ARTP Association for Respiratory Technology & Physiology

Standard Operating Procedure:	Performance of Spirometry in Adults
Target Audience:	All registered and unregistered healthcare professionals who are certified in the performance of spirometry
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Notes:	This document has been adapted from the ARTP standardised format describing the performance of both dynamic and static spirometry using either flow sensing spirometers or volume displacement spirometers.

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1. Introduction

Spirometry is a key tool in the diagnosis and monitoring of respiratory disease. The following document produced by the ARTP may be implemented within any practice where applicable. It outlines safe practice in the performance of quality assured spirometry.

2. Scope and Aims

This document covers a standard procedure which can be utilised in any healthcare setting where spirometry is performed. It is intended as a basic guideline that can be adapted alongside local protocols.

These test procedures are taken from the recommendations of the ARTP (Association for Respiratory Technology and Physiology) publication 'ARTP statement on pulmonary function testing 2020'. Updates to this document are unlikely to alter the test procedures significantly, but where an update occurs, readers should refer to these.

3. Background

Spirometry is a useful test to aid in the diagnosis of lung disease, and determine the degree of any impairment of lung volumes and flows. It provides several different values that indicate dynamic lung volumes. Spirometry should not be used in isolation when making diagnoses and clinical decisions, and should always be used alongside other investigations and clinical judgement.

The vital capacity (VC) is the maximal volume of air that can either be exhaled from the point of full inspiration or inspired from the point of full expiration. This can be measured as a relaxed/slow manoeuvre (SVC) or a maximal forced manoeuvre (FVC). The forced expiratory volume within the first second (FEV_1) is measured during the measurement of FVC to determine the presence of airway disease when expressed as a fraction of either the FVC (FEV_1/FVC) or SVC (FEV_1/SVC). The greatest value of FVC or SVC should be used, thus the lowest ratio should be used to indicate the degree of obstruction.

The measurement of maximal flow is known as the peak expiratory flow (PEF), which is measured during the first few milliseconds of a forced expiratory manoeuvre. It can be a useful indicator of lung compliance or limitation due to increased airway resistance.

4. Indications

The aim of performing spirometry is to:

- Detect the presence/absence of airway/ lung disease
- Quantify the extent of known disease
- Pre/post-surgery comparisons
- Determine effects of therapy
- Measure effects of occupational exposure

- Evaluate disability or impairment

5. Equipment

Prior to testing all equipment should be made readily available, checked it is fit for purpose and safe to use.
Equipment required:

1. Stadiometer
2. Calibrated weighing scales
3. Spirometer
4. 3L Calibration syringe
5. Barometer and thermometer (if not internal to equipment)
6. Chair with arms
7. Disposable mouthpiece
8. Bacterial/Viral filter
9. Nose clip
10. PPE in line with local infection control policy

5.1. Equipment is prepared for use

- All equipment used must be cleaned according to local infection control policy and manufacturer instructions.
- Equipment must be calibrated/ verified prior to use according to local policy and manufacturer instructions.
- All diagnostic procedures must be performed using a single patient use mouthpiece, bacterial/viral filter and clean nose clip.

Ambient temperature and barometric pressure should be measured and recorded prior to calibration using an accurate room thermometer and barometer. Results should be entered into the spirometer if this is not measured internally. Spirometers that internally measure and record the temperature and barometric pressure, should be checked against an external room thermometer and barometer. Spirometry should only be performed at ambient temperatures ideally between 20^0C and 25^0C. However, a lower limit of 17^0C and maximum 40^0C is acceptable. Where there is an increase in room temperature >2^0C, recalibration should take place[1].

6. Infection control

It is difficult to establish the degree of risk of cross-infection via lung function testing. Risk is low but the potential is real. It is important to practice appropriate routine cleaning and decontamination of all non-disposable consumables, equipment, work surfaces and personnel with local policies in place, including cleaning protocols, cleaning logs, practising good hand hygiene and appropriate use of personal protective equipment (PPE) as per recommended guidance[2]. Healthcare professionals and patients should wash their hands before and after the test, using either hand gel or soap and water.
Most bacterial/viral filters offer protection against 99.99% bacteria and viruses, including COVID-19. These should be attached to the spirometer prior to the patient performing the test and disposed of after each patient.

When planning spirometry lists, if possible, patients with an infection should be booked at the end of the list, whereas immunocompromised patients should be at the start of the list. This will help mitigate the risk to other patients.

Spirometry should be conducted in a well ventilated room to maximise airflow. A minimum of 6 air changes per hour in the room is recommended. There are High Efficiency Particulate Absorbing (HEPA) filters available which can filter most particulate matter, including COVID-19 particles. These can be purchased and, depending on the number of air changes in the room, can be set to clear the air within 15 minutes. This is not essential but depending on local protocols can be utilised to help reduce infection risk.

7. Pre-tests instructions

Patients should be correctly prepared for their appointment and be provided with relevant instructions prior to their appointment. Compliance with these instructions should be confirmed prior to testing. The patient will be advised to **avoid** the following:

- Smoking on the day of testing[2]
- Consuming alcohol for at least four hours prior to the test[3]
- Eating a substantial meal for at least 2 hours prior to the test[3]
- Vigorous exercise for at least 30 minutes prior to the test[3]
- Wearing tight clothing that may restrict full chest and abdominal expansion[3]
- To refrain from using their bronchodilators for the washout interval unless specifically instructed to do so. If bronchodilators have been taken prior to testing, record drug and time administered relative to testing in the report comments.

The washout intervals for bronchodilators have been recommended by the ATS/ERS (2019; Table 1) and ARTP (2020; Figure 1). The ARTP recommendations differ slightly from the ATS/ERS guidelines. The ARTP recommendations are based on evidence studying airway smooth muscle contraction using methacholine and suggest a longer washout out period for long-acting muscarinic antagonists and combination inhalers (Davis *et. al*. 2018). The ATS/ERS statement suggests shorter washout periods are acceptable as the broncho-protective effect provided by these agents is longer than the bronchodilating effects. Adhering to ATS/ERS guidelines (Table 1) is acceptable, but if there is any concern regarding lasting residual effects then the longer washout time should be used. When asking patients to withhold medications careful consideration should be given to the individual needs of the patient and it should be the healthcare professional's responsibility to assess whether it is appropriate.

Table 1: Recommended washout period for bronchodilating medication (ATS/ERS 2019 guidelines) Table taken from ATS/ERS (2019) standardisation of Spirometry 2019 update

Bronchodilator medication	Withholding time
Short-acting β_2 agonist (e.g. albuterol/salbutamol)	4-6 hours
Short-acting muscarinic antagonist (e.g. ipratropium bromide)	12 hours
Long-acting β_2 agonist (e.g. formoterol or salmeterol)	24 hours
Ultra long-acting β_2 agonist (e.g. indacaterol, vilanterol or olodaterol)	36 hours
Long-acting muscarinic antagonist	36-48 hours

Table 1 Recommended washout intervals prior to methacholine challenge test

Drug type	Example	Washout interval
Muscarinic antagonists	SAMA (eg, ipratropium)	12 hours
	LAMA (eg, tiotropium)	7 days
Beta-agonists	SABA (eg, salbutamol)	6 hours
	LABA (eg, salmeterol)	24 hours
	uLABA (eg, olodaterol)	48 hours
Xanthines	Theophylline	Not necessary
Inhaled glucocorticosteroid	Single dose (eg, budesonide)	Not necessary
	Stable dose (eg, budesonide)	Unknown
Leukotriene receptor antagonists	Single dose or up to 1 week (eg, montelukast)	Not necessary
	Stable dose	Unknown
Antihistamines	(eg, diphenhydramine, desloratadine)	Not necessary
Combination therapies (limited or no data)	ICS/LABA (eg, fluticasone/formoterol)	24 hours
	ICS/uLABA (eg, fluticasone/vilanterol)	48 hours
	LAMA/LABA (eg, glycopyrronium/indacaterol)	7 days

Figure 1: Reproduced with permission from Sylvester et al. (2020)

Compliance with these instructions should be checked prior to testing and any deviation from this should be documented accordingly. Patients requested to perform spirometry without a pre-booked appointment, should have pre-test instructions reviewed to assess whether or not it would be appropriate to proceed with the test.

8. Patient Preparation

Patients should be greeted and invited through for testing. All staff involved with the patient should introduce themselves by name/role to the patient (and carer if appropriate). Prior to testing the patient's demographics should be checked, confirming the patient's correct name, date of birth, identification number and address.

9. Contraindications

All patients should be assessed for any contraindications to testing to ensure they are safe to undergo spirometry. The majority of contraindications are relative[3] but where there is potential for risk to occur, the benefit of performing the test should be compared to the potential risk and a decision made whether the benefit outweighs the risk. If any of the following contraindications apply, then testing may not be performed unless discussed with a senior member of staff or requesting physician. Some relative contraindications in secondary care may be absolute in primary care, depending on local protocols.

9.1. Relative contraindications

Table 2: Recommended wait times before lung function testing[5]

Eye surgery	2-6 weeks
Unstable angina / angina attack	The use of sublingual GTN (glyceryl trinitrate) prior to testing
Recent MI	7 days
Pneumothorax	3 weeks
Brain surgery	3-6 weeks
Abdominal/ thoracic surgery	4 weeks
Vascular surgery	4-6 weeks

Nausea, vomiting, diarrhoea	clear for 48 hours
Middle ear infection	2 weeks once treated
Pulmonary embolism untreated	once treated with anticoagulants Haemoptysis of an unknown origin – rebook for 2 weeks
Stroke	once treated with anticoagulants

9.2. Absolute Contraindications

In some instances, there may be a greater risk to the patient by performing spirometry or pose a risk to others. Therefore, it is recommended that spirometry is avoided where possible in the following conditions[5]:

- Active untreated TB
- Aneurysm aortic or cerebral >6 cm or bulging
- Untreated pulmonary embolism

10. Test Procedure

1. Explain the purpose and nature of the test to the patient and gain their consent either verbally or written[3].
   - E.g. *"There are two parts to this test that will measure how fast you can blow out and how much air you can fully inhale and exhale in a slow manoeuvre and then a fast manoeuvre"*
2. Measure patients' height, preferably standing height where possible – instruct the patient to remove outdoor clothing and stand under the stadiometer with feet flat on the floor and heels, buttocks and scapulae against the wall or stadiometer and stand tall look straight ahead with chin perpendicular to the floor[3]. Where standing height is not possible or in patients with thoracic deformities, arm span, ulnar length or knee height should be considered as an alternative[3]. Height should be recorded to the nearest 0.5cm. The programme available here calculates estimated height using arm span, age and ethnicity: https://spirxpert.ers-education.org/en/download/armspan-to-height-software/
3. Weight should be measured – without outdoor clothing or shoes using calibrated scales and recorded to the nearest 0.1kg
4. Make sure the following are correctly recorded
   - Patient demographics (name, DOB, relevant identification number), ethnicity, birth sex
   - Age should be recorded to 1 decimal please
   - Smoking history (if smoked on day of test note time of last cigarette)
   - Medication including dose and time of any inhaled or oral medication prior to testing that may be applicable to the performance of spirometry.
5. Patient should be asked to loosen any tight-fitting clothing, where this is obviously restricting full chest wall and abdominal movement
6. Dentures should routinely be left in situ; however, it may be advisable for the patient to remove loose fitting dentures if these interfere with mouth seal.
7. Ask the patient to sit upright in a chair with arms with feet flat on the floor and legs uncrossed
8. Instruct the patient how to perform the test, starting with an SVC manoeuvre and demonstrate if necessary

11. Relaxed Vital Capacity

1. Spirometers differ in capabilities so it is important to be aware of what the spirometer being used allows
   - Some spirometers allow for tidal breathing prior to performing the manoeuvre, others require the patient to blow out immediately
   - Some spirometers allow for both an inspiratory and expiratory breath, others only allow an expiratory breath
2. Explain the test procedure to the patient, demonstrating as necessary
   - E.g. *"Take a deep breath in until you are completely full and then gently breathe all the way to empty, making sure to blow out for as long as you possibly can"*
   - (If doing IVC) "*Once you are empty take a deep gentle breath back in until you are completely full again*"
3. Connect the mouthpiece and/or filter to the spirometer and use a nose peg (essential for SVC, optional for FVC)
4. When the patient is on the mouthpiece, they should ensure they have a good tight lip seal and their tongue is not obstructing the mouthpiece.
5. If measuring expiratory VC only, instruct the patient to perform the following:

a. Maximal relaxed inspiration to full inspiratory capacity
b. Relaxed expiration to the point of full expiration, achieving end test criteria (Appendix A)

6. If measuring both inspiratory and expiratory VC's instruct the patient to do the following:

- Maximal relaxed inspiration to full capacity
- Maximal relaxed expiration to the point of full expiration, achieving end of test criteria (Appendix A)
- Maximal relaxed inspiration to total lung capacity

7. Remove the patient from the mouthpiece.
8. Examine the effort for any technical errors (Appendix A)
9. Allow the patient to rest for a minimum of 30 seconds before continuing
10. Repeat procedure as above; a minimum of 3 technically acceptable attempts should be performed and two reproducible efforts must have been achieved, a maximum of 8 attempts may be performed if required (Appendix A)

12. Forced Vital Capacity

1. Explain the test procedure to the patient with a visual demonstration as necessary
   a. E.g. "*take a deep breath in until you are completely full and then blow out as hard and as fast as you can until you are completely empty*"
   b. (if doing FV_{IN}) "*once you are completely empty, take a deep quick breath in again as fast as you can until you are completely full*"
2. Connect patient to the mouthpiece; nose clips are optional. Perform the manoeuvre in the following order, in a forced effort dependant manner:

   If measuring <u>expiratory only</u> instruct the patient to do the following:

   - Take a maximal inspiration to full capacity
   - Patient to place the mouthpiece in their mouth, past their teeth, lips tightly sealed around the mouth piece, ensure their tongue is not obstructing the mouthpiece

- Maximal forced expiration to the point of full expiration, achieving end of test criteria (Appendix A)

If measuring inspiratory (FIVC) and expiratory (FEVC) instruct the patient to do the following:

- Patient to place the mouthpiece in their mouth, past their teeth, lips tightly sealed around the mouth piece, ensure their tongue is not obstructing the mouthpiece
- 3-4 tidal breaths
- Maximal forced inspiration to full inspiratory capacity
- Maximal forced expiration to the point of full expiration/ residual volume (RV) achieving end test criteria (Appendix A)
- Maximal forced inspiration to total lung capacity

3. Remove the patient from the mouthpiece.
4. Examine the effort for any technical errors (Appendix A)
5. Allow the patient to rest for a minimum of 30 seconds before continuing
6. Repeat procedure as above. A minimum of 3 technically acceptable attempts should be performed and 2 reproducible efforts must be achieved, a maximum of 8 attempts may be performed if required (Appendix A).

13. Bronchodilator response

A bronchodilator response may be performed if there is a question regarding the diagnosis and if the following conditions are met:

- Patient must be able to perform technically acceptable and reproducible baseline spirometry
- Patient has withheld inhalers as instructed; otherwise true baseline will not be established.
  - If the patient is unable to withhold their inhalers, baseline spirometry only should be performed with appropriate comments reported.
  - Depending on the clinical question, if a patient has taken inhalers prior to testing and they are still obstructive this can provide enough information to aid the diagnosis/management plan.
- A bronchodilator should be administered according to local protocol.
  - This can be either via an MDI and a spacer or a nebuliser
- The patient should wait a minimum of 15-20 minutes if given a short acting β_2 agonist or 45 minutes for a short acting muscarinic antagonist prior to repeating spirometry
  - Enter the name of the bronchodilator, the dose and mode of delivery you have administered in the post test comments
  - Repeat the forced spirometry manoeuvres as per above (SVC may be required only if measuring a response to SVC if FVC is unreliable)

14. Reporting Results

1. Volumes are expressed in litres (L) and reported at body temperature and pressure saturated with water vapour (BTPS). Most spirometers will convert the results from ambient temperature and pressure, saturated (ATPS) to BTPS.
2. Testing should continue until three technically acceptable tests have been achieved and reproducibility criteria met, or a maximum of 8 manoeuvres have been performed
3. The best VC from at least three acceptable manoeuvres is reported

4. The best FEV_1, FVC and PEF from at least three acceptable forced manoeuvres is reported; measurements may be recorded from different manoeuvres providing they are technically acceptable and reproducible It is important to perform SVC's, especially in the elderly and patients with airflow obstruction, as when expiring forcefully these patients may experience dynamic airway compression, thus underestimating their true FVC.
5. In most patients FVC and SVC should be within 150mL
   a. FVC must not exceed SVC by more than 150mL as this implies poor effort on the relaxed manoeuvre. There is no physiological or pathophysiological reason why FVC should be more than 150mL greater than SVC.
   b. In the presence of severe airway obstruction, SVC may be larger than FVC due to dynamic airway collapse. If this occurs a comment should be added to the report
6. The FEV_1/(F)VC should be calculated using the greatest FEV_1 obtained, expressing it as a percentage of the VC or FVC (whichever is greater)
7. Results should be interpreted by a trained, certified healthcare professional in line with local policy.
8. Results should be saved and acted upon appropriately in accordance with local policy

15. References

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4. Sylvester, K.P., Clayton, N., Cliff, I., Hepple, M., Kendrick, A., Kirkby, J., Miller, M., Moore, A., Rafferty, G.F., O'Reilly, L. and Shakespeare, J., 2020. ARTP statement on pulmonary function testing 2020. BMJ Open Respiratory Research, 7(1), p.e000575.
5. Davis, B.E., Blais, C.M. and Cockcroft, D.W., 2018. Methacholine challenge testing: comparative pharmacology. Journal of asthma and allergy, pp.89-99.
6. An update on contraindications for lung function testing Brendan G Cooper, Lung Investigation Unit, University Hospitals Birmingham NHS Foundation Trust, Edgbaston, Birmingham B10 2TH, UK; brendan.cooper@uhb.nhs.uk
7. ATS ERS Lung Function Interpretation Standards 2022

16. Appendix A

ARTP Lung Function Reporting Document 2020
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Slow/Relaxed Spirometry Manoeuvres

Acceptability	Reproducibility
Efforts/trials must be free from artefact	VC need to be within <150ml of each other
No cough	A minimum of 3 efforts/trials
No leak or hesitation at the mouthpiece	A maximum of 8 efforts/trials
No obstruction of the mouthpiece with the tongue	
Plateau reached	

Forced Spirometry Manoeuvres

Acceptability	Reproducibility
Efforts/trials must be free from artefact	A minimum of 3 efforts/trials
No cough within the first second	A maximum of 8 efforts/trials. After 8 attempts the probability of getting a better result is significantly reduced. Do not reject results, comment on repeatability and report best efforts.
Rapid rise to PEF (FVL). The highest reading of at least 3 technically acceptable blows should be recorded. A poorly co-ordinated start to the manoeuvre, indicated by a rise time of 10-90% of PEF of > 150ms or a back extrapolated volume of > 5% of the FVC or 0.1L if the FVC is < 2.0L. In subjects <6yrs back extrapolated volume <75ml or 10% of the FVC is acceptable).	The two largest values of FVC must not differ by more than 150ml of each other The two largest values of FEV_1 must not differ by 150ml of each other. PEF-approximately 90% of subjects can achieve three PEF measures within 30 L/min (0.5L/s), 95% of subjects are within 40 L/min. Maximum number of 5 attempts for PEF.
No early termination of expiratory effort, plateau reached (the volume–time curve shows no change in volume (<0.025 L) for last 1 second of the test). Note that if plateau has <u>not</u> been achieved the FEV_1 may still be of some use. Early termination is not a reason to eliminate all data obtained as indices such as FEV_1 may not be affected and will still be valid.	For those with an FVC of ≤1.0 L, the two largest FVC and FEV_1 must be within 100ml of each other.
Forced Expiratory Time (FET) ≥3 s in children aged >6 and <10 years and for ≥6 s in subjects aged >10 years. Consideration must be given to restrictive subjects (FET can be < 6seconds). Pre-school children can reach a volume plateau in <1 s. Do not report FEV_1 if FET <1 s. Instead consider using $FEV_{0.75}$/FVC%.	FVL reproducible in shape. This is particularly important when there is a suggestion of upper airway obstruction.

Forced Spirometry Manoeuvres continued

Acceptability	Reproducibility
No obstruction of the mouthpiece with the tongue, distortion of mouthpiece due to excessive biting or obstruction by the teeth.	The chosen results should be the greatest values from three technically acceptable tests. FEV_1 and FVC may be taken from different manoeuvres.
Test performed with an open glottis	
No leak at the mouth (consideration must be given to patients with neuromuscular weakness and those with facial palsy)	
No extra breath taken during effort	
Maximal inspiration to TLC prior to forced expiratory effort.	If the maximum FVC is followed immediately by a full inspiration back to TLC and recorded as a single manoeuvre, then the FIVC must not exceed FVC by more than 100mls or 5% of the FVC, whichever is greater. If FIVC exceeds FVC by more than this, then it suggests the blow did not start from TLC.

Document Approval Table

Approved by:	ARTP Standards Committee
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