhalation with cough.
- Exhalation not complete due to lack of effort or less than 6 seconds.
- Inhalation not complete.
- Leak at the mouth.
- Obstruction in mouth piece due to tongue or false teeth.
Parameters represented in the Flow volume:

- **FVC**: Forced Vital Capacity
- **FEV1**: Forced Expiratory Volume after 1 second
- **FEV1/FVC%**: FEV1/FVC% ratio
- **PEF**: Peak Expiratory Flow
- **FEF25**: Forced Expiratory Flow at 25% of FVC
- **FEF50**: Forced Expiratory Flow at 50% of FVC
- **FEF75**: Forced Expiratory Flow at 75% of FVC
- **MMEF 25/75**: Mean Maximum Expiratory Flow between 25-75% of FVC
- **FVC IN**: Forced Vital Capacity Inspired
- **FIF 50**: Forced Inspiratory Flow at 50% of FIVC
Pulmonary Function Test Results

Pohsa t/a Medical & Audiometric Saleas

013 661 2180

Visit date 02/04/2009

ID 7712210014083
Last name Oliphant  Age 31
First name N  Gender Female
Date of birth 21/12/1977  Height, cm 168
Ethnic group Caucasian  Weight, kg 100
Smoke

Interpretation
Normal Spirometry

Conclusion / Medical report

PRE Trial date 12/05/2009  12:32:31 PM

Parameters  BTPS  Pred  PRE  %Pred  POST  %Pred  %Chg  PRE#1

Forced Vital Capacity
Best values from all loops

- FVC  L  3.75  4.21  112
- FEV1  L  3.26  3.90  120
- FEV1/FVC  %  83.2  92.6  111
- PEF  L/s  7.20  8.77  122

Values from best loop

- FEF25  L/s  3.97  4.94  125
- FEF25  L/s  6.23  7.27  117
- FEF50  L/s  4.50  4.99  111
- FEF75  L/s  2.10  2.84  135
- FIVC  L  3.75  3.69  82
- FIV1  L  3.26  2.97  91
- FIV1/FIVC  %  83.2  96.1  115
- ELA  Years  31  31

Lung Volumes and breathing pattern

- VC  L
- IVC  L
- FEV1/VC  %
- ERV  L
- IC  L

Maximum Voluntary Ventilation

- MVV  L/min

Signature

Instrument used
Spirobank II S/N 001686
Spirometer Calibration Report

Calibration test SUCCESSFULLY COMPLETED. The Device is now using the following correction values:
(Expiration: 0.92%, Inspiration: -1.23%)

Date 21/05/2009
Time 10:02

Device
SPIROBANK II
Serial Number 001686
Version 3.1
Turbine Reusable

Calibration Test Results
BTPS 1.124
Test Target 3 L

Calibration Test Details

<table>
<thead>
<tr>
<th></th>
<th>3.01</th>
<th>3.00</th>
<th>3.09</th>
<th>3.02</th>
<th>3.05</th>
<th>3.05</th>
<th>3.02</th>
<th>3.07</th>
<th>3.02</th>
<th>3.04</th>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Inspiration (L)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* Volume Out Of Range (Excluded from Calibration)

IMPORTANT: Flow and volume values measured during calibration are at ATP (Ambient Temperature and Pressure) conditions. All spirometry parameters instead are converted to BTPS conditions (Body Temperature and Pressure, Saturated). E.g., a 3L syringe (ATP) measured during calibration will produce an FVC of 3.08 L (BTPS).

User WINSPIRO
Signature
SPIROMETRY PROTOCOL

Rating of impairment related to lung function.

**NORMAL:**
- FVC and FEV > 80%
- FEV / FVC x 100 > 75%

**MILD:**
- FVC and FEV > 60 - 79%
- FEV / FVC x 100 > 60 - 74%
(Usually not correlated with diminished ability to perform most jobs)

**MODERATE:**
- FVC > 51 - 59%
- FEV > 41 - 59%
- FEV / FVC x 100 > 41 - 59%
(Progressively correlated with diminished ability to meet the physical demands of many jobs)

**SEVERE:**
- FVC > 50%
- FEV > 40%
- FEV / FVC x 100 > 40%
(Unable to meet the physical demands of most jobs including travel to work)

FEV / FVC %

<table>
<thead>
<tr>
<th>OBSTRUCTIVE</th>
<th>NORMAL</th>
<th>RESTRICTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 80%</td>
<td>80 - 100%</td>
<td>80%</td>
</tr>
<tr>
<td>- Lungs fill effortlessly but unable to blow out effectively within the first second</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Air trapping occurs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Factors that may influence test include:

- Medication such as bronchodilators
- Recent viral infection, flu, pneumonia, bronchitis (acute lung diseases)
- Serious illnesses (pulmonary emboli) (chronic lung diseases)
- Cigarettes 1 hour before testing
- A heavy meal 1 hour before testing
- Height and weight - obesity
- Pregnancy
- Exposure such as coal dust, fly ash and asbestos
- Injury to chest and lungs
- Tight clothing
- Incorrect technique
- Inability to follow instruction
- Test position
Correct test position:

- Feet on floor
- Legs together
- Back straight
- Neck slightly extended
- Remember lips must seal mouth piece
- Don't bite the mouth piece
- Take a deep breath, blast out hard and do not stop blowing until told to do so ± 6 seconds
- Every action need to be quick and forceful - blast
- Use abdominal muscles
Lung Diseases:

A. Chronic Obstructive Lung Diseases: (COPD)

Is a decrease or loss of air flow to volume.

Emphysema
Chronic bronchitis
Asthma
Cystic fibroses
Tumours
Vocal cord dysfunction

B. Restrictive Lung Diseases

Is a decrease or loss of lung volume (lung tissue).

Lung cancer, pulmonary edema, pneumonia, surgical removal of lung tissue, tumour.

Interstitial lung Diseases:
- idiopathic fibrosis
- pneumoconiosis
- sarcoidosis

- neuromuscular disorders
- congestive heart failure

Disease that effect chest wall and pleura:
- spinal cord
- peripheral nerves
- respiratory muscles
- reduction of thoracic space caused by pleural effusion, pneumothorax
- limited movement of diaphragm cause by pregnancy and abdominal fluid
SPIROMETRY FOR ALL

BY THOMAS L. PETTY, MD

The fact is that spirometry is more valuable in predicting premature death from heart attack than the electrocardiogram and, therefore, should be part of the physical examination.

Thus, the concept of entities such as "early small airways disease" have crept into the literature. These are erroneous and only serve to confuse. The only values that are of established clinical value in spirometry are the forced vital capacity (FVC), the FEV1, and the ratio between the two.

Today there is a massive need for simple, idiot-proof and almost indestructible handheld office devices that will give us only these key numbers. Industry is capable of producing such devices, which simply display FVC, FEV1 and the ratio along with peak flow. (This is just like a Doppler automatic blood pressure cuff device used in drugstores all over America, which displays systolic and diastolic blood pressure.) If repeatability of values can be achieved there can be little doubt about the effort of the individual and the validity of the results. In fact, it has been shown that patients can be taught to do their own spirometry at home with accuracy equivalent to that in the pulmonary function laboratory.

Additionally, all smokers should receive spirometry. So should everyone with chronic cough, dyspnea or wheeze—the hallmarks of COPD, asthma, and related disorders. In fact, it would be wise to do spirometry as a baseline prognostic database for all adults, at least once in their lifetime. All primary care deliverers need a spirometer for their office. This can cut the time required to receive values from a pulmonary function laboratory, with great savings in cost. The flow of traffic through the office or clinic need not be interrupted. Spirometry can be done along with the other vital signs.

If screening spirometry is abnormal, as it often is in smokers with no symptoms, more detailed pulmonary function testing can follow. Thus the simple, handheld spirometer will not compete with the full pulmonary function laboratory. In fact, simple spirometry will identify more patients who need formal spirometry and possibly other lung function tests.

It never ceases to amaze me that physicians will give potent and potentially toxic drugs, such as bronchodilators and systemic corticosteroids, to patients without ever making any measurement to establish their need or to determine that maximum benefit has been achieved. Certainly no one would give insulin without checking blood sugar, warfarin sodium without prothrombin tests, or an antihypertensive without measuring blood pressure. How can physicians adequately and accurately treat airflow or even restrictive disorders without measurements of outcome? The fact is that they cannot.

Today there is a new initiative Known as National Lung Health Education Program (NHELP).

The motto of NHELP is “Test Your Lungs/Know Your Numbers. NHELP focuses on the importance of early identification and intervention in COPD when most people have few or no symptoms.

It is well established that most lung cancer is found in heavy smokers with airflow obstruction. The only way for NHELP to succeed is for all primary care physicians to have a spirometer in their own offices and clinics.

“Spirometry for all” should become the battle cry of the respiratory care professionals.

The Journal for Respiratory Care Practitioners
South African Thoracic Society

GUIDE FOR

OFFICE SPIROMETRY IN ADULTS

Principal Authors:

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Departments of Medicine, \textsuperscript{1}Tygerberg Hospital and University of Stellenbosch, Tygerberg; \textsuperscript{2}Pretoria Academic Hospital and University of Pretoria, Pretoria; \textsuperscript{3}Groote Schuur Hospital and University of Cape Town, Cape Town.

ABSTRACT

Objective: To provide guidelines for office spirometry.

Options: More stringent standards are required for diagnostic laboratories and research.

Outcomes: To minimise variations and improve the quality and usefulness of spirometry in clinical practice in South Africa.

Evidence: Recommendations are based on key international publications. Additionally, research publications regarding reference values for South Africans have been considered.

Benefits, harm and costs: The medical, social and economic benefits of standardisation of lung function testing were considered in the recommendations.

Validation: The document has been reviewed and endorsed by the South African Thoracic Society.

Conclusions: Requests for spirometry should clearly state the indication. Spirometry equipment should carry a certificate of validation that established performance criteria have been met. Equipment should be regularly calibrated and maintained. Individuals
performing spirometry should be adequately trained and demonstrate a high level of competence. Subject preparation, testing, quality control and interpretation of results should be standardised according to published guidelines. Finally, it is the task of the clinician to integrate test results with pre-test information and knowledge of the patient and disease.

1. Glossary

ATPS = Ambient Temperature, Barometric Pressure Saturated with Water Vapour
ATS = American Thoracic Society
ECCS = European Community for Coal and Steel
ERS = European Respiratory Society
FEF$_{25-75\%}$ = Forced Expiratory Flow at 25-75% of Forced Vital Capacity
FEV$_1$ = Forced Expiratory Volume in One Second
FVC = Forced Vital Capacity
LLN = Lower Limit of Normal
RSD = Residual Standard Deviation
SATS = South African Thoracic Society
TLC = Total Lung Capacity
VC = Vital Capacity.

2. Introduction

Spirometry is an essential component of a complete respiratory evaluation, but inadequate standards and variations in standard operating procedures reduce its usefulness$^1$. Good quality spirometry necessitates a competent operator, accurate and reliable equipment and a co-operative patient. It involves a series of standard procedures and quality control checks to produce technically satisfactory results. Finally, the results take reference standards into account and are interpreted with
consideration of the indications and the clinical information regarding the test subject.

Various authorities have published detailed guidelines for the standardisation of spirometry. This statement has been prompted by the increasingly widespread use of office spirometry in South Africa and a perceived need for a simple guidance document on its proper performance. This includes recommendations on the use of reference standards and the interpretation of results. More recently selective South African reference standards have become available for the normal range of forced vital capacity (FVC) and forced expiratory volume in one second (FEV₁). Diagnostic and research lung function laboratories will require more stringent standardisation of spirometry than proposed in this document.

3. Definitions and Background Information

Spirometry. Spirometry is only one of a number of tests to evaluate respiratory function. Used in its simplest form, it measures the gas volume and the rate of airflow during a maximal, forced expiration. The mechanical properties of the airways as well as the lung, pleura, chest wall and respiratory muscles, contribute to these results.

Spirometer. Two major types of spirometers can be found:

- Volume-displacing. These have the advantage of cost and ease of operation, but handling of data is laborious unless it contains a microprocessor.
- Flow-sensing. These can produce flow-volume loops for instant pattern recognition, have adequate potential for handling and storage of data, but require more knowledge and diligence to operate.

Spirogram. The results are displayed in graphic form with absolute values and percentages of a reference standard. The volume-displacing device generates a volume-time curve (Figure 1a) and the flow-sensing device generates a flow-volume curve (Figure 1b). Some flow-sensing devices can also derive a volume-time curve.

Measurements. Depending on the type and level of sophistication, spirometers can produce a range of measurements from which extrapolations can be made.

Minimum requirements:

- **Forced Vital Capacity (FVC):** The vital capacity (VC) refers to the maximum volume of gas that can be inhaled from the position of maximal expiration or exhaled from the position of maximal inspiration. This can be measured during either slow breathing or forced breathing. One is primarily interested in performance during maximal forced expiration, thus FVC. The unit of measurement is litres.
- **Forced Expiratory Volume in 1 second (FEV₁):** The FEV₁ refers to the gas volume exhaled during the first second of the FVC manoeuvre. Of all the spirometric measurements, the FEV₁ has the best overall correlation with respiratory functional ability. The unit of measurement is *litres*.

- **FEV₁/FVC:** The FEV₁ as a fraction of the FVC is of primary diagnostic value (see section 9.3) and is usually expressed as a percentage (FEV₁/FVC x 100).

**Other measurements:**

- **Other VC manoeuvres:** The slow VC or inspiratory VC can provide additional information when severe airflow limitation is present (see section 8.1).

- **Peak Expiratory Flow (PEF):** The PEF is the maximum flow that can be generated during forced expiration. Acceptability criteria for the flow-volume curve include PEF criteria (see section 8.2.1).

- **Forced Expiratory Flow at 25%, 50% or 75% of the FVC (FEF₂₅%, FEF₅₀% or FEF₇₅%):** Under certain conditions the maximum instantaneous flow at 25%, 50% or 75% of the FVC is useful to detect early obstruction.

**Calibration.** Calibration is the process whereby the accuracy (truthfulness of measurements) and precision (repeatability of measurements) of an instrument is checked and corrected.

**Validation.** Validation is the process of establishing and certifying the accuracy and precision of an instrument.

**Operator.** The term operator refers to the person performing spirometry.

4. **Indications**

Indications for spirometry should be specific for the diseases under investigation. This emphasises the importance of close co-operation with a clinician when referring for
spirometry or planning a respiratory surveillance programme. The most frequent indications for spirometry in a clinical context are listed below:

- **Confirming a diagnosis.**
  - Individuals with symptoms and signs of obstructive lung disease.
  - Individuals with symptoms and signs of restrictive lung disease.

- **Monitoring change in health status.**
  - Individuals with chronic respiratory diseases - to monitor changes in severity, including responses to treatment.
  - Individuals working in occupations that expose them to injurious substances - to monitor lung function changes.

- **Grading respiratory impairment**
  - Individuals requiring evaluations for medico-legal purposes (e.g. insurance or disability).
  - Individuals on treatment-action plans.
  - Elderly individuals and individuals with chronic respiratory diseases undergoing thoracotomy or upper-abdominal surgery, and all individuals requiring lung resection - to determine operative and post-operative risk.

- **Screening for lung disease.**
  - Smokers - to screen for COPD or early signs of airflow limitation.
  - Individuals with persistent respiratory symptoms, including shortness of breath (dyspnoea), chest tightness, wheezing, coughing, sputum production and chest pain.
  - New employees with potential for exposure to injurious workplace substances - to establish a baseline.
  - Individuals regularly exposed to injurious workplace substances - to screen for disease-specific abnormalities.

It should be noted that the sensitivity and specificity of office spirometry as a screening test might vary according to the disease in question. A normal spirogram would, for instance, exclude clinically significant COPD or asbestosis, but not asthma or silicosis. A symptom questionnaire might be a more appropriate screening tool for asthma, followed by confirmatory lung function tests and include a bronchial challenge test if the spirogram is normal. For silicosis, a chest radiograph would be a more...
appropriate screening test because lung function abnormalities usually develop after radiographic changes.

5. Spirometer Performance Recommendations

5.1 Certificate of Validation

Accuracy and precision of commercially available spirometers are not automatically guaranteed. The American Thoracic Society (ATS) recommends minimal performance criteria for the range of volumes and flow-rates, accuracy and precision. Specifications for the most important measurements are summarised in Table 1. Spirometers should have proof of validation according to ATS standards. Alternatively, published results of biological validation, using subjects with and without lung function impairment, should be available.

Other factors that should be considered in the purchase of a spirometer include:

- The ability to produce real-time spirograms
- Computer-driven technical quality indicators
- The ability to print results for record keeping purposes
- For occupational surveillance - adequate facility to save all test results and test quality indicators
- Availability of after-sales service

When in doubt, independent professional advice should be obtained before a spirometer is purchased.

5.2 Daily Calibration

Spirometers must be calibrated frequently to ensure they remain accurate during use. This is one of the primary functions of the operator and should be performed at least daily. All the systems that are currently available require calibration. Volume calibration automatically ensures calibration of flow. Calibration involves the following steps:

- Set the spirometer to register gas at ambient conditions (ambient temperature, barometric pressure, saturated with water vapour (ATPS)). Enter room temperature and barometric pressure (also obtainable daily from the local airport or weather bureau).
- Specify calibration syringe size e.g. 3 litres.
- Connect calibration syringe and inject the maximum volume of air into the spirometer. For the flow-measuring device slow, moderate and fast injections must be performed. Repeat calibration if the recorded volume is not within 3% or 50 ml, whichever is the greater. If the measured volume remains outside the acceptable range, check for air leaks or malfunctioning. If
bacterial filters are used, calibration should be performed with the filter in place.

Spirometers should be routinely maintained according to the manufacturer's specifications. Flow-sensors are particularly sensitive to moisture, secretions and dust and should be cleaned regularly (+/- once a week). A once-yearly maintenance and complete calibration check by the manufacturer is also recommended.

6. Operator

6.1 Qualifications

The operator must have an understanding of the principles underlying the measurements and equipment operation. In addition, the operator must be able to ensure optimum subject co-operation, provide acceptable, reproducible results and recognise common abnormalities. Training of Pulmonary Medical Technologists includes this competency and others, including those related to advanced lung function tests and laboratory quality assurance.

6.2 Quality Assurance

A quality assurance programme is critical to ensure a well functioning spirometry laboratory. This may be difficult to attain in a routine clinical practice. At a minimum, a calibration and maintenance log as well as electronic or hard copies of whole spirograms should be kept so that accuracy and precision of past tests can be verified. Additionally, standard operating procedures should be documented.

6.3 Hygiene and Infection Control

Mouthpieces, nose clips, proximal valves and tubing are potential vehicles for transmission of infection. Transmission of *M. tuberculosis* and other aerosolised microorganisms must be avoided. The need for infection control is in part determined by the test procedures followed (expiratory versus expiratory-inspiratory) and the type of apparatus (open versus closed-circuit). Expiratory manoeuvres without re-breathing reduce the potential for infection and is the method of choice for mass screening purposes. Recommendations are:

- A well-lit and ventilated area to perform spirometry.
- Anti-bacterial masks for operators.
- Gloves to remove mouthpieces, nose clips or tubing.
• Disposable mouthpieces.
• Cleaning of spirometers according to the manufacturer's recommendations and the frequency of tests done.

During procedures involving inspiratory manoeuvres, full requirements for infection control must be met including the use of anti-bacterial filters.

7. Subject Preparation

7.1 Withdrawal of Medication and Current Respiratory Infections.

Note the time of last bronchodilator use. If a bronchodilator test is required, short-acting bronchodilators should be withdrawn for at least 4 hours and long-acting bronchodilators and theophylline for at least 12 hours. Current respiratory infections must be excluded before spirometry is performed.

7.2 Morphologic and Demographic Details.

Collect information and enter into the program:

• Date and name.
• Age, sex, race, weight and standing height (measured without shoes). This information is required for the calculation of expected or normal reference values for individuals (see section 9.2).

7.3 Positioning the Subject

• Subjects must be made to feel comfortable. Shelter the subject from other patients to minimise inhibitions or distractions. Loosen tight clothing. Leave well fitting dentures in, but remove loose fitting ones.
• The sitting position is recommended. The chin should be slightly elevated and the neck slightly extended. This posture should be maintained during the forced expiration. Discourage excessive bending at the waist.
• The use of a nose clip is recommended especially for inspiratory manoeuvres.
• Instruct the patient when to insert the mouthpiece e.g. at the end of maximal inspiration. Ensure that the subject does not bite the mouthpiece too hard, that the lips are sealed tightly around it and that the tongue does not obstruct the mouthpiece in any way.

7.4 Instruction and Demonstration.

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Spirometry is extremely effort-dependent and the operator must ensure maximum subject co-operation. Sub-maximal efforts are a frequent cause of abnormal results. Techniques should be explained in simple terms and demonstrated to the patient. One statement that works well is: “I am going to have you blow into the machine to see how big your lungs are and how fast the air comes out. It does not hurt but requires your co-operation and lots of effort”. Explain and demonstrate the use of a nose clip and mouthpiece. Remind the patient of a few key points. “Be sure to take as deep a breath as possible, blast out hard and do not stop blowing until I tell you to do so.” Give feedback about the performance, encourage and describe what improvements can be made.

8. Test Manoeuvre, Acceptability and Reproducibility

8.1 Test Manoeuvre

Test manoeuvres are determined in part by the setting and level of sophistication of the spirometer:

- **FVC test with or without a slow VC test.** For reasons of ease, cost and infection control this method is recommended for mass screening. For the FVC test the test subject is required to inhale maximally before inserting the mouthpiece and starting the test. Expiration should be rapid, forceful and complete, lasting at least 6 seconds. The FVC, FEV₁ and FEV₁/FVC are recorded. If significant obstruction is demonstrated, proceed with a slow VC test. The slow VC test is preceded by a maximal inspiration, the mouthpiece is inserted and the patient then breathes out in a relaxed fashion and for as long as possible. Allow for up to 15 seconds. Only the VC is recorded. Rationale for the performance of a slow VC test: the slow VC provides additional information on the characteristics of the obstructive defect. A reduction in the FVC compared to the slow VC signifies dynamic collapse of unsupported airways during forced expiration leading to air trapping.

- **Inspiratory-expiratory manoeuvres (for the flow-measuring device).** A period of quiet breathing is followed by a complete expiration, a rapid, forceful and complete inspiration and finally, a rapid, forceful and complete expiration. Some programmes require that the expiratory manoeuvre be performed before the inspiratory manoeuvre. However, the first method is recommended, since this will reveal air trapping as described above. As with the slow VC manoeuvre, air trapping does not occur during the forced inspiratory manoeuvre. In this case a reduced FVC compared to the inspiratory VC will reveal air trapping.
8.2 Termination of Testing

Testing is complete when 3 technically acceptable spirograms had been obtained; at least 2 of which must be reproducible.

Acceptability Criteria. Technically acceptable spirograms (Figure 1) have recognisable characteristics that include:

- An unhesitating start-of-test with an initial steep rise.
- The PEF of the flow-volume curve is reached within 15% of the expired volume.
- A continuous smooth expiration without artefacts caused by coughing, variable effort, second inhalations or leaks influencing the FEV₁ or FVC.
- A complete expiration until the lungs are “empty”, lasting at least 6 seconds (longer in severe obstruction) or until the volume-time curve has reached a plateau and the flow-volume curve has gradually returned to zero flow.

Reproducibility Criteria. Evidence of good compliance or reproducibility is shown by curves that are more or less superimposed on each other (Figure 2).

If these criteria are not met testing should be terminated after 8 attempts. Technically unsatisfactory manoeuvres should be rejected. A number of the common patterns are illustrated in Figures 3 - 5. The best of all acceptable curves should be used and the lack of reproducibility clearly noted. Causes of non-reproducible curves include airway responsiveness as found in asthma leading to a progressive decline in FEV₁ and FVC with successive attempts. When a bronchodilator test is performed, reproducibility before and after the use of a bronchodilator is essential for a valid interpretation of the response.

9. Results Interpretation and Reporting

9.1 Choose the Best Test

Choose the highest FVC and FEV₁ recorded from all acceptable curves, including the pre- and post bronchodilator curves, even though it may come from separate curves. The best spirogram is the one with the largest sum of FVC and FEV₁ and should be used for all other assessments.

9.2 Compare Results with Reference Standards
Observed spirometric test values from individuals are evaluated for a deviation from normal that may indicate the presence of disease, by comparison with predicted values from a normal reference population. Predicted values for FVC and FEV₁ are calculated from equations based on an individual’s age and height (see Table 3), with separate equations for males and females, since these characteristics are the most important determinants of lung and airway size in healthy individuals. The comparison is made as observed / predicted, expressed as a percentage. Office spirometers are typically programmed with prediction equations derived from the study of reference populations of European descent. Populations of European descent, when compared to other populations usually show higher lung volumes and higher forced expiratory flow-rates, but similar or lower FEV₁/FVC ratios. Use of inappropriate reference values can result in an increased rate of abnormal results in clinically normal people which could, in certain contexts result in unfair discrimination. However, trying to take ancestry into account when calculating predicted values in all contexts where spirometry is used presents practical difficulties and may not be feasible. Reference equations for calculating predicted values have been identified based on studies carried out in South Africa. Use of indigenous prediction equations, as detailed in Table 3, is recommended when spirometry is used for a more precise evaluation of respiratory impairment as might be required for medico-legal purposes. ECCS (European Community for Coal and Steel) or other prediction equations endorsed by the ATS or European Respiratory Society are widely available in software for office spirometry. Programmes usually use a factor such as 0.9 to adjust for ancestry other than European. Use of such factors is acceptable when understood as an approximation. Operators should be aware of the pre-programmed reference equations and adjustment factors used in their spirometry software.

### 9.3 Interpretation

Diagram 1 provides a simple algorithm for the categorisation of spirometric results using fixed percentages to define abnormal. An FVC and FEV₁ below 80% of the predicted value is regarded as below the lower limits of normality. Diagnostic interpretation of results should, however, be made with consideration of pre-test information. When spirometry is used in a screening or occupational surveillance context, best practice is to define abnormal as less than the lower 95% confidence limit or two standard deviations of the predicted value (1.64 x S.D. – see Table 3). FVC or FEV₁ greater than 100% predicted has only positive implications.

### 9.3.1 Obstructive defect
The sensitivity and specificity of spirometry to detect expiratory airflow limitation (obstruction) and predict a bronchodilator response is highest when FEV₁/FVC less than 70% is set as the lower limit of normal. The absence of obstruction by these criteria excludes clinically significant COPD\textsuperscript{22}. The presence of airflow obstruction is readily recognisable on the flow-volume curve (Figure 6). In smokers, borderline values of FEV₁/FVC in the presence of a normal FEV₁ and FVC should alert the clinician to the possibility of early COPD. This is confirmed by reduced values of FEF\textsubscript{25-75}%. A bronchodilator test is always indicated if an obstructive defect is detected. The absence of obstruction does not exclude a diagnosis of asthma. A bronchodilator test may still be of value if asthma is suspected and spirometry is apparently normal. Severity of obstruction is graded according to the percentage of predicted FEV₁\textsuperscript{13}. Failure to detect a mild obstructive defect or under-estimation of the degree of obstruction is the commonest false negative in office spirometry. This is usually due to under-estimation of FVC for technical or physiological reasons.

9.3.2 Restrictive defect

Restrictive lung function is defined by a reduced Total Lung Capacity (TLC), as determined by body plethysmography or other advanced tests. A reduced FVC, determined by spirometry, suggests a restrictive defect. Figure 7 represents a restrictive lung function pattern. The severity of the defect is usually graded according to the percentage of reference FVC. A range of conditions can reduce FVC:

- Conditions impeding movement of the chest wall (e.g. pain, pleural thickening or effusion, neuromuscular weakness, skeletal abnormality or hyperinflation with air trapping).
- Diffuse conditions of lung parenchyma causing stiffness of the lung (e.g. interstitial lung disease with fibrosis, pulmonary oedema).
- Conditions causing reduced communicating lung volume (e.g. lung resection, occlusion of a main bronchus, post-tuberculous lung destruction and space-occupying lesions in the chest).

Diagnostic interpretation of a reduced FVC can be difficult and referral to a specialist should be considered if the impairment is significant (FVC < 60% of reference). Detection of restrictive abnormalities is the commonest false positive in office spirometry and may be due to a poorly performed test (see figures 4 and 5) or use of inappropriate prediction equations.

9.3.3 Obstruction with a reduced FVC
This pattern can be found either with severe obstruction or with a combination of an obstructive and restrictive condition. Measurements of the VC utilising inspiratory or slow manoeuvres (see section 8.1), and a bronchodilator test are required to adequately measure volumes and flow. The severity of the defect is graded according to the indicator showing the most severe defect, usually the FEV\textsubscript{1}.

9.3.4 Bronchodilator response

A bronchodilator test determines whether airway obstruction is reversible with inhaled beta-2 agonists or not (Figure 7). Both the percentage and the absolute volume improvement in FEV\textsubscript{1} are important. An improvement of at least 12% and 200 ml after salbutamol 400 micrograms or equivalent is regarded as significant. The post-bronchodilator test should be done at least 10 minutes after administration of the bronchodilator. The maximum effect of the bronchodilator is only reached after at least 20 - 30 minutes and if no response is noted after 10 minutes, the FEV\textsubscript{1} should be repeated once more time has elapsed. Both pre- and post-bronchodilator FEV\textsubscript{1} should be reproducible; otherwise a “response” cannot be confidently interpreted as such. The percentage improvement is calculated as follows:

\[
\left\{ \frac{\text{FEV}_1 \text{ post-BD} - \text{FEV}_1 \text{ pre-BD}}{\text{FEV}_1 \text{ pre-BD}} \right\} \times 100
\]

It must be remembered that the dose of bronchodilator medication, recent prior medication and timing of the post-medication manoeuvre can all significantly influence the measured results. The test should be standardised within a centre.

9.4 Grading of Severity

For uniformity of practice, lung function abnormalities should be graded as either mild, moderate or severe. In Table 2 a guide to grading the severity of abnormalities is presented\textsuperscript{13}. It must be noted that an accurate diagnosis is a prerequisite for grading severity of impairment and that non-spirometric factors may contribute significantly to impairment.

Clinicians are cautioned when using spirometry alone to grade impairment for medico-legal or other purposes. Although the FEV\textsubscript{1} has the best correlation with respiratory impairment, especially in COPD, it may only be one component of impairment. If there is a discrepancy between what the patient states, clinical severity and spirometry...
results, additional investigations are indicated and the individual should be referred to a specialist with diagnostic lung function facilities. These may include carbon monoxide diffusion capacity, especially relevant in interstitial lung diseases, exercise testing or bronchial challenge testing. Special considerations also apply to asthma. Complete guidelines for the evaluation of respiratory impairment are available.¹³,¹⁴

9.5 Reporting

When reporting on spirometry the following evidence should be presented:

- Identification of subject and date of testing.
- Numerical values and graphs to assess acceptability.
- Evidence of reproducibility.
- Origin of reference standard.
- Latest calibration date.

The report should refer to lung function and not disease (e.g. "obstructive lung function defect without reversibility") rather than "chronic obstructive lung disease"), as the reporter does not always have full clinical details to make an appropriate diagnosis. It is the function of a clinician to incorporate the results of spirometry into a final diagnosis.

10. The Spirometry Standardisation Working Group

SATS Council appointed a Working Group during 1999. This document has been circulated to members of Council and other interested parties and presented at the SATS Conference in August 2001.

11. Acknowledgements

The working group would like to thank all reviewers for their input and the staff of the lung function laboratory at Tygerberg Hospital for assistance with graphic material.

12. References


Table 1. Minimal performance criteria for diagnostic spirometers

<table>
<thead>
<tr>
<th>Measurable Range</th>
<th>Accuracy (BTPS)</th>
<th>Flow Range (L/s)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC 0.5 to 8 L</td>
<td>± 3% of reading or ± 0.050 L, whichever is greater</td>
<td>0 to 14</td>
<td>30</td>
</tr>
<tr>
<td>FVC 0.5 to 8 L</td>
<td>± 3% of reading or ± 0.050 L, whichever is greater</td>
<td>0 to 14</td>
<td>15</td>
</tr>
<tr>
<td>FEV₁ 0.5 to 8 L</td>
<td>± 3% of reading or ± 0.050 L, whichever is greater</td>
<td>0 to 14</td>
<td>1</td>
</tr>
<tr>
<td>PEF</td>
<td>± 10% of reading or ± 0.300 L/s, whichever is greater</td>
<td>0 to 14</td>
<td></td>
</tr>
<tr>
<td>Flow -14 to +14 L/s</td>
<td>± 5% of reading or ± 0.200 L/s, whichever is greater</td>
<td>0 to 14</td>
<td>15</td>
</tr>
</tbody>
</table>

Validation with 3 L calibration syringe and/or standard waveforms. The time point from which all FEV₁ measurements are taken determined through back extrapolation².

Table 2. Guide for grading spirometric abnormalities based on percent observed/predicted

<table>
<thead>
<tr>
<th></th>
<th>Normal*</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV₁</td>
<td>&gt;80%</td>
<td>60-79%</td>
<td>41-59%</td>
<td>≤40%</td>
</tr>
<tr>
<td>FVC</td>
<td>&gt;80%</td>
<td>60-79%</td>
<td>51-59%</td>
<td>≤50%</td>
</tr>
</tbody>
</table>

An alternative, acceptable definition of the lower limit of normal (LLN) is the lower 5% limit of predicted normal or 5th percentile. [see Table 3].
Table 3.1: ECCS prediction equations from Quanjer et al.

<table>
<thead>
<tr>
<th>Predicted</th>
<th>Equation</th>
<th>1.64 x RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>4.30H - 0.029A - 2.49</td>
<td>0.75</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>5.76H - 0.026A - 4.34</td>
<td>0.89</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>3.95H - 0.025A - 2.60</td>
<td>0.64</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>4.43H - 0.026A - 2.89</td>
<td>0.67</td>
</tr>
</tbody>
</table>

H: standing height (m); A: age (yr); RSD: residual standard deviation. Between age 18 and 25 years substitute age 25 in the equation. An acceptable lower limit of normal (LLN) is the 5th percentile: predicted value - 1.64 x RSD. Alternatively, use 80% of predicted as LLN.

Table 3.2. Prediction equations from Louw et al.: African men and from Mokoetle et al.: African women

<table>
<thead>
<tr>
<th>Predicted</th>
<th>Equation</th>
<th>1.64 x RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>0.029H - 0.027A - 0.54</td>
<td>0.84</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>0.048H - 0.024A - 3.08</td>
<td>1.00</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁ (L)</td>
<td>0.034H - 0.028A - 1.87</td>
<td>0.62</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>0.045H - 0.023A - 3.04</td>
<td>0.71</td>
</tr>
</tbody>
</table>

H: standing height (cm); A: age (yr). An acceptable lower limit of normal (LLN) is the 5th percentile: predicted value - 1.64 x RSD. Alternatively, use 80% of predicted as LLN.
Figure 1. (a) Volume-time, and (b) Flow-volume curve

Figure 2. (a) Volume-time, and (b) Flow-volume curve each demonstrating 3 acceptable expiratory manoeuvres, only #2 and #3 of which are reproducible.
Figure 3. (a) Volume-time, and (b) Flow-volume curves respectively demonstrating cough artefacts (X) that can influence the FVC, FEV\textsubscript{1} and FEF\textsubscript{25-75\%}.

Figure 4. (a) Volume-time, and (b) Flow-volume curves demonstrating glottis closure (X) resulting in premature termination of effort and reduced FVC.

Figure 5. (a) Volume-time curve demonstrating a slow rise and the end-of-test not reaching a plateau, and (b) Flow-volume curve with a late peak flow and an
abrupt end-of-test. Subsequent efforts will confirm these as sub-maximal efforts by demonstrating non-reproducibility.

Figure 6. Flow-volume curves demonstrating (a) partially reversible and (b) non-reversible obstructive patterns (Black=pre-bronchodilator; Grey=post-bronchodilator; Broken line=reference standard).
Figure 7. Flow-volume curve demonstrating a restrictive pattern (Broken line=reference curve). The hump on the down-slope of the expiratory curve was reproducible (not demonstrated). It represents a normal physiological phenomenon of the expiratory curve.
Diagram 1. An algorithm for the categorization of spirometry results. The absolute \( \text{FEV}_1 / \text{FVC} \) is expressed as a percentage. The 5th percentile is an acceptable alternative definition of the lower limit of normal (LLN) and is calculated as follows: predicted value - 1.64xSD [see Table 3]. FVC is based on percent observed/predicted.