Undertaking Spirometry testing in Paediatrics

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Key Amendment

Date	Amendment	Approved by
19th Nov 2020	Document extended for 1 year	Dr J West/Paediatric QIM
26th March 2021	Document reviewed and approved for 3 years	Paediatric Guideline Review meeting
9th Feb 24	New spirometer section. PPE section	Paediatric Guideline Review Meeting

Introduction

Respiratory disorders can cause changes within the lungs and airways of a patient. The most important effects are on airway calibre and lung elastic recoil. Simple tests, such as dynamic lung volumes – commonly called spirometry, where volumes and flows are measured during forced expiratory and inspiratory manoeuvres, are valuable in the detection of some of these abnormalities associated with respiratory disorders.

Spirometry is the measurement of volumes and flows during forced expiratory manoeuvres in order to detect mechanical abnormalities associated with respiratory disorders. Spirometry should be performed with a graphic representation of the manoeuvre with both flow-volume and volume-time displayed.

The measurements obtained are:

- **FVC (Forced Vital Capacity)**. It is the maximum volume of air that can be forcefully expired after a maximum inspiration.
- **FEV_1 (Forced Expiratory Volume in 1 second)**. The maximum volume of air that can be forcefully expired in the first second of the FVC.
- **FEV_1 /FVC (%)**. This is the ratio of Forced Expiratory Volume in 1 second and Forced Vital Capacity.
- **PEF (Peak Expiratory Flow Rate).** The highest flow achieved from a maximal forced expiratory manoeuvre started without hesitation from a position of maximal lung inflation.
- **FEF (Forced Expiratory Flow Rates) FEF25%, FEF50%, FEF75%.** The measure of the maximum flow achievable when 75%, 50%, and 25% of the FVC has been exhaled.
- **VC (Vital Capacity)**. This is a non-forced measurement and is often greater than the FVC in COPD. It gives a more accurate measure of lung volume when the

airways are floppy, as in emphysema. The NICE guideline states the measurement of slow VC may allow the assessment of airflow obstruction in patients who are unable to perform a forced measurement to full exhalation.(Appendix 1)

Staff who may undertake this procedure in Paediatrics

- Trained healthcare professionals/nurses/AHP's working within the respiratory team
- Respiratory physiologists within the Lung Function department

Qualified healthcare professionals undertaking this role must have completed (or working towards) a relevant spirometry course (as recognised by the ARTP).

Lung function tests in children require a successful rapport with children over a wide range of ages. The value of spirometry results can be compromised by poor patient instruction and by inadequate training of the operator. Therefore, the operator should have a sound understanding and training of spirometry practice to ensure that the technique is safe and accurate. Retraining should be carried out after a period of time if practice lapses, to ensure competency.

Equipment

The paediatric department has x2 NDD Easy On-PC spirometers. One device is kept at Worcester and one in Redditch paediatric outpatients. Easy on-PC software has been downloaded onto the desktop computers in clinic and laptops of professionals using the application.

Easy On-PC spirometer

The machine requires accurate data regarding the patient; including name, date of birth, weight, height and ethnic origin. The machine gives predicted results and a percentage of the actual to predicted result to aid with interpretation of the results. The software has various child incentive screens to aid the child's understanding of the procedure.

A disposable single-patient use spirette mouthpiece is required, using ultrasound technology to provide accurate flow and volume measurements.

Calibration/ Verification of machine

The manufacturers of the Easy on-PC device state that calibration is not required.

Nevertheless quality control or verification should be performed before each clinic session, (or if the machine has travelled in a car or there has been a sudden change in room temperature) to determine the accuracy and precision of the spirometer by using a known standard or signal. Within the department this is done via a three litre syringe. The air from the syringe is injected into the machine between 2 and 12 litres / seconds 3 times as per the manufacturer's guidance. The machines are verified with a bacterial filter in place; the filter is then marked as the testing filter and changed monthly. The resistance of the filter is low as per the ATS (1995) advice and adheres to the manufacturers recommendations regarding verification.

The operator carrying out the spirometry procedure is responsible for verification of the machine. Room temperature will need to be recorded to enable results to be reported at BTPS (body temperature pressure standard). A log of verification (Appendix 2) must be maintained and each verification test documented.

The 3 litre syringe must have a leak test (attempting to expel air from it with the outlet blocked) once a week. As with all medical equipment within the Trust, both the machine and syringe must be tested yearly by the medical engineering department.

If any machine fails their verification test the machine should be checked that it has been set up correctly and the verification test repeated. If the verification test still fails the machine should immediately be taken out of use. Under no circumstances should spirometry testing take place on a machine that failed its verification test. The failure should be logged and the manufacturing company contacted.

Infection Control

The spirettes used for testing are single patient use and must be discarded after use. All parts of the equipment are to be wiped with a 70% Isopropyl Alcohol impregnated cloth (which provides a suitable form of cleaning and low-level disinfection) before the start of a clinic, after each patient has used the machine and at the end of a clinic.

PPE should be worn when completing spirometry: Staff should wear disposable apron and gloves, fluid resistant face mask and eye protection should be considered.

Setting

Spirometry can be carried out on a ward, outpatient clinics or in the lung function laboratory. It can also be performed at the patients' home if required. The patient should be made comfortable and offered privacy during the procedure.

Appropriateness of Spirometry Testing

Spirometry can be performed on children from around the age of five. However, as it requires the ability to follow detailed instructions each child will be assessed on an individual basis. In children with Cystic Fibrosis spirometry may be introduced at an earlier age in order for the child to be familiar with the testing. In these instances the results obtained need to be taken with caution and clinical decisions should not be made according to these results alone.

Indications for Spirometry testing

- Detecting the presence or absence of lung dysfunction
- Quantifying the severity of known lung disease

- Assessing the change in lung function over time or assessing the effect of therapy
- Assessing potential response to environmental or occupational exposure
- Assessing the risk for surgical procedures known to affect lung function

Limitations/Hazards/Complications

Relative Contraindications

- Untreated pneumothorax.
- Unstable cardiovascular status
- Recent pulmonary embolism, thoracic or abdominal surgery
- Recent eye surgery
- The presence of acute disease process which might interfere with test performance.

The requesting clinician should be aware that forced expiratory manoeuvres might aggravate the following conditions and the patient's diagnosis and history should always be provided with the referral form so that spirometry is performed with caution:

- Haemoptysis of unknown origin
- Thoracic, abdominal or cerebral aneurysms

Hazards / Complications

- Pneumothorax
- Increased intracranial pressure
- Syncope, dizziness, light-headedness
- Chest pain
- Paroxysmal coughing
- Contraction of nosocomial infections
- Oxygen desaturation due to interruption of oxygen therapy
- Bronchospasm

Requests for Spirometry

From all paediatric consultants and anaesthetists for pre-operative reviews.

Reason for request

- Assessment of lung function
- Pre-surgery screening
- Differential diagnosis
- Assessment for nebuliser trial
- Assessment of response to treatment
- Serial measurement - respiratory muscle assessment

Procedure

Spirometry is an effort-dependent test that requires careful instruction from the operator and co-operation from the patient. Personnel who carry out Spirometry must follow the procedures and preparation for testing set out by the BTS/ARTP (1994) and Levy et al (2009).

The consultant should discuss spirometry testing with the patient prior to the test. An information leaflet (appendix 4) should have been given to the child and family with an opportunity to ask any questions.

Spirometry can take up to 20 minutes to perform, depending on the patient, technique and severity of breathlessness. For a bronchodilator assessment additional time is required. (appendix 5). The display of each manoeuvre is essential and should be inspected to confirm that the test is acceptable. Each result should be reviewed for reproducibility.

Preparation	**Rationale**
1. Check the spirometer verification at the beginning of the clinic session	To determine accuracy and precision of spirometer
2. Explain the test and obtain patient's verbal permission	To obtain patient's consent and cooperation
3. Measure weight in indoor clothes and height without shoes	For the calculation of reference values
4. Ask about contra-indications, recent illness, medication use and record on data sheet (appendix 6)	To ensure there are no contraindication to testing and effect of medication on results

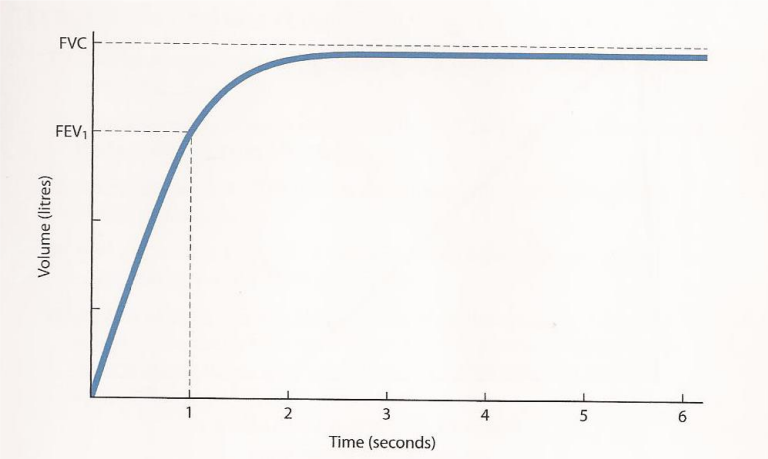
Perform FEV1 and FVC manoeuvre (open circuit method)	**Rationale**
Instruct subject to sit in an upright posture with head slightly elevated	Ensure erect sitting position to enable good chest expansion.
1. Inhale fully and maximally	Encourage a full inhalation as failure to inhale fully will underestimate results
2. Place mouthpiece in mouth between the teeth and close lips around the mouthpiece	To ensure there is a good seal around the mouth, and the tongue and teeth do not obstruct the mouthpiece.
3. Exhale sharply and maximally for as long as possible until no more air can be expelled, while maintaining an upright position	Encourage sharpness of the blow (like a peak flow). Failure to combine speed and length will overestimate FEV_1
4. Repeat instructions, coaching vigorously	Encourage subject to improve technique and to obtain best effort
5. Repeat for a minimum of three technically acceptable manoeuvres	To meet acceptability criteria, the two best FEV_1 and FVC should be within 5%
6. Allow subject sufficient time to rest between manoeuvres	Test requires a great deal of effort and is demanding for breathless patients
7. Examine the display of each measurement carefully	To confirm that it's acceptable
8. Write comment regarding technique / effort on the test report.	To inform clinician on the reliability of results

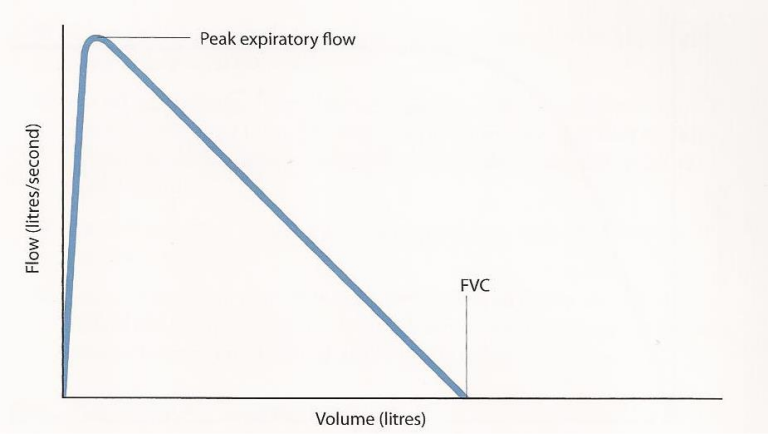
The child should be seated for the procedure as the forced blowing can cause episodes of dizziness, light-headedness and fainting. However, some children prefer to stand when completing the test. The child can stand whilst carefully observing for any of the above signs.

In line with the BTS/ARTP (1994) children are not required to perform relaxed VC as expiring for 6 stipulated manoeuvres is too tiring. It is more appropriate to determine maximal expiration by looking for a clear plateau on the volume / time plot.

Technically acceptable effort is where the patient has used maximum effort for the forced manoeuvre and has exhaled immediately from the position of maximal inspiration and has exhaled completely to a position of maximum expiration. The patient should not make a slow start to the forced manoeuvre and should not cough.

The trace needs to be smooth and free from irregularity with the volume / time trace plateauing for at least 1 second (there should not be an "S" shape at the beginning of the trace). The flow / volume should rise almost vertically to a peak and the trace should merge smoothly with the horizontal axis at the end of the blow.





Within paediatrics it is recommended that acceptability criteria stipulates that reproducibility must be within 5% rather than 100ml, as in small children 100ml is a loose definition and could reach nearly 10% of their lung volume.

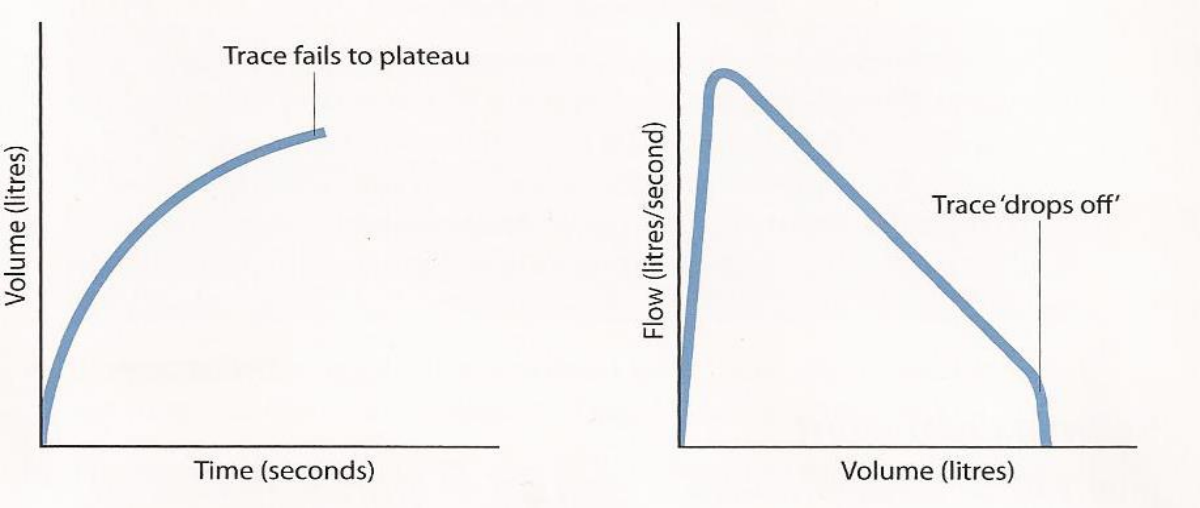
If further in-depth lung function tests are required the patient should be referred to the local territory centre.

Common errors in measurement

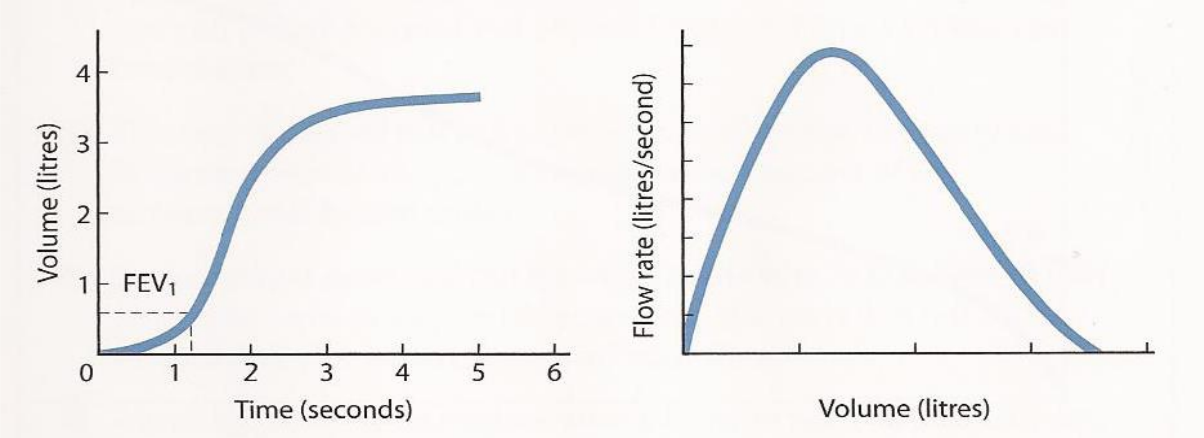
The display of each manoeuvre is essential and should be inspected to confirm that the test is acceptable. A test should be rejected if:

- There is a leak at the mouth
- The mouthpiece is obstructed with the tongue or false teeth
- Coughing during the manoeuvre
- A poorly co-ordinated start to the test
- Early termination of the blow
- The patient did not inspire fully to total lung capacity
- The expiratory effort was sub-maximal

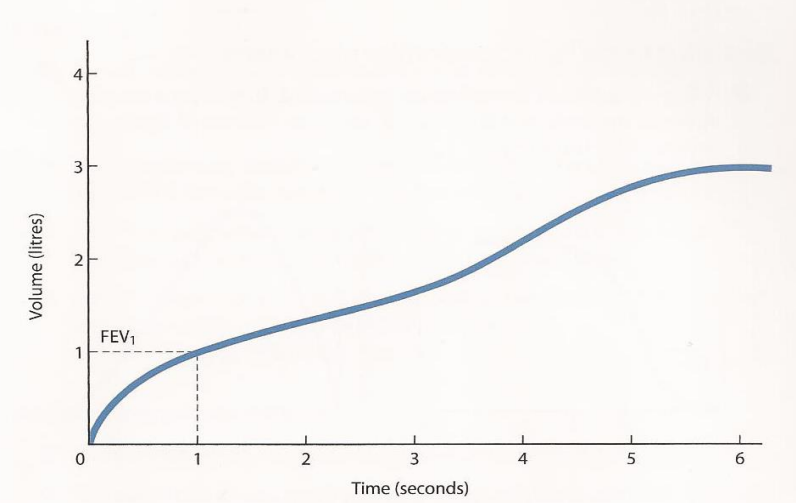
Example of trace for abrupt end



Example of slow start to the forced expiratory manoeuvre



Example of an air leak



If technically acceptable results are not achieved e.g. because of coughing or poor technique, the reason should be explained on the data sheet.

The data sheet should be completed and filed in patient's records with spirometry results and graphs.

Interpretation of Results

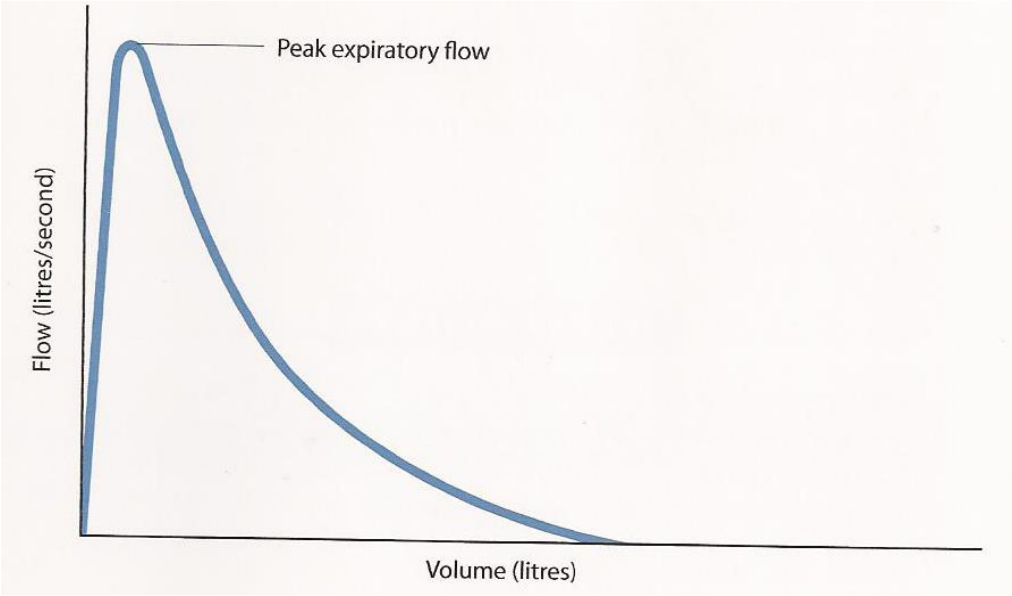
The requesting consultant should be informed of the results as soon as possible after the test has been performed. It is the requesting consultant's responsibility to interpret the results.

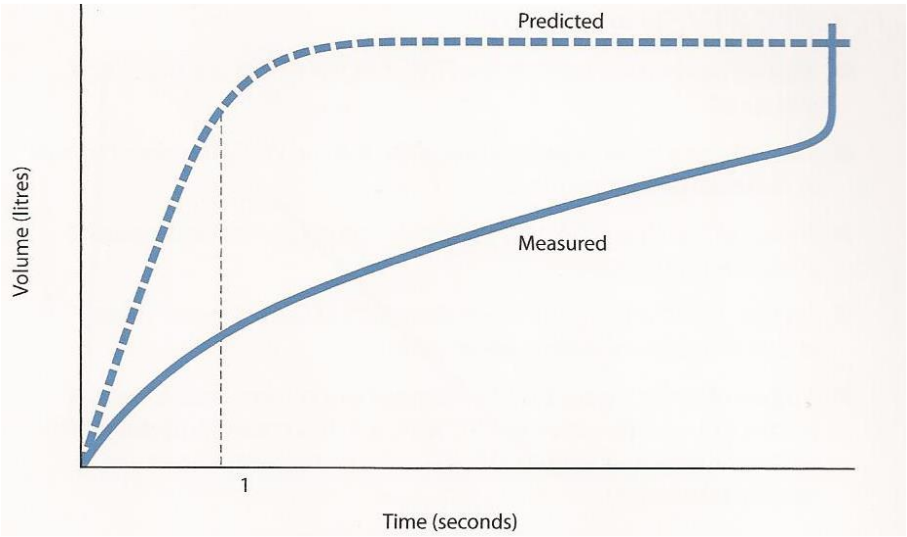
Obstructive Spirometry

Diseases that cause obstructive ventilatory defects are common and include asthma and cystic fibrosis. Obstructive airway disease causes a reduction in the rate at which air can be expired from the lungs but do not always affect the maximum volume of air that can be expired.

Obstruction of the airways slows the rate at which air can be exhaled. This reduces the volume of air forcibly expired in the first second of the second of the forced expiratory manoeuvre. Hence the volume of the FEV_1 will be reduced usually to less than 80% of the reference range. In mild and moderate airflow obstruction the FVC is usually normal (over 80% of the reference range). In severe airway obstruction the FVC may also be reduced, as a result of dynamic airway collapse and air trapping (however, not normally to the same reduction as the FEV_1). The FEV_1, as a ratio of the FVC is therefore reduced. A ratio of less than 70% is usually considered to be diagnostic of airflow obstruction with a ratio of 80% of the reference range being indicative of airflow obstruction. Airway obstruction results in prolonged expiratory time (generally longer than 6 seconds).

The slower rate at which air can be expired produces a flatter volume / time trace; with the trace taking longer to plateau. The flow / volume trace must still rise almost vertically to PEF. Although the PEF may be reduced it must still be reached in the first 10 milliseconds of the blow. As air is cleared from the obstructed airways the flow rate decreases more rapidly than normal producing a concave scooped shape to the curve. The trace should still merge smoothly with the horizontal axis of the graph at the FVC.





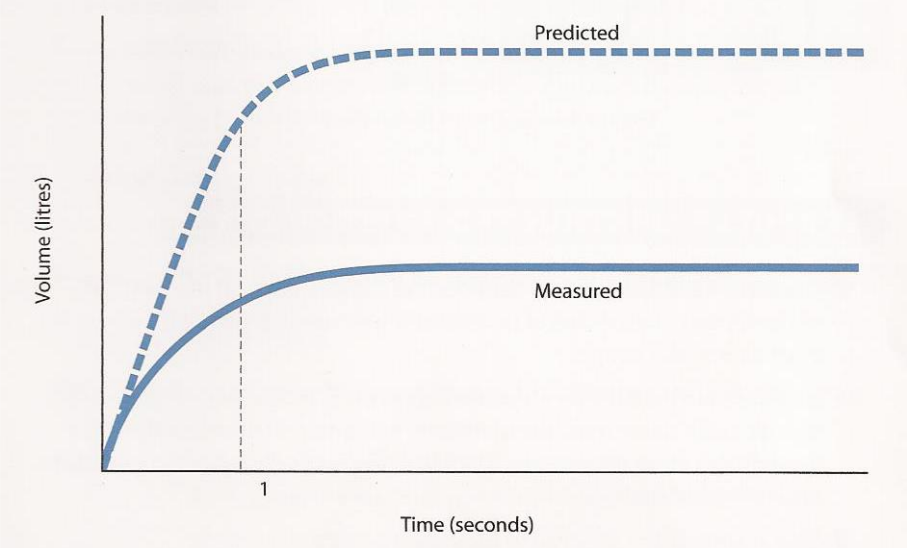
Bronchodilator Response

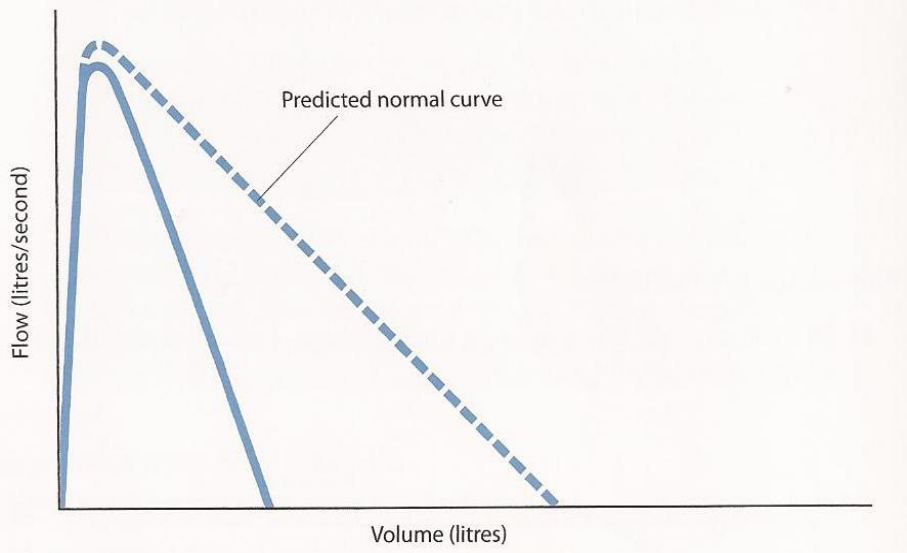
Consider a bronchodilator test in children and young people with obstructive spirometry (FEV1/FVC ratio less than 70%). An improvement in FEV1 of 12% or more should be regarded as a positive test. (NICE 2017).

Restrictive Spirometry

Restrictive spirometry can arise as a result of problems within and outside of the lungs. Any condition that prevents full expansion of the thoracic cavity can cause restrictive spirometry. Respiratory causes of restrictive ventilatory defects are comparatively rare. A common cause of apparent restrictive spirometry is poor technique.

Lung volumes are reduced but airflow is unaffected in restrictive ventilatory defects. The volume of FEV_1 and FVC are both reduced in proportion to each other. Both the FEV_1 and FVC will be less than 80% of their reference range. As the airways are not obstructed the FEV_1 and FVC ratio will be normal. When the lung volumes are significantly reduced it may be possible to expire more than 75% of the total volume in the first second, simply because the volume is so small. In this case the FEV_1 and FVC ratio will be abnormally high. As lung volumes are small and airflow is normal the expiratory time may be very short (2-4 seconds or less). The volume / time trace will be a normal shape, but will be small and will plateau early. As restrictive defects do not affect airflow so the flow / volume trace must rise almost vertically to a normal or near-normal PEF. Airflow from the airways is normal so the trace will not show the scooping typical of obstruction. The FVC is reduced so the trace will reach the horizontal axis of the graph quickly, giving a narrow appearance to the trace.


Predicted
Measured
Volume (litres)
1
Time (seconds)


Predicted normal curve
Flow (litres/second)
Volume (litres)

Peak Expiratory Flow

The PEF measurement is commonly used within paediatrics for asthma management, and when a good technique is demonstrated, it is used to monitor their asthma control including being part of their asthma management plan and to examine the severity of an exacerbation. This is the simplest, quickest and cheapest test of lung function.

Whilst children under the ages of 6 or 7 years may be able to use a PEF meter their test results are frequently unreliable and cannot be accurately reproduced. In this age group clinical symptoms and history are of greater importance. It is important not to cause confusion between inhaling and blowing techniques

The Peak Flow meters used within the Trust are the Mini-Wright Peak Flow meters that adhere to the EU scale. The meter operates by the patient blowing into the mouthpiece. The plastic baffle moves down the inside of the body of the meter which in turn pushes the pointer down the scale on the outside to give the patient a reading.

All Peak Flow meters used in the ward environment are single patient use and the child takes the meter home with them. The meter should be labelled with the child's name and the date it is given.

The child should be asked to bring their Peak Flow meter to all clinic appointments so that their Peak Flow can be tested. If the child forgets their meter, a clinic meter is used. A one way disposable mouthpiece is then used that prevents the child inhaling through the mouth piece. After use, the mouth piece is disposed of appropriately and the meter cleaned using antibacterial wipes. The family should be reminded that the GP should re-prescribe a new peak flow meter annually. The clinic meters should be changed annually.

It is much easier, and more effective, to show a patient how to use a peak flow meter, than to explain it to them in words only.

- Stand or sit up straight
- Check cursor is on zero (L/Min position)
- Take a deep breath in - place Peak Flow Meter in the mouth (hold horizontally) and close lips
- Blow suddenly and hard
- Note number indicated by cursor
- Return cursor to zero
- Repeat twice and obtain three readings
- Write down the best of the three readings

Individual PEFs vary enormously, like the length of their stride, or the strength of their grip, therefore readings of up to 100 litres per minute above or below 'predicted' values can be considered normal. A predicted PEF reading is only helpful when no previous recordings have been made - the patient's previous best PEF reading is the most relevant information. The normal peak flow ranges can be viewed in Appendix 7. It is important to remember that some patients record higher readings than their predicted normal values and one in 20 normal people will be outside the normal range

A diurnal variation (i.e. the difference between the lowest and the highest of the daily readings) of more than 20% **and** at least 60 l/min on three or more days in a week for two weeks is highly suggestive of asthma (BTS/SIGN 2011)

Appendix 1 – Vital Capacity

Comparison of VC and FVC is indicative of bronchoconstriction or air trapping in the airways; however, VC testing is not routinely done in paediatrics.

The procedure for VC is as follows:

The patient is fitted with a nose-clip and instructed to breathe in as deeply as possible through the mouth (i.e. full inspiration), place lips around the mouthpiece, and blow out steadily into the equipment until no more air can be exhaled.

The manoeuvre is like a deep sigh and should neither be forced nor held back. It is recommended that a nose clip be worn when doing the VC. There is a tendency to exhale through the nose during relaxed exhalation. Wearing a nose clip will ensure all exhaled air is measured through the mouth so that the result is not underestimated.

Appendix 2

VERIFICATION LOG FOR Easy on-PC

Time	Location	Room Temp	Visual Check	Syringe Leak Test**	Calibration Volume	Measured Volume	Volume Difference	Signature

Any problems with machine must be reported immediately and the machine taken out of use.

**The syringe leak test must take place weekly.

Appendix 3

Breathing Tests in the Children's Clinic

The breathing test that is performed in the Children's clinic is called Spirometry. This involves blowing out as fast as possible into a special piece of equipment called a Spirometer. This is like blowing candles out on a birthday cake.

The test will be performed with you sitting. You will be asked to take a deep breath in and then to blow out into a special mouthpiece as fast as possible and try and keep blowing until your lungs are empty. This will be performed a minimum of three times, but you will be given plenty of rest between each blow. This test measures the volume and speed of the air you can blow out from your lungs and will give the doctor an indication of how well your lungs are working. Before performing the test the doctor and nurse will talk to you about the test and answer all of your questions. Please write any questions down that you have so that you don't forget. Before the test the nurse will measure your height and weight as this information is important when looking at the results. It is often helpful if you bring all your medication with you to the appointment.

It is advisable:

- Not to wear tight clothing for the appointment as this constricts your lungs.
- Not to take vigorous exercise, 30 minutes before the appointment
- Not to have a heavy meal up to 2 hours prior to your appointment
- To go to the toilet before the test

There are some reasons when lung function tests cannot/may not be performed including recent eye, chest or abdominal surgery and vomiting within the past few days

The nurse will complete a checklist before the tests.

If you have any concerns about the test please do not hesitate to contact the Children's Clinic

Appendix 4

Bronchodilator assessment

Bronchodilator response can be assessed by repeating spirometry after waiting for the appropriate time. Short acting β2 adrenoceptors e.g. Salbutamol reach peak effect 20 min after inhalation, and anticholinergic inhalers e.g. Ipratropium Bromide 45min after inhalation.

Appendix 5

SPIROMETRY TESTING -Patient Data Sheet

Patient Sticker Name Date of Birth Hospital Number

Date Of Test:
Time Of Test:
Weight:_____kg

Height: _____cm

	YES	NO
Have you been unwell /had an infection/ had an exacerbation in past 6 weeks ?		
Have you had a course of steroids or antibiotics in the past 6 weeks?		
Have you coughed up blood in the past 6 weeks?		
Have you had a pneumothorax in the past 3 months?		
Have you been vomiting or had any pains in the past week?		
Have you had any stomach / chest or eye surgery in the past 3 months?		
Have you had a perforated ear drum in past 3 months?		
Have you had a heart attack, angina, aneurysm , unstable blood pressure or stokes in the past?		
Could you be pregnant?		

If patient answers Yes to any question please check with consultant that they wish test to go ahead.

	Yes/ No	Time
Have you had a big meal in last 2 hours?		
Have you done any exercise in the last 30 minutes?		
Have you been to the toilet recently?		
Have you had a cigarette or an alcohol drink today?		

What medication have you taken today and when?_____

VC (%pred)	FEV_1 (%pred)	FVC (%pred)	FEV_1/FVC (pred)	PEF (pred)

Comments On Test:_____

_____

_____

Name and Signature:_____
Please attached printed graph to this sheet and file in notes.

Appendix 6

PAEDIATRIC NORMAL VALUES

PEAK EXPIRATORY FLOW RATE

For use with EU / EN13826 scale PEF meters only

Height (m)	Height (ft)	Predicted **EU** PEFR (L/min)		Height (m)	Height (ft)	Predicted **EU** PEFR (L/min)
0.85	2'9"	87		**1.30**	4'3"	212
0.90	2'11"	95		**1.35**	4'5"	233
0.95	3'1"	104		**1.40**	4'7"	254
1.00	3'3"	115		**1.45**	4'9"	276
1.05	3'5"	127		**1.50**	4'11	299
1.10	3'7"	141		**1.55**	5'1	323
1.15	3'9"	157		**1.60**	5'3"	346
1.20	3'11"	174		**1.65**	5'5"	370
1.25	4'1"	192		**1.70**	5'7"	393

Normal PEF values in children correlate best with height; with increasing age, larger differences occur between the sexes. These predicted values are based on the formulae given in Lung Function by J.E. Cotes (Fourth Edition), adapted for EU scale Mini-Wright peak flow meters by Clement Clarke.
Date of preparation – 7th October 2004

Mini-Wright™ PEAK FLOW METER

Mini-Wright (Standard Range) EU scale
Blue text on a yellow background

Single Patient Use: Part Ref: 3103388
Multiple Patient Use: Part Ref: 3103387
NHS Logistics Code: FDD 609

Mini-Wright (Low Range) EU scale
Blue text on a yellow background

Single Patient use: Part Ref: 3104708
Multiple Patient Use: Part Ref: 3104710

For more information, visit the website **www.peakflow.com**

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