SPIROMETRY

The Measurement and Interpretation of Ventilatory Function in Clinical Practice

by

Associate Professor David P. Johns PhD, CRFS, FANZSRS
Principle Research Fellow,
Menzies Research Institute and School of Medicine,
University of Tasmania, Tasmania

Professor Rob Pierce MD, FRACP
Director, Respiratory Medicine and Sleep Disorders
Austin and Repatriation Medical Centre, Victoria

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This handbook is not intended to be a comprehensive guide to spirometry. Those seeking detailed information should refer to the recommended text below.

Recommended Text Book

Pocket Guide to Spirometry, 2nd edition
David P. Johns & Rob Pierce
McGraw-Hill Australia, 2007

Contents

Introduction

A great deal can be learned about the mechanical properties of the lungs from measurements of forced maximal expiration and inspiration. Since Hutchinson first developed the spirometer in 1846, measurements of the so-called dynamic lung volumes and of maximal flow rates have been used in the detection and quantification of diseases affecting the respiratory system. Over the years it has become obvious that the spirometer and peak flow meter used to measure ventilatory function are as deserving of a place in the family practitioner's surgery as the sphygmomanometer. After all, who would dream of managing hypertension without measurement of blood pressure?

It is important to appreciate that the clinical value of spirometric measurements is critically dependent on the correct operation and accuracy of the spirometer, performance of the correct breathing manoeuvre and use of relevant predicted normal values.

Staff performing spirometry should first attend a comprehensive training course. This is important because inadequate training will result in poor quality spirometry that is of little clinical value.

This handbook was written as a guide for those involved in the performance and interpretation of spirometry in clinical practice, i.e. medical practitioners and assisting nursing staff, and as an introduction to the topic for scientists and technicians. It is not intended to be an exhaustive review but rather a guide aiming to help improve the knowledge and techniques of those already doing and interpreting spirometry, and to introduce spirometry to those learning how to do it for the first time. The important facts about types of spirometers, how the test is actually performed and interpreted, and some common pitfalls and problems are covered in the main text.

Those seeking more detailed information, including case histories, are referred to our other publications:

1. Johns DP, Pierce R. *Pocket Guide to Spirometry*, 2nd edition. Sydney: McGraw-Hill Australia, 2007.
2. Burton D, Johns DP, Swanney M. *Spirometer Users' and Buyers' Guide*. Melbourne: Department of Health and Ageing, 2005.
3. Johns DP, Pierce R. How to Perform and Interpret Spirometry [CD ROM]. Melbourne: Medi+World International, 2004.

Measurement of Ventilatory Function

Conventionally, a spirometer is a device used to measure timed expired and inspired volumes, and from these we can calculate how effectively and how quickly the lungs can be emptied and filled.

A spirogram is thus a volume-time curve and Figure 1 shows a typical curve. Alternatively, measures of flow can be made either absolutely (e.g. peak expiratory flow) or as a function of volume, thus generating a flow-volume curve (Figure 2), the shape of which is reproducible for any individual but varies considerably between different lung diseases. A poorly performed manoeuvre is usually characterised by poor reproducibility.

The measurements which are usually made are as follows:

1. **VC** (vital capacity) is the maximum volume of air which can be exhaled or inspired during either a maximally forced (**FVC**) or a slow (**VC**) manoeuvre. VC is normally equal to FVC unless airflow obstruction is present, in which case VC is usually higher than FVC.
2. **FEV_1** (forced expired volume in one second) is the volume expired in the first second of maximal expiration after a maximal inspiration and is a useful measure of how quickly full lungs can be emptied.
3. **FEV_1/VC** (or **FEV_1/FVC**) is the FEV_1 expressed as a percentage of the VC or FVC (whichever volume is larger) and gives a clinically useful index of airflow limitation.
4. **$FEF_{25-75\%}$** is the average expired flow over the middle half of the FVC manoeuvre and is regarded as a more sensitive measure of small airways narrowing than FEV_1.
   Unfortunately $FEF_{25-75\%}$ has a wide range of normality, is less reproducible than FEV_1, and is difficult to interpret if the VC (or FVC) is reduced or increased.
5. **PEF** (peak expiratory flow) is the maximal expiratory flow rate achieved and this occurs very early in the forced expiratory manoeuvre.
6. **$FEF_{50\%}$ and $FEF_{75\%}$** (forced expiratory flow at 50% or 75% FVC) is the maximal expiratory flow measured at the point where 50% of the FVC has been expired ($FEF_{50\%}$) and after 75% has been expired ($FEF_{75\%}$). Both indices have a wide range of normality but are usually reproducible in a given subject provided the FVC is reproducible.
7. **FVC_6** is the forced expiratory volume during the first 6 seconds and is a surrogate of the FVC. The FVC_6 (and FEV_1/FVC_6) is gaining popularity because stopping the expiratory manoeuvre after 6 seconds is less demanding and easier to perform for patients with airflow obstruction and the elderly yet is similar to conventional FVC and FEV_1/FVC for diagnosing and grading airflow obstruction.

All indices of ventilatory function should be reported at body temperature and pressure saturated with water vapour (BTPS). If this is not done the results will be underestimated, because when the patient blows into a 'cold' spirometer, the volume recorded by the spirometer is less than that displaced by the lungs.

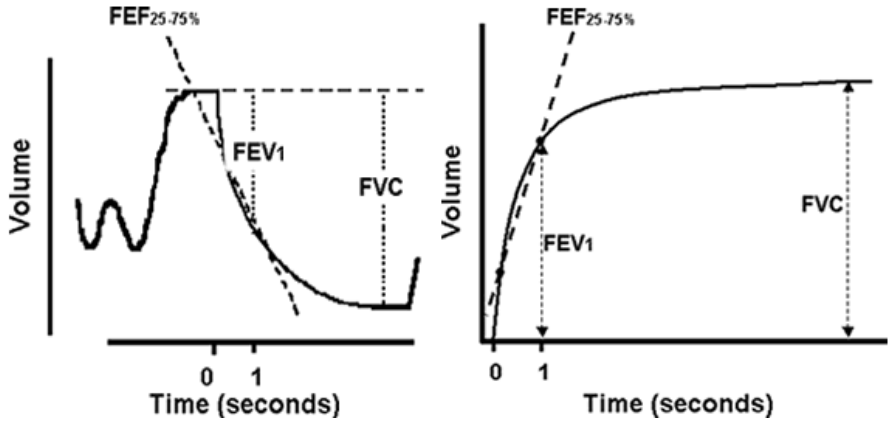

Figure 1

Normal spirogram showing the measurements of forced vital capacity (FVC), forced expired volume in one second (FEV_1) and forced expiratory flow over the middle half of the FVC ($FEF_{25-75\%}$).
The left panel is a typical recording from a water-sealed (or rolling seal) spirometer with inspired volume upward; the right panel is a spirogram from a dry wedge-bellows spirometer with expired volume upward.

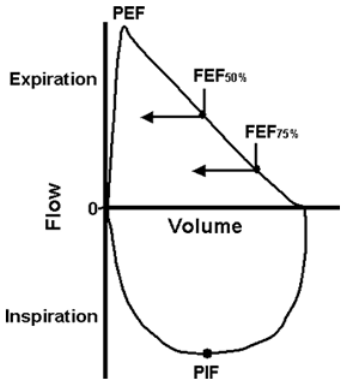

Figure 2
Normal maximal expiratory and inspiratory flow-volume loop.

Measurement Devices

Commonly used devices include volume-displacement and flow-sensing spirometers for use in the office or laboratory and portable devices suitable for personal use.

Volume-Displacement Spirometers

Conventional spirometers provide a direct measure of respired volume from the:

- displacement of a bell (water sealed);
- piston (rolling seal); or
- bellows (e.g. wedge bellows).

The results are normally presented as a graphic display of expired volume against time (a spirogram). The indices FEV_1, FVC and VC are generally manually calculated (including correction to BTPS) from the spirogram by the operator and for this reason volume-type spirometers are considered time consuming and less convenient for routine use in the doctor's surgery.

Generally, volume spirometers are simple to use, accurate, reliable, easy to maintain and provide a clear and permanent record of the test. They are, however, less portable than flow spirometers, and more difficult to clean and disinfect.

Flow-Sensing Spirometers

Over recent years advances in electronics and microprocessor technology have led to the development of a new range of portable spirometers. Flow spirometers generally utilise a sensor that measures flow as the primary signal and calculate volume by electronic (analog) or numerical (digital) integration of the flow signal. The most commonly used flow sensors detect and measure flow from:

- the pressure drop across a resistance (e.g. pneumotach or orifice);
- the cooling of a heated wire (anemometer);
- electronically counting the rotation of a turbine blade; or
- the time of flight of an ultrasonic sound pulse directed across the expired gas flow (ultrasonic sensor).

For the general practitioner these devices have largely replaced the volume spirometer because they are usually portable and they automatically calculate a large range of ventilatory indices, provide immediate feedback on the quality of each blow, select the best result, store patient results, calculate reference values for the patient being tested and provide a print-out of the results including the spirogram and flow-volume loop. These features, together with their portability, ease of use and maintenance (e.g. cleaning and disinfection) have resulted in the increasing popularity of flow-based spirometers.

Some flow spirometers have single patient use disposable sensors, effectively eliminating the need for cleaning and disinfection. However, the accuracy of each new sensor may need to be established. Accuracy and reproducibility depend on the stability and calibration of the electronic circuitry and appropriate correction of flow and volume to BTPS conditions.

Spirometers need to be calibrated (or their accuracy validated) regularly (see *Appendix A*).

Monitoring Devices

Mechanical devices for personal use by patients, such as the peak flow meter, have been available for several decades for serial monitoring of lung function and have proven useful in the management of asthma. Most peak flow meters are robust and provide reproducible results essential for serial monitoring. However, they often have limited accuracy and, because they provide only a single effort-dependent index of ventilatory function, they have limited application in the initial assessment of respiratory diseases.

Measurements of PEF are reduced in diseases causing airways obstruction. Peak flow monitoring is particularly useful for following trends in lung function, quantifying response to treatment and identifying trigger factors in asthma.

Portable peak flow meters are a reasonably reliable tool for patients to monitor their own airway function.

Recently several small, inexpensive yet accurate battery-powered devices for measuring ventilatory function (including FEV_1) have been developed, some of which can store the test data which can be downloaded onto a computer for review and statistical analysis.

Factors to Consider when Choosing a Spirometer

- Ease of use
- Provision of easy to read real-time graphic display of the manoeuvre
- Provision of immediate quality feedback concerning the acceptability of blows, including reproducibility
- Provision to interface with clinical software packages
- Provision of customisable final spirometry report
- Provision to print the final report
- Price and running costs
- Reliability and ease of maintenance
- Training, servicing and repair of the spirometer provided by supplier
- Ability to trial the spirometer in your setting before purchase
- Provision of a disposable sensor or a breathing circuit that can be easily cleaned and disinfected
- Provision of appropriate normal reference values with lower limits of normal
- Robustness
- Provision of a comprehensive manual describing the spirometer's operation, maintenance and calibration
- Calibration requirements
- Conformance with accepted spirometry performance standards
- Compliance with electrical safety standards

A summary of the specifications and features of spirometers currently available in Australia and New Zealand is provided in the *Spirometer Users' and Buyers' Guide*, which is published on the National Asthma Council Australia website (http://nationalasthma.org.au).

Faced with such a large variety of spirometers, general practitioners have to choose an instrument suitable for use in their own surgery. Readers are advised to contact their State Asthma Foundation for further information and advice on peak flow meters, and local respiratory laboratories regarding spirometers.

The Technique - How to Do it and Common Pitfalls and Problems

How to Do It

To ensure an acceptable result, the FVC manoeuvre must be performed with maximum effort immediately following a maximum inspiration; it should have a rapid start and the spirogram and flow-volume curve should be a smooth continuous curve.

To achieve good results, carefully explain the procedure to the patient, ensuring that he/she is sitting erect with feet firmly on the floor (the most comfortable position, though standing gives a similar result in adults, but in children the vital capacity is often greater in the standing position). Apply a nose clip to the patient's nose (this is recommended but not essential) and urge the patient to:

- breathe in fully (must be absolutely full)
- seal his/her lips around the mouthpiece
- immediately blast air out as fast and as far as possible until the lungs are completely empty
- breathe in again as forcibly and fully as possible (if inspiratory curve is required and the spirometer is able to measure inspiration).

If only peak expiratory flow is being measured then the patient need only exhale for a couple of seconds.

Essentials are:

- to breathe in fully (must be absolutely full)
- a good seal on the mouthpiece
- very vigorous effort right from the start of the manoeuvre and continuing until absolutely no more air can be exhaled
- no leaning forward during the test
- obtain at least 3 acceptable tests that meet repeatability criteria (see below)

Remember, particularly in patients with airflow obstruction, that it may take many seconds to fully exhale. It is also important to recognise those patients whose efforts are reduced by chest pain or abdominal problems, or by fear of incontinence, or even just by lack of confidence. There is no substitute for careful explanation and demonstration - demonstrating the manoeuvre to the patient will overcome 90% of problems encountered and is critical in achieving satisfactory results. Observation and encouragement of the patient's performance are also crucial.

At least three technically acceptable manoeuvres should be obtained, ideally with less than 0.15 L variability for FEV_1 (and FVC) between the highest and second highest result.

Each individual test is acceptable if it meets the following acceptability and repeatability criteria.

Acceptability Criteria

- The patient followed instructions
- A continuous maximal expiratory manoeuvre throughout the test (i.e. no stops and starts) was achieved and was initiated from full inspiration
- There was no evidence of hesitation during the test
- The test was performed with a rapid start
- The PEF has a sharp rise (flow-volume)
- No premature termination, i.e. expiration continued until there was no change in volume and the patient had blown for ≥3 seconds (children aged <10 years) or for ≥6 seconds (patients aged ≥10 years). However, the patient or practitioner can terminate the blow if the patient cannot or should not continue
- There were no leaks
- No cough (note FEV_1 may be valid if cough occurs after the first second)
- No glottis closure (Valsalva)
- No obstruction of the mouthpiece (e.g. by the tongue or teeth)
- No evidence that the patient took an additional breath during the expiratory manoeuvre

Repeatability Criteria

- Obtain 3 acceptable tests, i.e. each test should meet the stated acceptability criteria
- The two largest values for FVC should agree to within 0.15L
- The two largest values for FEV_1 should agree to within 0.15L

Obtain additional tests if these repeatability criteria are not met.

Results to Report

- FEV_1 - report the largest value
- FVC - report the largest value
- PEF - report the largest value
- $FEF_{25-75\%}$ - report the value from the test with the highest sum of FEV_1 + FVC

It is important that the acceptability criteria be applied and unacceptable tests discarded before assessing repeatability, as the latter is used to determine whether additional tests from the three acceptable ones already obtained are required. These criteria (together with a properly maintained and calibrated spirometer) help to ensure the quality of your results.

Tests that do not fully meet the acceptability criteria may still be useful. For example, FEV_1 may still be valid if cough or premature termination of the blow occurs after the first second. The report should state when the results are obtained from manoeuvres that do not meet acceptability and repeatability criteria.

Figures 3 (a) and 3 (b) show some problematic examples compared with well-performed manoeuvres.

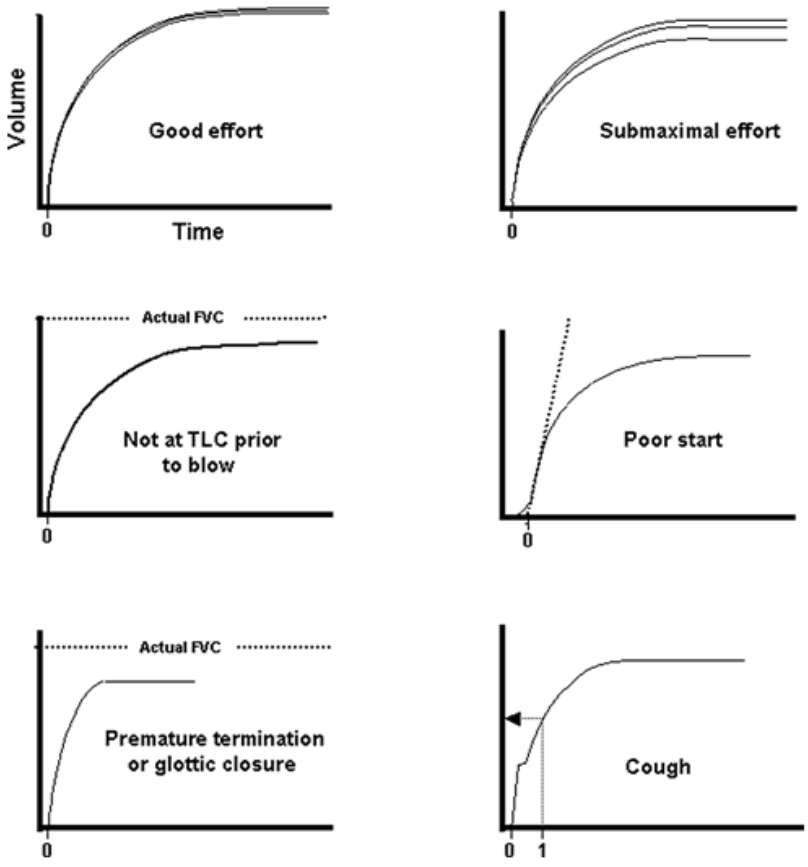

Fig 3 (a)

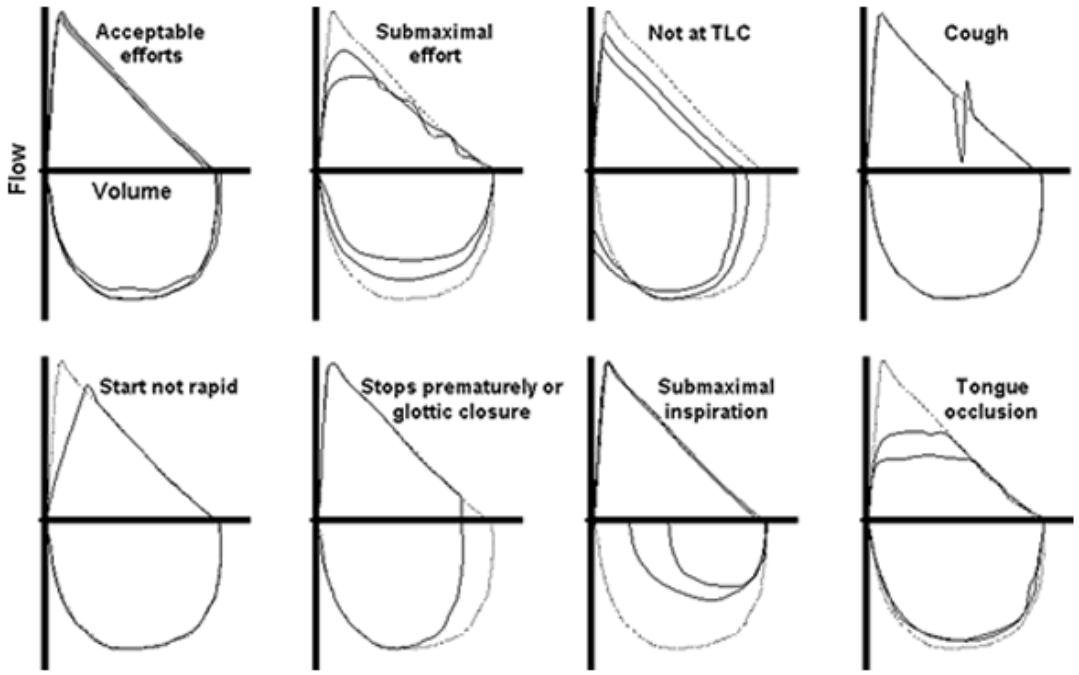

Fig 3 (b)

Patient-Related Problems

The most common patient-related problems when performing the FVC manoeuvre are:

1. Submaximal effort
2. Leaks between the lips and mouthpiece
3. Incomplete inspiration or expiration (prior to or during the forced manoeuvre)
4. Hesitation at the start of the expiration
5. Cough (particularly within the first second of expiration)
6. Glottic closure
7. Obstruction of the mouthpiece by the tongue
8. Vocalisation during the forced manoeuvre
9. Poor posture.

Once again, demonstration of the procedure will prevent many of these problems, remembering that all effort-dependent measurements will be variable in patients who are uncooperative or trying to produce low values.

Glottis closure should be suspected if flow ceases abruptly during the test rather than being a continuous smooth curve. Recordings with cough, particularly if this occurs within the first second, or hesitation at the start should be rejected. Vocalisation during the test will reduce flows and must be discouraged - performing the manoeuvre with the neck extended often helps.

The vigorous effort required for spirometry is often facilitated by demonstrating the test yourself.

Instrument-Related Problems

These depend largely on the type of spirometer being used. On volume-displacement spirometers look for leaks in the hose connections; on flow-sensing spirometers look for rips and tears in the flowhead connector tube; on electronic spirometers be particularly careful about calibration, accuracy and linearity. Standards recommend checking the calibration at least daily and a simple self-test of the spirometer is an additional, useful daily check that the instrument is functioning correctly.

Predicted Normal Values

To interpret ventilatory function tests in any individual, compare the results with reference values obtained from a well-defined population of normal subjects matched for sex, age, height and ethnic origin and using similar test protocols; and carefully calibrated and validated instruments.[1]

Normal predicted values for ventilatory function generally vary as follows:

1. Sex: For a given height and age, males have a larger FEV_1, FVC, FEF25-75% and PEF, but a slightly lower FEV_1/FVC.
2. Age: **FEV_1**, **FVC**, **$FEF_{25-75\%}$** and **PEF** increase, while **FEV_1/FVC** decreases, with age until about 20 years old in females and 25 years in males.

   After this, **all indices** gradually fall, although the precise rate of decline is probably masked due to the complex interrelationship between age and height. The fall in FEV_1/FVC with age in adults is due to the greater decline in FEV_1 than FVC.
3. Height: All indices other than FEV_1/FVC increase with standing height.
4. Ethnic Origin: Caucasians have the largest FEV_1 and FVC and, of the various ethnic groups, Polynesians are among the lowest. The values for black Africans are 10-15% lower than for Caucasians of similar age, sex and height because for a given standing height their thorax is shorter; normal values for Indigenous Australians may be even lower. Chinese have been found to have an FVC about 20% lower and Indians about 10% lower than matched Caucasians. There is little difference in PEF between ethnic groups.

There is a vast literature of normal population studies, many of which have deficiencies in sample size, definition of normality, inclusion of smokers and choice of equipment. *Appendix B* provides tables of mean predicted values from a well-conducted study on a US Caucasian population[2].

Interpretation of Ventilatory Function Tests

Measurements of ventilatory function may be very useful in a diagnostic sense but they are also useful in following the natural history of disease over a period of time, assessing preoperative risk and in quantifying the effects of treatment. The presence of ventilatory abnormality can be inferred if any of FEV_1, VC, PEF or FEV_1/FVC are outside the normal range.

Classifying Abnormal Ventilatory Function

The inter-relationships of the various measurements are also important diagnostically *(see Table and Figure 4).* For example

1. A reduction of FEV_1 in relation to the forced vital capacity will result in a low FEV_1/FVC and is typical of **obstructive ventilatory defects** (e.g. asthma and emphysema). The lower limit of normal for FEV_1/FVC is around 70-75% but the exact limit is dependent on age. The exact values by age, sex and height are given in the tables in Appendix B. In obstructive lung disease the FVC may be less than the slow VC because of earlier airway closure during the forced manoeuvre. This may lead to an overestimation of the FEV_1/FVC. Thus, the FEV_1/VC may be a more sensitive index of airflow obstruction.
2. The FEV_1/FVC ratio remains normal or high (typically > 80%) with a reduction in both FEV_1 and FVC in **restrictive ventilatory defects** (e.g. interstitial lung disease, respiratory muscle weakness, and thoracic cage deformities such as kypho-scoliosis).
3. A reduced FVC together with a low FEV_1/FVC ratio is a feature of a **mixed ventilatory defect** in which a combination of both obstruction and restriction appear to be present, or alternatively may occur in airflow obstruction as a consequence of airway closure resulting in gas trapping, rather than as a result of small lungs. It is necessary to measure the patient's total lung capacity to distinguish between these two possibilities.

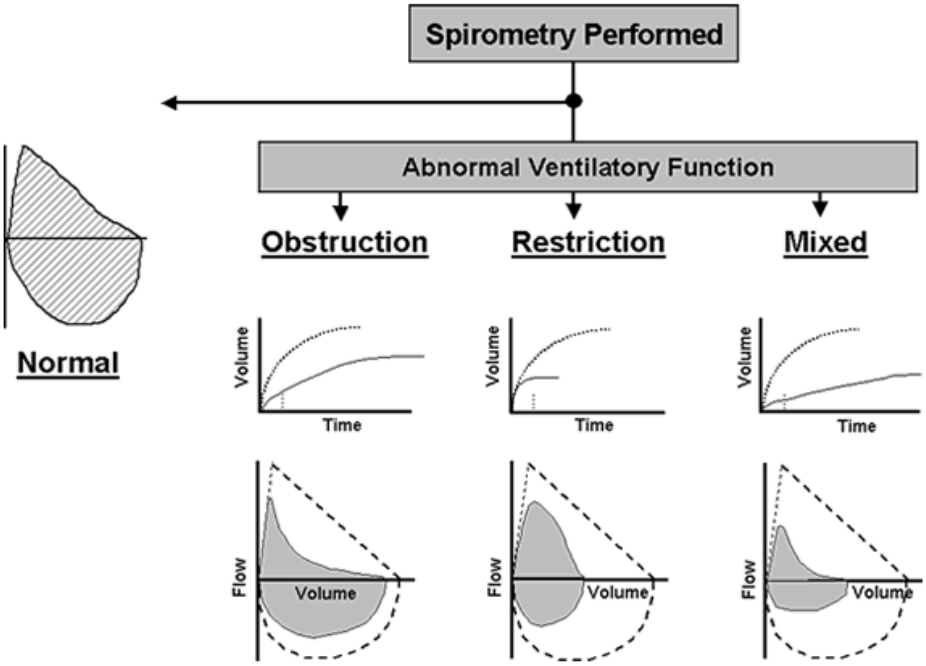

Figure 4
Schematic diagram illustrating idealised shapes of flow-volume curves and spirograms for obstructing, restrictive and mixed ventilatory defects.

Classification Of Ventilatory Abnormalities by Spirometry

	OBSTRUCTIVE	RESTRICTIVE	MIXED
FEV_1	↓	↓ or Normal	↓
FVC	↓ or Normal	↓	↓
FEV_1/FVC	↓	Normal or ↑	↓

The shape of the expiratory flow-volume curve varies between **obstructive ventilatory defects** where maximal flow rates are diminished and the expiratory curve is scooped out or concave to the x-axis, and **restrictive diseases** where flows may be increased in relation to lung volume (convex).

A "tail" on the expiratory curve as residual volume is approached is suggestive of obstruction in the small peripheral airways. Examination of the shape of the flow-volume curve can help to distinguish different disease states, but note that the inspiratory curve is effort-dependent.

For example, a plateau of inspiratory flow may result from a floppy extra-thoracic airway, whereas both inspiratory and expiratory flow are truncated for fixed lesions.

Expiratory flows alone are reduced for intra-thoracic obstruction *(Figure 5)*.

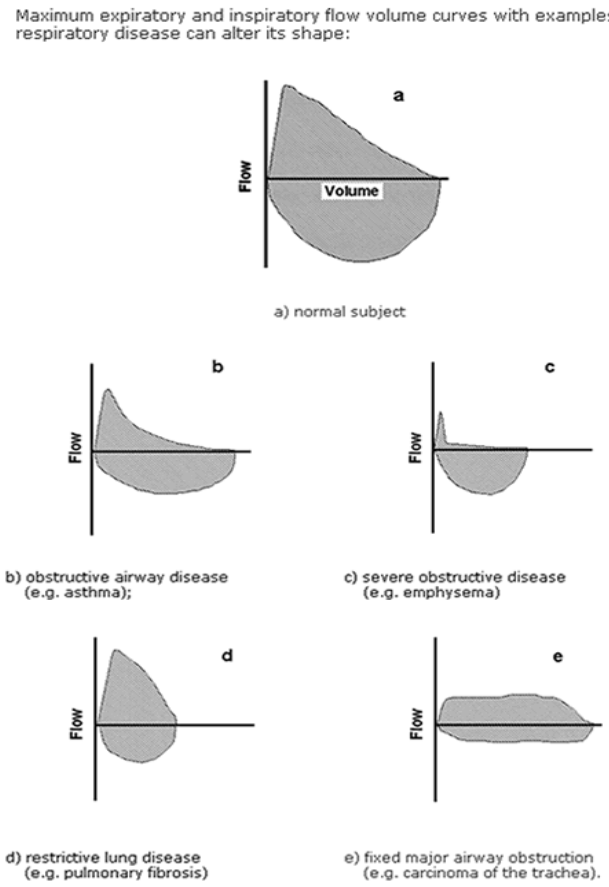

Figure 5
Maximum expiratory and inspiratory flow volume curves with examples of how respiratory disease can alter its shape

Measuring Reversibility of Airflow Obstruction

To measure the degree of reversibility (typically increased in asthma) of airflow obstruction, perform spirometry before and 10 to 15 minutes after administering a bronchodilator by metered dose inhaler or jet nebuliser. $Beta_2$ agonists (e.g. salbutamol, terbutaline, etc.) are generally considered the benchmark bronchodilator.

To express the degree of improvement,

- calculate the absolute change in FEV_1 (i.e. post-bronchodilator FEV_1 minus baseline FEV_1) and
- calculate the percentage improvement from the baseline FEV_1.

$$\% \text{ Improvement} = 100 \times \frac{FEV_1 \text{ (post-bronchodilator)} - FEV_1 \text{ (baseline)}}{FEV_1 \text{ (baseline)}}$$

There is presently no universal agreement on the definition of significant bronchodilator reversibility. According to the ATS/ERS the criteria for a significant response in adults is:

$\geq$12% improvement in FEV_1 (or FVC) and an absolute improvement of $\geq$0.2 L

Normal subjects generally exhibit a smaller degree of reversibility (up to 8% in most studies). The absence of reversibility does not exclude asthma because an asthmatic person's response can vary from time to time and at times airway calibre in asthmatic subjects is clearly normal and incapable of dramatic improvement.

Peak Flow Monitoring

When peak expiratory flow is measured repeatedly over a period and plotted against time (e.g. by patients with asthma), the pattern of the graph can be helpful in identifying particular aspects of the patient's disease. Typical patterns are

- the fall in PEF during the week with improvement on weekends and holidays which occurs in occupational asthma; and
- the 'morning dipper' pattern of some patients with asthma due to a fall in PEF in the early morning hours.

Isolated falls in PEF in relation to specific allergens or trigger factors can help to identify and quantify these for the doctor and patient. A downward trend in PEF and an increase in its variability can identify worsening asthma and can be used by the doctor or patient to modify therapy. PEF monitoring is particularly useful for people with poor perception of their own airway calibre. Response to asthma treatment is usually accompanied by an increase in PEF and a decrease in its variability.

Further practical information about measuring peak flow is given in the National Asthma Council's *Asthma Management Handbook*.

PEF self-monitoring can be useful in asthma management, particularly in those with poor perception of their own airway calibre.

Choosing an Appropriate Test

It is worth trying to recognise clinical situations and choosing the appropriate test for each. For example,

- If upper airway obstruction is suspected, flow-volume curve with particular emphasis on inspiration is the best test.
- For the diagnosis of asthma, spirometry before and after the administration of a bronchodilator, looking for an obstructive pattern with significant improvement, would apply. It is usually necessary to repeat spirometric assessment of airway function at follow-up visits in asthma and other lung conditions where change can occur over short periods of time.
- In patients suspected of having asthma but in whom baseline spirometry is normal, it may be appropriate to try bronchial challenge testing with measurement of spirometry before and after provocation by exercise or by inhalation of histamine, methacholine or hypertonic saline.

To identify asthma triggers or treatment responses over long periods of time, regular PEF monitoring by the patient can be helpful.

Spirometry is most useful for:

- Detection of disease and its severity
- Identification of asthma triggers
- Progress/natural history monitoring
- Treatment response assessment
- Preoperative assessment

Infection Control Measures

In patients with a known infectious disease, many laboratories prefer to measure ventilatory function using a pneumotachograph or other electronic sensor, as these can be more easily cleaned and sterilised than conventional bellows or water-sealed spirometers.

Although the transmission of respiratory pathogens (e.g. *Mycobacterium avium, M. tuberculosis* and *aspergillus species)* via spirometers has not been fully established, the potential risks are difficult to disprove. During spirometry patients can generate flows up to 14 L/sec (840 L/min) which can easily mobilise saliva and create dense macro- and micro-aerosols by entrainment of the fluid lining the mucous membranes. These can then be deposited in the equipment. Unless such deposition is prevented or the equipment is rigorously cleaned and decontaminated, the chance of cross-infection exists.

Mouthpieces must be disposed of or cleaned and disinfected between patients because the greatest danger of cross-infection is via direct contact with bodily fluids.

Since it is usually impractical to effectively decontaminate the interior surfaces of a spirometer between patients, most lung function laboratories clean and disinfect their equipment periodically (weekly or monthly) or use a disposable, low-resistance micro-aerosol filter inserted between the subject and spirometer to prevent contamination. Filters also have the advantage of protecting sensors and the internal surfaces of the spirometer from damage and reduce the corroding effects of cleaning agents and disinfectants. The extent to which the use of filters can effectively obviate the need for cleaning and disinfection is unclear. The cost of filters may be offset by reduced cleaning and disinfection costs. Other laboratories use disposable mouthpieces containing a one-way valve to prevent inspiration from equipment, but this is only possible when performing solely expiratory spirometry. However, their effectiveness at reducing the risk of cross-infection does not appear to have been studied.

If disassembling the spirometer for cleaning, it is essential to:

- thoroughly dry the components before reassembling
- check the spirometer for correct operation
- adjust the calibration, if necessary.

Summary

Measurements of ventilatory function should be part of the routine assessment of patients with respiratory disease.

Spirometry measurements can detect respiratory abnormalities and help to differentiate the various disease processes which result in ventilatory impairment.

They also have an important role in following the natural history of respiratory disease and its treatment.

Appendix A - Calibration Checks

From a practical point of view it is necessary to perform calibration checks on spirometers: a calibration syringe is generally needed. The frequency of performing checks will vary with the clinical setting and the type of instrument being used, and the need to adjust the calibration will depend on whether it is outside control limits. Flow-type spirometers generally require daily calibration checks. An important determinant is the stability of the calibration over time and this can only be established with hindsight, having performed many calibration checks on the instrument. All spirometers must be recalibrated after cleaning or disinfection, or if an unusual or unexpected result indicates a problem.

Typically, spirometers should be accurate (volume to within ± 0.05 L or ±3%, whichever is greater; flow to within ±0.2 L/sec or ±5%, whichever is greater) and calibrated periodically with an accurate (certified) 3 L syringe. When a spirometer is moved into a cooler or hotter environment, it is important to allow time for it to reach the new temperature and to measure it, otherwise the BTPS correction factor will be incorrect. Similarly, the calibration syringe needs to be at the same temperature as the spirometer and for this reason it is usually stored near the spirometer. In order to detect changes in overall spirometer performance, the ventilatory function of one or more subjects with stable respiratory function should be measured and recorded regularly as part of an ongoing quality control programme.

Records of calibration checks, quality control and service history should be kept with the equipment. In the surgery, testing yourself (if you have stable function) on your spirometer every week or two is a practical way of ensuring quality control. A variation of >5% in FEV_1 or FVC should alert you to a problem and the need to have your instrument properly checked and serviced

Flow measurement devices (e.g. pneumotachographs, turbinometers) should be checked regularly for linearity over the physiological range of flows (0-14 L per second). A good test of linearity is to deliver a given volume (e.g. with a 3 L syringe) at a wide variety of flows, ensuring that the volume recorded by the instrument is close to 3.00 L over the whole range of flows. When 3 L is passed into the spirometer it should record a volume to within ±3.5%; that is, a spirometer is accurate if the recorded volume is between 2.895 L and 3.105 L.

Peak flow meters can generally be expected to wear out after about 12 to 24 months of heavy use, although there is little published data to support this, whereas a volume-displacement spirometer will usually last years if properly maintained and serviced.

Appendix B - Predicted Normal Values

There is a vast literature of normal population studies, many of which have deficiencies in sample size, ethnicity, definition of normality, inclusion of smokers and choice of equipment. In the absence of population-specific reference values, measurements for patients of mainly European origin are better predicted by European values while those for patients of mainly British and Irish origin are better predicted by North American values.

The following tables provide mean predicted values for Caucasians of both sexes for FEV_1, FVC, FEV_1/FVC, $FEF_{25–75\%}$ and PEF. The tables are based on a large and well-conducted study in asymptomatic, lifelong non-smokers aged 8 to 80 years who participated in the National Health and Nutrition Examination Survey (NHANES III).[2,3] It is not recommended to extrapolate beyond the age and height range of the population used to obtain the reference equations.

Age is shown in years, height is shown in centimetres.

Respiratory function tables

From the National Asthma Council Australia. *Asthma Management Handbook 2006*. Melbourne: National Asthma Council Australia, 2006. Used with permission.

FEV_1 (L) Male

Age		20	25	30	35	40	45	50	55	60	65	70	75	80
	145 cm	3.19	3.08	2.97	2.85	2.72	2.58	2.44	2.28	2.12	1.94	1.76	1.57	1.37
	150 cm	3.40	3.29	3.18	3.06	2.93	2.79	2.64	2.49	2.32	2.15	1.97	1.78	1.58
	155 cm	3.61	3.51	3.39	3.27	3.14	3.01	2.86	2.70	2.54	2.37	2.19	2.00	1.80
	160 cm	3.83	3.73	3.62	3.50	3.37	3.23	3.08	2.93	2.76	2.59	2.41	2.22	2.02
	165 cm	4.06	3.96	3.85	3.73	3.60	3.46	3.31	3.15	2.99	2.82	2.64	2.45	2.25
	170 cm	4.30	4.19	4.08	3.96	3.83	3.69	3.55	3.39	3.23	3.05	2.87	2.68	2.48
	175 cm	4.54	4.44	4.33	4.20	4.07	3.94	3.79	3.63	3.47	3.30	3.12	2.93	2.73
	180 cm	4.79	4.69	4.58	4.45	4.32	4.19	4.04	3.88	3.72	3.55	3.37	3.18	2.98
	185 cm	5.05	4.95	4.83	4.71	4.58	4.44	4.30	4.14	3.98	3.80	3.62	3.43	3.24
	190 cm	5.31	5.21	5.10	4.98	4.85	4.71	4.56	4.41	4.24	4.07	3.89	3.70	3.50
	195 cm	5.58	5.48	5.37	5.25	5.12	4.98	4.83	4.68	4.51	4.34	4.16	3.97	3.77

FVC (L) Male

Age		20	25	30	35	40	45	50	55	60	65	70	75	80
	145 cm	3.63	3.57	3.50	3.42	3.32	3.21	3.09	2.95	2.80	2.63	2.45	2.26	2.06
	150 cm	3.91	3.85	3.78	3.69	3.60	3.49	3.36	3.22	3.07	2.91	2.73	2.54	2.33
	155 cm	4.19	4.13	4.06	3.98	3.88	3.77	3.64	3.51	3.36	3.19	3.01	2.82	2.62
	160 cm	4.48	4.43	4.36	4.27	4.17	4.06	3.94	3.80	3.65	3.48	3.31	3.11	2.91
	165 cm	4.79	4.73	4.66	4.57	4.48	4.37	4.24	4.10	3.95	3.79	3.61	3.42	3.21
	170 cm	5.10	5.04	4.97	4.89	4.79	4.68	4.55	4.42	4.26	4.10	3.92	3.73	3.52
	175 cm	5.42	5.36	5.29	5.21	5.11	5.00	4.88	4.74	4.59	4.42	4.24	4.05	3.85
	180 cm	5.75	5.69	5.62	5.54	5.44	5.33	5.21	5.07	4.92	4.75	4.57	4.38	4.18
	185 cm	6.09	6.03	5.96	5.88	5.78	5.67	5.55	5.41	5.26	5.09	4.91	4.72	4.52
	190 cm	6.44	6.38	6.31	6.23	6.13	6.02	5.90	5.76	5.61	5.44	5.26	5.07	4.87
	195 cm	6.80	6.74	6.67	6.59	6.49	6.38	6.25	6.12	5.97	5.80	5.62	5.43	5.22

FEV_1/FVC (%) Male

Age	20	25	30	35	40	45	50	55	60	65	70	75	80
All Heights	83.9	82.9	81.9	80.8	79.8	78.8	77.7	76.7	75.7	74.6	73.6	72.6	71.5

FEV_1 (L) Female

Age		18	20	25	30	35	40	45	50	55	60	65	70	75	80
	145 cm	2.72	2.70	2.64	2.57	2.49	2.40	2.30	2.18	2.06	1.94	1.80	1.65	1.49	1.32
	150 cm	2.89	2.87	2.81	2.74	2.66	2.57	2.46	2.35	2.23	2.10	1.97	1.82	1.66	1.49
	155 cm	3.07	3.05	2.98	2.91	2.83	2.74	2.64	2.53	2.41	2.28	2.14	1.99	1.83	1.66
	160 cm	3.25	3.23	3.16	3.09	3.01	2.92	2.82	2.71	2.59	2.46	2.32	2.17	2.01	1.85
	165 cm	3.44	3.41	3.35	3.28	3.20	3.11	3.01	2.90	2.78	2.65	2.51	2.36	2.20	2.03
	170 cm	3.63	3.61	3.54	3.47	3.39	3.30	3.20	3.09	2.97	2.84	2.70	2.55	2.39	2.23
	175 cm	3.83	3.80	3.74	3.67	3.59	3.50	3.40	3.29	3.17	3.04	2.90	2.75	2.59	2.42
	180 cm	4.03	4.01	3.95	3.88	3.79	3.70	3.60	3.49	3.37	3.24	3.10	2.95	2.80	2.63
	185 cm	4.24	4.22	4.16	4.08	4.00	3.91	3.81	3.70	3.58	3.45	3.31	3.16	3.01	2.84
	190 cm	4.46	4.43	4.37	4.30	4.22	4.13	4.03	3.92	3.80	3.67	3.53	3.38	3.22	3.05
	195 cm	4.68	4.65	4.59	4.52	4.44	4.35	4.25	4.14	4.02	3.89	3.75	3.60	3.44	3.27

FVC (L) Female

Age		18	20	25	30	35	40	45	50	55	60	65	70	75	80
	145 cm	2.97	2.98	2.99	2.98	2.95	2.90	2.83	2.74	2.63	2.51	2.36	2.20	2.01	1.81
	150 cm	3.19	3.20	3.21	3.19	3.16	3.11	3.05	2.96	2.85	2.72	2.58	2.41	2.23	2.03
	155 cm	3.42	3.42	3.43	3.42	3.39	3.34	3.27	3.18	3.08	2.95	2.80	2.64	2.46	2.25
	160 cm	3.65	3.66	3.67	3.65	3.62	3.57	3.50	3.42	3.31	3.18	3.04	2.87	2.69	2.49
	165 cm	3.89	3.90	3.91	3.89	3.86	3.81	3.75	3.66	3.55	3.42	3.28	3.11	2.93	2.73
	170 cm	4.14	4.15	4.15	4.14	4.11	4.06	3.99	3.91	3.80	3.67	3.53	3.36	3.18	2.98
	175 cm	4.39	4.40	4.41	4.40	4.37	4.32	4.25	4.16	4.05	3.93	3.78	3.62	3.43	3.23
	180 cm	4.66	4.67	4.67	4.66	4.63	4.58	4.51	4.42	4.32	4.19	4.05	3.88	3.70	3.50
	185 cm	4.93	4.94	4.94	4.93	4.90	4.85	4.78	4.69	4.59	4.46	4.32	4.15	3.97	3.77
	190 cm	5.21	5.21	5.22	5.21	5.18	5.13	5.06	4.97	4.87	4.74	4.59	4.43	4.25	4.04
	195 cm	5.49	5.50	5.51	5.49	5.46	5.41	5.35	5.26	5.15	5.02	4.88	4.71	4.53	4.33

FEV_1/FVC (%) Female

Age	18	20	25	30	35	40	45	50	55	60	65	70	75	80
All Heights	87.0	86.6	85.5	84.4	83.4	82.3	81.2	80.2	79.1	78.1	77.0	75.9	74.9	73.8

FEV_1 (L) Male children (<20 years)

Age		8	10	12	14	16	18	20
	125 cm	1.42	1.49	1.61	1.76	1.95	2.17	2.43
	130 cm	1.60	1.67	1.79	1.94	2.13	2.35	2.61
	135 cm	1.78	1.86	1.98	2.13	2.31	2.54	2.79
	140 cm	1.98	2.06	2.17	2.32	2.51	2.73	2.99
	145 cm	2.18	2.26	2.37	2.52	2.71	2.93	3.19
	150 cm	2.38	2.46	2.58	2.73	2.92	3.14	3.40
	155 cm	2.60	2.68	2.79	2.94	3.13	3.35	3.61
	160 cm	2.82	2.90	3.02	3.17	3.35	3.58	3.83
	165 cm	3.05	3.13	3.24	3.40	3.58	3.80	4.06
	170 cm	3.29	3.37	3.48	3.63	3.82	4.04	4.30
	175 cm	3.53	3.61	3.72	3.87	4.06	4.28	4.54
	180 cm	3.78	3.86	3.97	4.13	4.31	4.53	4.79
	185 cm	4.04	4.12	4.23	4.38	4.57	4.79	5.05

FVC (L) Male children (<20 years)

Age		8	10	12	14	16	18	20
	125 cm	1.67	1.63	1.66	1.78	1.98	2.26	2.62
	130 cm	1.91	1.86	1.90	2.02	2.22	2.50	2.86
	135 cm	2.15	2.11	2.15	2.27	2.47	2.75	3.11
	140 cm	2.41	2.37	2.40	2.52	2.72	3.00	3.37
	145 cm	2.68	2.63	2.67	2.79	2.99	3.27	3.63
	150 cm	2.95	2.91	2.95	3.06	3.26	3.54	3.91
	155 cm	3.24	3.19	3.23	3.35	3.55	3.83	4.19
	160 cm	3.53	3.49	3.52	3.64	3.84	4.12	4.48
	165 cm	3.83	3.79	3.83	3.94	4.14	4.43	4.79
	170 cm	4.14	4.10	4.14	4.26	4.46	4.74	5.10
	175 cm	4.47	4.42	4.46	4.58	4.78	5.06	5.42
	180 cm	4.80	4.75	4.79	4.91	5.11	5.39	5.75
	185 cm	5.14	5.09	5.13	5.25	5.45	5.73	6.09

FEV_1/FVC (%) Male Children (<20 years)

Age	8	10	12	14	16	18	20
All Heights	86.4	86.0	85.6	85.2	84.8	84.3	83.9

PEF (L/min) Male children (<20 years)

Age		8	10	12	14	16	18	20
	125 cm	189	203	223	249	281	320	365
	130 cm	208	222	242	268	300	339	384
	135 cm	228	242	262	288	320	359	404
	140 cm	249	262	282	308	341	380	425
	145 cm	270	284	304	330	362	401	446
	150 cm	292	306	326	352	384	423	468
	155 cm	315	329	349	375	407	446	491
	160 cm	339	352	372	398	431	470	515
	165 cm	363	377	396	423	455	494	539
	170 cm	388	402	422	448	480	519	564
	175 cm	414	428	447	474	506	545	590
	180 cm	441	454	474	500	533	571	616
	185 cm	468	481	501	527	560	599	644

FEV_1 (L) Female Children (<18 years)

Age		8	10	12	14	16	18
	125 cm	1.45	1.58	1.71	1.84	1.97	2.10
	130 cm	1.59	1.73	1.86	1.99	2.12	2.25
	135 cm	1.75	1.88	2.01	2.14	2.27	2.40
	140 cm	1.91	2.04	2.17	2.30	2.43	2.56
	145 cm	2.07	2.20	2.33	2.46	2.59	2.72
	150 cm	2.24	2.37	2.50	2.63	2.76	2.89
	155 cm	2.41	2.54	2.68	2.81	2.94	3.07
	160 cm	2.59	2.73	2.86	2.99	3.12	3.25
	165 cm	2.78	2.91	3.04	3.17	3.30	3.44
	170 cm	2.97	3.11	3.24	3.37	3.50	3.63
	175 cm	3.17	3.30	3.43	3.56	3.70	3.83
	180 cm	3.38	3.51	3.64	3.77	3.90	4.03
	185 cm	3.59	3.72	3.85	3.98	4.11	4.24

FVC (L) Female Children (<18 years)

Age		8	10	12	14	16	18
	125 cm	1.58	1.70	1.82	1.93	2.05	2.17
	130 cm	1.77	1.89	2.01	2.12	2.24	2.36
	135 cm	1.97	2.08	2.20	2.32	2.44	2.56
	140 cm	2.17	2.29	2.41	2.52	2.64	2.76
	145 cm	2.38	2.50	2.62	2.73	2.85	2.97
	150 cm	2.60	2.72	2.84	2.95	3.07	3.19
	155 cm	2.82	2.94	3.06	3.18	3.30	3.42
	160 cm	3.06	3.18	3.29	3.41	3.53	3.65
	165 cm	3.30	3.42	3.54	3.65	3.77	3.89
	170 cm	3.55	3.66	3.78	3.90	4.02	4.14
	175 cm	3.80	3.92	4.04	4.16	4.28	4.39
	180 cm	4.07	4.18	4.30	4.42	4.54	4.66
	185 cm	4.34	4.45	4.57	4.69	4.81	4.93

FEV_1/FVC (%) Female Children (<18 years)

Age	8	10	12	14	16	18
All Heights	89.1	88.7	88.3	87.8	87.4	87.0

PEF (L/min) Female Children (<18 years)

Age		8	10	12	14	16	18
	125 cm	184	220	249	269	281	285
	130 cm	198	235	263	283	295	299
	135 cm	213	249	278	298	310	314
	140 cm	228	265	293	313	325	329
	145 cm	244	281	309	329	341	345
	150 cm	261	297	325	346	358	362
	155 cm	278	314	342	363	375	379
	160 cm	295	332	360	380	392	396
	165 cm	314	350	378	398	411	415
	170 cm	332	369	397	417	429	433
	175 cm	352	388	416	436	449	453
	180 cm	371	408	436	456	468	472
	185 cm	392	428	456	477	489	493

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Comments to:
Associate Professor David P. Johns
Menzies Research Institute and School of Medicine
University of Tasmania,
Hobart, Australia
Email: david.johns@utas.edu.au

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Tel: (03) 8699 0476

Fax: (03) 8699 0400

Email: nac@nationalasthma.org.au

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