Interpreting spirometry in the occupational setting

Van der Linden L,
RN, RM, CHN, Psych. Nurs., Dip. ICU, Dip. & Degree Modules Spirometry (UK), Dip. Module Asthma (SA)
Correspondence: 39 Muirfield Circle, Mount, Edgecombe CC1, Durban, 4302. South Africa. Tel: +27 (0)83 659 5299, e-mail: linds@icon.co.za http://www.spirometrysa.co.za and http://www.lungwellness.co.za

ABSTRACT

Interpreting spirometry is not a case of simply picking up a spirogram and assessing the numerical values, nor is it reading a pre-programmed computerised feedback report which can be incorrectly pre-programmed and therefore gives at times an incorrect computerised interpretation. It is, rather, a logical and systematic process of checks and considerations, each of which is essential in order to ultimately report a correct and educated interpretation of the spirogram at hand. The purpose of this Back to basics article is to describe the sequence of events that must be adhered to in order to achieve a graphic and digital result that will be of sufficient technical adequacy to allow confident interpretation in the occupational health setting.

Key words: spirometry, interpretation, technical adequacy, abnormality classification

INTRODUCTION

Interpreting spirometry is not a case of simply picking up a spirogram and assessing the numerical values, nor is it reading a pre-programmed computerised feedback report which can be incorrectly pre-programmed and therefore gives at times an incorrect computerised interpretation. It is, rather, a logical and systematic process of checks and considerations, each of which is essential in order to ultimately report a correct and educated interpretation of the spirogram at hand. Equipment verification and calibration, the use of correct predicted values together with correction for ethnic origin and the reliability of the data all need to be taken into account when interpreting the final test result.

When utilising that spirometry result, it must also be remembered that whilst spirometry is useful in detecting disease and giving us an objective result on an individual's actual lung function as well as following the course of disease over time, it cannot on its own diagnose disease, measure the actual symptoms a patient feels, identify the symptomatic response to treatment or determine the actual disability.

The purpose of this article is to describe the sequence of events that must be adhered to in order to achieve a graphic and digital result that will be of sufficient technical adequacy to allow confident interpretation in the occupational health setting. It is understandable that not all subjects will give a spirometric result that matches the perfect idealised test that is usually achieved in the laboratory circumstance. However, there are certain minimum requirements even in the occupational health setting that must still be met for the test to be meaningful and useful for interpretation.

The use of appropriate reference values

Reference values are predicted values based on equations that take into account age, height, gender and ethnicity and are derived from extensive studies of normal, healthy population groups. The subject's blow is analysed against the predicted values and the result recorded as a percentage of predicted. Most people in the population will be close to this average or "predicted value", but some normal people will be above and others below the average due to various factors, some of which are unknown. The bottom of the normal range is described by the lower limit of normal (LLN). The LLN is the 5th percentile and the use of percentage of predicted for interpretation is an accepted alternative.[1] Further explanation is beyond the scope of this article.

The choice of reference values is challenging in our ethnically and culturally diverse population groups in South

Africa. The reference values for each individual subject should be chosen from a study done on individuals with the same ethnic and anthropometric characteristics as the subject being tested.[2,3] Typically, in South Africa the use of the European Community of Coal and Steel Workers (ECCS) values are used for subjects of white European descent (previously termed Caucasian).[1,4] Subjects who are not of white European descent usually show a lower forced vital capacity (FVC) and forced expiratory volume in the first second (FEV1) due to different limb length to chest ratio, and therefore a correction factor of 0.9 should be used for these subjects when referenced against ECCS predicteds.[4] The advice in the 2003 Mines Health and Safety Inspectorate Guidance Note for Occupational Medical Practitioners: Lung Function Testing given in this regard is currently under review to accommodate this correction factor.[5]

Data quality control

In order for a test to meet the minimum standard for quality control of data, all three blows need to meet all acceptability and repeatability criteria, as shown in Table 1.[4,6,7] If they do not, the subject should blow again until all criteria are met. If every effort has been made to get acceptable blows and this has not been achieved, usability criteria, as per Table 1, can be applied with caution and the final interpretation would then take these factors into account.

If a test is less than optimal it may still contain useful information and should therefore not be discarded but used with caution and understanding. For this the effects on interpretation of testing errors need to be fully understood.

Acceptability criteria

- Satisfactory unhesitating start.
- Smooth upward rise to peak.
- Peak that shows good effort.
- Smooth, continuous downward curve.
- No early termination.
- 6 second push out (3 secs for children), or cannot or should not continue.

Repeatability criteria

- Three acceptable blows.
- Min 3 and max 8 tests.
- 3 blows that are superimposed.
- Highest FVC within 150 mls of next highest FVC.
- Highest FEV1 within 150 mls of next highest FEV1.

Usability criteria

- No hesitation at the start of the test.
- No coughing during the first second of the blow.

Table 1. Criteria for acceptability, repeatability and usability[3,5,6]

Pre	Pred	Best	%Prd	2nd	3rd
FVC	4.11	2.93*	71%	2.88*	2.86*
FEV1	3.46	2.66	77%	2.67	2.58*
FEV1/FVC	0.80	0.91	113%	0.93	0.90
FEV6	–	–	–	–	–
FEV1/FEV6	–	–	–	–	–
PEFR	8.60	11.04	128%	11.34	11.29
FEF25-75	4.25	4.69	110%	4.77	4.14

Figure 1. Example of the numerical data for a spirometry test

Selecting the best test

Once the validity of the three measurements has been established the best test should be identified so that the correct values can be used for interpretation. ACOEM recommends that occupational spirometry test reports include values and curves from all acceptable curves and that the largest FVC and largest FEV1 be interpreted, even if they come from different curves.[8] The SANS 451 simplifies this concept, taking into account the situation where the spirometer software cannot create a new "best" test from a highest FVC and FEV1 should they come from two different blows by stating on page 29 that choosing the best test is done by selecting the blow with the largest sum of FVC and FEV1.[4] In Figure 1 the best test is indicated with the label "Best" above the column. You will see here that the highest FVC is 2.93L in the first blow and the highest FEV1 is 2.67L from the second blow. Therefore the best test is the blow with the highest sum of FVC and FEV1 which is the test in the column labelled "Best".

Understanding flow volume and volume time curves

In order to interpret the spirogram, the flow volume and volume time curves should be fully understood. Both graphs in Figure 2 show the same three blows, but with different X and Y axial references giving you differing perspectives of characteristics of the blow. The flow volume curve on the left graphically depicts volume on the horizontal X axis and flow on the vertical Y axis. What is seen on this graph is mainly the part of the blow that occurs in the first second. This graph is not intuitively interpretable on its own but does readily reflect abnormalities in the exhalatory flow pattern as well as errors in technique. If a subject takes a deep breath in after the exhalation a line below the horizontal X axis will show and this is known as the inspiratory curve. This is what differentiates a graph or test as a simple flow volume curve (exhalation only) as opposed to a flow volume loop (exhalation followed by inhalation). This inspiratory portion of the test should only be carried out in the occupational health setting when adequate infection control measures are available, e.g. bacterial filters or disposable tubes.[9] The inspiratory portion of the test does not add enough valuable information to offset the infection control risk to interpretation for it to be carried out as a standard in the occupational health setting.[1,3]

"Interpreting spirometry is . . . a logical and systematic process of checks and considerations . . ."

The graph on the right, the volume time curve, depicts volume on the vertical Y axis and time on the horizontal X axis, showing the entire FVC and is most useful for assessing the end of the test. On this graph you can see the absolute cut off of the FVC which is not easy to see on the flow volume curve.

Measurements of spirometry

Spirometry can measure static and dynamic lung volumes. "Static" in spirometry simply means the measurement of volume only, whereas "dynamic" spirometry measures volume based on time.[10] For example a static lung volume could be the vital capacity (VC) which is the maximum amount of air that can be exhaled after the fullest inspiration possible and is not measured on time at all. An example of a dynamic lung volume would be the FVC which is the measurement of the maximum volume of air expired with maximal effort from a position of maximal inhalation.

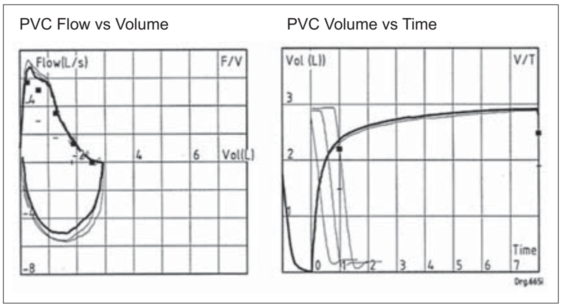


Figure 2. Graphs of the same three blows, depicting the flow volume curve on the left and the volume time curve on the right

Source: SANS 451, p. 35[4]

Pre	Pred	Best	%Prd	2nd	3rd
FVC	2.63	2.43	92%	2.37	2.22
FEV1	2.27	2.29	101%	2.26	2.11
FEV1/FVC	0.86	0.94	109%	0.95	0.95
FEV6	–	–	–	–	–
FEV1/FEV6	–	–	–	–	–
PEFR	6.19	6.67	108%	6.46	5.79
FEF25-75	3.71	4.12	111%	4.13	3.89

Figure 3. An example of a spirogram to show how the numerical data can be displayed

Interpretation cannot take place unless the following measurements used in spirometry are known and understood.[1]

- *FVC – forced vital capacity:* The maximum volume of air moved with maximum effort from maximum inspiration to maximum expiration.
- *FEV1 – forced expiratory volume in the first second:* The maximum volume of air moved with effort from maximum inspiration in the first second of the FVC.
- *FEV1/FVC – FEV1 as a ratio or percentage of the FVC:* The volume of air moved in the first second of the FVC expressed as a percentage of what was blown out in the total FVC.
- *PEF – peak expiratory flow rate:* The maximum rate of airflow in the FVC manouevre.
- *FEF25-75% – forced expiratory flow between 25 and 75% of the FVC:* The average rate of airflow in the middle portion of the FVC.

THE PROCESS OF INTERPRETATION

From the information gathered from the spirometry test certain deductions about what is happening throughout the lung can be made. Assessing the shape of the flow volume and volume time graphs together with an assessment of the numerical data will allow identification of a normal or abnormal test result.

Numerical data

For interpretation purposes, numerical data is read from the percentage (%) of predicted column. In the example in Figure 3, the FVC % of predicted is 92% and the FEV1 % of predicted is 101%. The FEV1/FVC, being how much

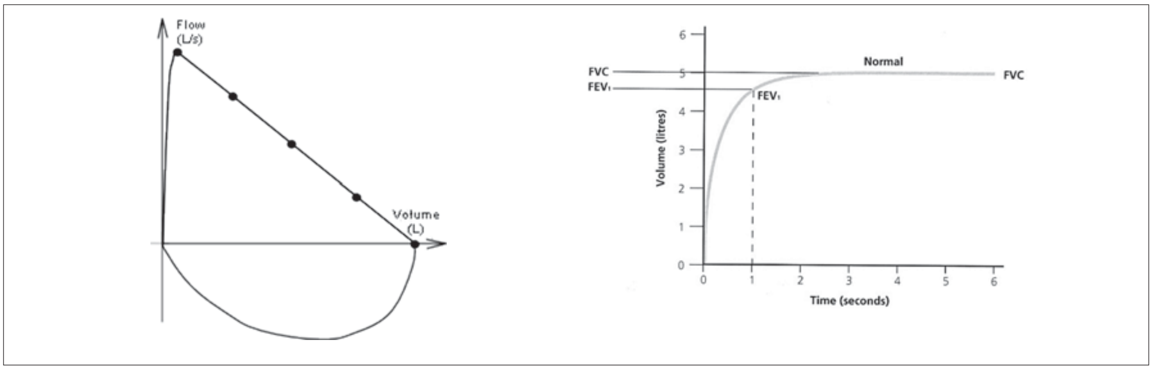


Figure 4. Examples of a normal flow volume loop on the left and a normal volume time graph on the right. (Diagrams taken with permission from Booker, Class Publishing Ltd and Education for Health UK[11])

air was blown out in the first second as a ratio of what was blown out in total, is read from the patient's actual blow. In this example, of the 2.43L of air blown out in total (FVC), 2.29L was blown out in the first second (FEV1). Therefore the FVC/FEV1 ratio of 2.29L to 2.43L in this example is 0.94 or 94%.

Classifying the abnormality

One of the aims of interpreting spirometry is to confirm a clinical diagnosis and classify the severity of the disease. The report should refer to the actual lung function and not the disease. In the occupational health clinic setting, the operator, who is normally the occupational health nurse or spirometrist, can identify basic abnormalities and when to refer. The referral doctor, who is usually the occupational medical practitioner or specialist, will use the information displayed on the spirogram to assist in making a final clinical diagnosis.[1] If the actual symptoms and the degree of spirometric impairment differ, more information will be required to evaluate fitness to perform an occupation or to support an application for compensation benefits.

After determining the technical adequacy of the test, the next step is to establish whether or not there is an abnormality. There are certain patterns of abnormal results that help categorise the clinical problem. Spirometry results are classified into one of four groups, based on their patterns. These are normal, obstructive impairments, restrictive impairments, and mixed obstructive/restrictive impairments. The results from a client can easily be assessed and classified by following the steps listed hereafter in the order shown:

- examine the flow volume and volume time curves;
- examine the FEV1/FVC;
- examine the FVC and FEV1; and
- examine other parameters.

The pattern of curves for each of the groups will be explained hereafter.

Normal spirometry

A flow/volume loop that has a typical shape is shown in Figure 4.[11] Going right, the exhalation tracing rises steeply from the baseline, does an inverted U turn at the apex, falls in a smooth downslope, and becomes almost horizontal at the end as it returns to the baseline. The down sloped curve from the apex of the curve to the end is usually smoothly concave, but there may be a smoothish convex hump near the top of the downslope.

A normal spirometry test, as in the case of Figure 5, would show:

- a volume time curve that is normal in appearance, ie rises smoothly, curves and plateaus;
- FEV1/FVC ≥ 70%;

Pre	Pred	Best	%Prd	2nd	3rd
FVC	2.55	3.41	134%	3.36	3.33
FEV1	2.19	2.82	129%	2.74	2.75
FEV1/FVC	0.86	0.83	96%	0.82	0.83
FEV6	–	–	–	–	–
FEV1/FEV6	–	–	–	–	–
PEFR	6.11	5.30	87%	5.29	5.35
FEF25-75	3.42	3.05	89%	2.90	2.97
Texp	–	5.78	–	5.82	5.87
Vext%	–	1.71	–	1.19	1.50
Cautions:					
Usability					
Acceptability		Time		Time	Time
Reproducibility					
SVC	2.92	–	–	–	–

* below lower limit of normal (LLN)

FVC Flow vs Volume Pre- FVC Volume vs Time Pre-

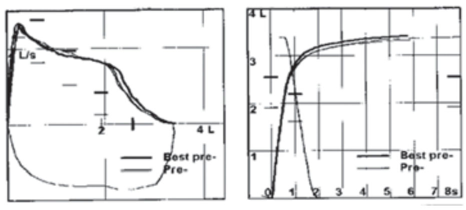


Figure 5. Example of a normal spirometry test

- FVC ≥ 80% of predicted, and above the 5th percentile;
- and FEV1 ≥ 80% of predicted and above the 5th percentile.

Lung function decreases with age and the normal average rate of decline in FVC and FEV1 is approximately 40 ml per annum.[5] Therefore, if an individual loses more than 200 ml[5] within a year or 15%[12] in either FVC or FEV1 within a year further investigation would be necessary to assess the cause. The assessment of average annual decline is particularly important in subjects who have a normal result as they can have a significant drop in results but still fall within the LLN's and therefore if the current result is not compared to previous results significant deterioration could be missed.

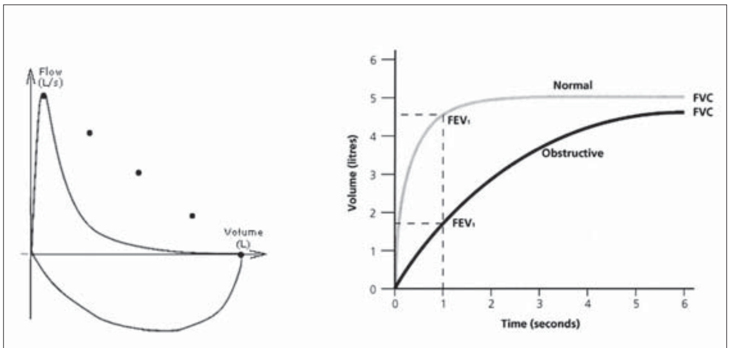


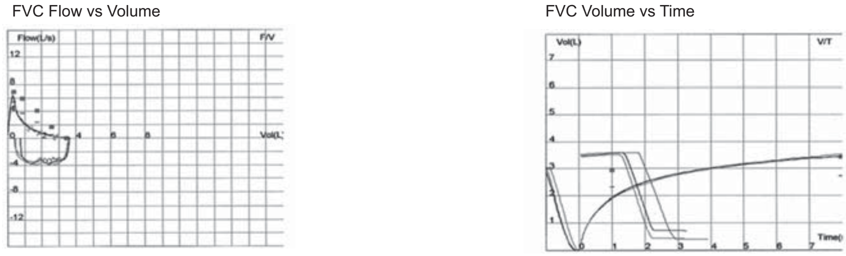
Figure 6. Examples of an obstructive flow volume loop on the left and an obstructive volume time graph on the right. (Diagrams taken with permission from Booker, Class Publishing Ltd and Education for Health UK[11])

Obstructive impairments

Any disease that reduces the cross sectional area (diameter) of the airway will reduce airflow and produce an obstructive ventilatory disorder. These common diseases are asthma, COPD, chronic bronchitis, emphysema, bronchiectasis, cystic fibrosis, localised airway obstruction, and upper airway obstruction. An obstructive spirometry test, as shown in Figures 6 and 7, resulting from such reduced airflow is characterised by:

- lessening of the upslope of the volume time curve which makes the graph look flatter;
- increased concavity or scooping on the downslope of a flow volume curve; and
- FEV1/FVC ≤ than 70%.

If a test appears to be obstructive, it is necessary to carry out a bronchodilator reversibility test in order to clarify the obstruction further.[1,12] A reversibility test is simply spirometry carried out before and then after the administration of a bronchodilator drug and is the next logical step to provide additional or confirmatory information on the obstructive impairment already noted. A significant bronchodilator response is considered to be at least a 12% improvement in FEV1 in addition to at least a 200 ml increase in FEV1.[2,13,14] This test must be carried out by a person qualified to administer the medication and should not be done if the medication is contraindicated in the patient for any reason.



Result	Pred	Best	%Prd	2nd	%Prd	3rd	%Prd
FVC (L)	3.43	3.61	105%	3.59	105%	3.52	102%
FEV1 (L)	2.95	¤1.95	66%	¤1.92	65%	¤1.89	64%
FEV1/FVC		¤0.54%		¤0.53%		¤0.54%	
PEFR (L/s)	6.87	5.98	87%	6.30	92%	6.38	93%
FEF25% (L/s)	5.89	¤2.23	38%	¤2.50	42%	¤2.55	43%
FEF50% (L/s)	4.12	¤1.02	25%	¤0.93	23%	¤0.97	24%
FEF75% (L/s)	1.67	¤0.28	17%	¤0.29	17%	¤0.40	24%
FEF25-75% (L/s)	3.38	¤0.77	23%	¤0.77	23%	¤0.76	22%

Figure 7. Example of a spirometry test showing an obstructive impairment

The FVC/FEV1 is inversely proportional to age and height. What this means is that the FEV1/FVC ratio decreases with age as a result of normal age-related decline in lung function. Therefore, even though using a fixed FEV1/FVC % to define obstruction is widely recommended, it can lead to the incorrect over-interpretation of an obstruction in the elderly or very tall subjects and missed interpretations of obstruction in young or very short subjects. For this reason, extra care

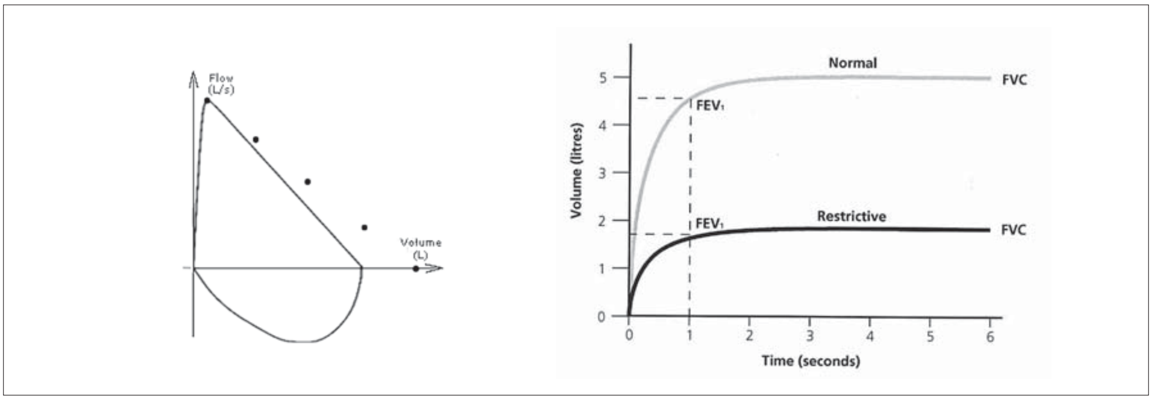


Figure 8. Examples of a restrictive flow volume loop on the left and a restrictive volume time graph on the right. (Diagrams taken with permission from Booker, Class Publishing Ltd and Education for Health UK[11])

should be exercised in interpreting obstruction using the fixed ratio of FVC/FEV1.[9]

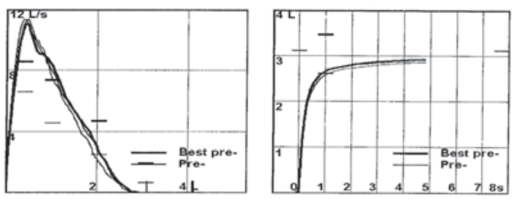
Restrictive impairments

The diseases that prevent the lungs from expanding or cause the lungs to become stiff produce restrictive ventilatory disorders.[1] This decreases the maximum volume of air that is able to be moved in and out of the lungs but the air still moves freely through the airways. A restrictive disorder, unlike an obstructive disorder, will not reduce the speed at which air can be exhaled from the lungs relative to a given volume, but will reduce the volume of air that is contained in the lungs on maximal exhalation. Restrictive disorders can be found in the following conditions: disorders of lung parenchyma, chest wall disorders, neuromuscular disorders, pleural diseases, and systemic diseases.

A spirogram test with restrictive impairments, as shown in Figures 8[11] and 9 will exhibit:

- normal shaped but small volume time trace;
- narrowing of the flow volume curve, may even appear convex;

FVC Flow vs Volume Pre- FVC Volume vs Time Pre-



Pre-	Pred	Best	%Prd	2nd	3rd
FVC	4.11	2.93*	71%	2.88*	2.86*
FEV1	3.46	2.66	77%	2.67	2.58*
FEV1/FVC	0.80	0.91	113%	0.93	0.90
FEV6	–	–	–	–	–
FEV1/FEV6	–	–	–	–	–
PEFR	8.60	11.04	128%	11.34	11.29
FEF25-75	4.25	4.69	110%	4.77	4.14

Figure 9. Example of a spirometry test showing a restrictive impairment

- FEV1/FVC normal ≥ 70% or high above ≥ 80–100%; and
- FVC and FEV1 both reduced to a similar extent (below 80% of predicted) such that the ratio FEV1/FVC is normal or in some cases elevated.

Restrictive impairments are often over diagnosed incorrectly due to poor patient effort, i.e. the patient does not blow out totally. To be certain of restrictive defects the patient should be referred for static lung volume measurements as well. Spirometry alone can only infer a restrictive impairment and is not the appropriate method to investigate or diagnose these conditions.

Mixed obstructive/restrictive impairments

Mixed obstructive/restrictive spirometry tests arise from disease processes that cause features of both an obstructive and restrictive defect. An example of this is cystic fibrosis, which can cause excess mucus production and damage to lung tissue.

A mixed impairment spirometry test (Figures 10[11] and 11) will show:

- the volume time curve is small and flat;

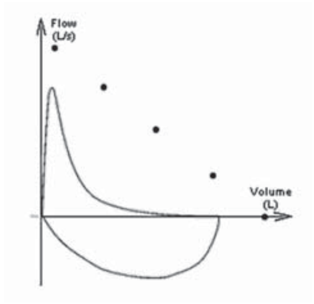


Figure 10. Example of what a mixed obstructive-restrictive impairment looks like on the flow volume loop. (Diagrams taken with permission from Booker, Class Publishing Ltd and Education for Health UK[11])

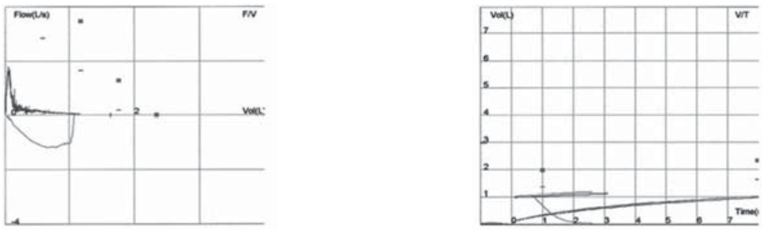
- on the flow volume curve there is concavity as well as reduced volume;
- FEV1/FVC below 70%;
- FVC below 80% of predicted; and
- FEV1 and FVC post bronchodilator administration are below 80% of predicted.

Grading the abnormality

The main reason for grading the severity of the impairment found on spirometry is to quantify the respiratory impairment and/or disability for medico-legal purposes and to optimise and standardise treatment practices.[1] The severity of impairment is linked to physical ability or impairment.

Spirometric abnormalities can be graded as mild, moderate or severe according to the SATS table shown in Figure 12.[1] Using the FVC and FEV1 percentages of predicted and the actual FEV1/FVC percentage, the index showing the lowest value is used for grading. In most instances:

- The severity of an obstructive impairment is graded on the best FEV1 as a percentage of predicted;
- The severity of a restrictive impairment is graded on the best FVC as a percentage of predicted;
- The severity of a mixed obstructive and restrictive abnormality is graded on the basis of either best FEV1 or best FVC as a percentage of predicted, with the worst of the two grades determining the grade. A good example of the grading of a possible mixed obstructive/restrictive



Result	Pred	Best	%Prd	2nd	%Prd	3rd	%Prd
FVC (L)	*2.34	¤1.17	50%	¤1.13	48%	¤1.07	46%
FEV1 (L)	*1.97	¤0.34	17%	¤0.32	16%	¤0.35	18%
FEV1/FVC		¤0.29%		¤0.28%		¤0.33%	
PEFR (L/s)	5.52	¤1.56	28%	¤1.67	30%	¤1.69	31%
FEF25% (L/s)	5.06	¤0.21	4%	¤0.21	4%	¤0.26	5%
FEF50% (L/s)	3.46	¤0.13	4%	¤0.12	3%	¤0.15	4%
FEF75% (L/s)	1.29	¤0.08	6%	¤0.07	6%	¤0.08	6%
FEF25-75% (L/s)	2.91	¤0.12	4%	¤0.11	4%	¤0.13	5%

Figure 11. Example of a spirometry test showing a possible mixed obstructive-restrictive impairment

Parameter	Normal	Mild (able to meet physical demands of most jobs)	Moderate (diminished ability to meet physical demands of many jobs)	Severe (unable to meet physical demands of most jobs)
% pred FVC	≥80	60–79	51–59	≤50
% pred FEV1	≥80	60–79	41–59	≤40
FEV1/FVC%	≥70	60–69	41–59	≤40

Impairment grade is allocated according to the worst affected parameter. Refer to pulmonologist if impairment grade and clinical assessment do not agree.

SAMJ, Vol 94, No. 7, Table V, p586

Figure 12. South African Thoracic Society spirometric impairment grading table[1]

impairment can be seen in Figure 11. Here the best FVC is found in the "Best" column at 1.17L and 50% of predicted whilst the best FEV1 is found in the 3rd column at 0.35L and 18% of predicted. The FEV1 being the lowest of percentage of predicted between the FVC and FEV1 would then be used for grading. Using the grading table[1] in Figure 12 the FEV1 at 18% predicted would be a severe impairment.

CONCLUSION

Interpretation is a step by step process taking into account equipment verification and calibration, the use of correct predicted values together with correction for ethnic origin and the reliability of the data by applying acceptability and repeatability criteria. Assessing the shape of the flow volume and volume time traces is as important as assessing the numerical data. The severity of the abnormality is assessed using the South African Thoracic Society grading table.

RECOMMENDATIONS

1. If a test is less than optimal it may still contain useful information and should therefore not be discarded but used with caution and understanding of how the testing error affects the results.
2. Interpretation should be clear and concise and is useful to assist in the diagnosis of a subject but cannot be used alone to diagnose a subject with a respiratory disease.
3. In the event of an airway obstruction it is good practice to carry on with a bronchodilator reversibility study, especially in new subjects, which further assists in defining the obstructive abnormality as asthma or COPD.[9]
4. In cases where there is evidence of a restrictive impairment or a mixed impairment, referral for the measurement of Total Lung Capacity and gas transfer is recommended.[9]
5. If the actual symptoms and the degree of spirometric impairment differ, more information will be required to evaluate fitness to perform an occupation or to support an application for compensation benefits.
6. Do not depend on computer generated interpretations which can often be incorrect or misleading.

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