

# The flow/volume curve as a mass screening test with emphasis on quality control

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## Summary

Air flow through the airways is influenced by different mechanical characteristics of the respiratory system and can be affected by pathological changes in the lungs. Lung volume is probably the most important independent variable determining air flow through the airways. Therefore, it is logical that lung volume should form the ordinate of a curve used to demonstrate the variation of airflow through the airways during forced inspiratory and expiratory manoeuvres. The flow/volume curve is in many ways superior to other measurements of lung function for clinical and epidemiological assessments. Most of the problems that have to be overcome in obtaining satisfactory and repeatable flow/volume curves are discussed and illustrated. A computer system which optimises quality control is described. By making use of this system, operator error can be reduced to a minimum. It is recommended that hard copies of the three efforts must be available and that all flow/volume measurements be controlled by a knowledgeable person before the results are entered in the records.

*S Afr Med J* 1989; 75: 261-270.

When accurately performed and properly reported, pulmonary function tests can provide valuable clinical information on functional impairment of the lung. The need for accuracy of measurement and of appropriate predictive values is influenced by the application for which the results are to be used.<sup>1</sup> Where the aim is to detect early changes before symptoms develop, e.g. in industry, accuracy and repeatability are of the utmost importance. It is therefore essential to use reliable equipment and quality control is vital. This implies much more than just calibrating the apparatus.

The maximal expiratory flow/volume curve yields more information than the spirogram (volume/time curve) by permitting easier pattern recognition of air-flow abnormalities due to disease involving either the large or small airways. Obstruction of peripheral airways is readily detected from the increased convexity of the volume axis in the descending portion of the flow/volume curve,<sup>2-4</sup> but may be overlooked in the standard analysis of the expiratory spirogram (Fig. 1). A flow/volume curve test with a 1 second timer (and with registration of the tidal volume) allows measurement of not only the conventional indices of the direct spirogram such as the forced vital capacity (FVC) and the forced expiratory volume in 1 second (FEV<sub>1</sub>), but also of peak expiratory flow rate, peak inspiratory flow rate and flows at 50% and 75% of the expired volume (Fig. 2).

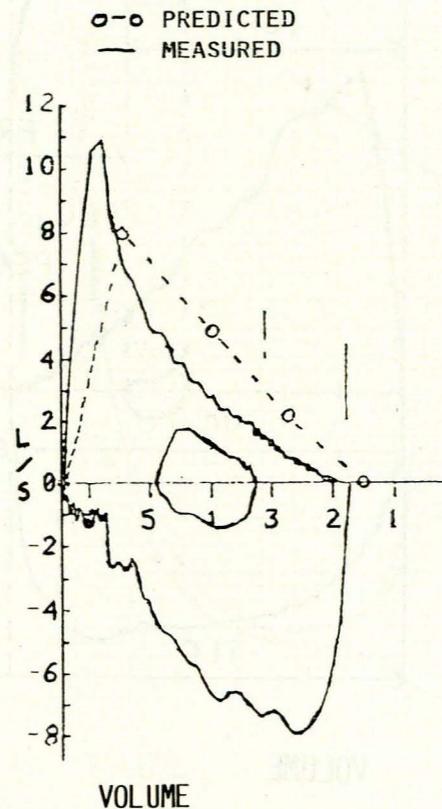


Fig. 1. Flow/volume curve of a 29-year-old asthmatic male subject. PEFR is 137% and FEV<sub>1</sub> 84% of predicted normal, FEV<sub>1</sub>/FVC ratio 71%, while FEF<sub>50</sub> is 60% and FEF<sub>75</sub> 51% of predicted normal. The descending portion of the curve shows an increased convexity towards the volume axis, PEFR and FEV<sub>1</sub> being within normal limits.

When flow/volume tests are used in epidemiological studies and for the screening and detection of early lung disease in people working in high-risk areas in industry and mining, it is essential to have a clear understanding of the concept of normality,<sup>5</sup> the factors that determine an individual's lung volumes and maximal flow, and the many sources of variation that may confound the test results. The significant differences in test results obtained by various laboratories using the different types of equipment, techniques, or normal values<sup>6,7</sup> make it essential that the more basic technical aspects of spirometry must be addressed prior to the important issues of the clinical usefulness, indications for testing and the interpretation of results.

In this article all the factors affecting the repeatability and accuracy of both the inspiratory and expiratory flow/volume curves will be discussed with reference to the relevant pathophysiology. The quality of the curves registered is improved by a customised computer system. Because the technique of obtaining a flow/volume curve can be critical, suggestions concerning the execution of the test are made.

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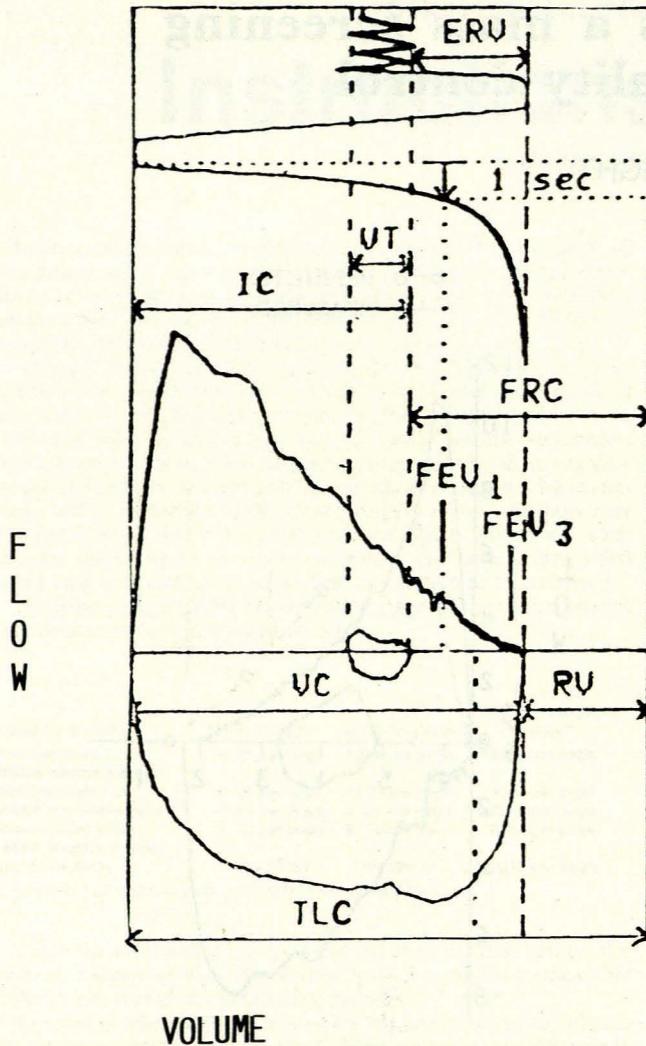


Fig. 2. The relationship between the spirogram (volume/time) and MEFV curve (ERV = expiratory reserve volume; VT = tidal volume; IC = inspiratory capacity; FRC = functional residual capacity; FEV<sub>1</sub> = forced expiratory volume in one second; FEV<sub>3</sub> = forced expiratory volume in three seconds; VC = vital capacity; RV = residual volume; TLC = total lung capacity).

### General comments regarding equipment and quality control

The confusion caused by the large number of different devices available for lung function testing was aggravated by the advent of the use of computers in the lung function laboratory. Several methods are applied to measure the same variable, e.g. hot wires, low-inertia rotating vanes and resistive-type pneumotachographs are used for the measurement of air flow. Some methods integrate flow/time to obtain volume, others differentiate volume/time to obtain flow, while spirometers can vary from conventional wet-cylindrical to dry-wedge types. The investigator should choose the equipment that suits his purposes best, but must ensure that it meets the minimum internationally accepted performance standards, such as those recommended by the American Thoracic Society.<sup>8,9</sup> Briefly, these minimum requirements are:

1. The volume range should be at least 7,0 l and the accuracy should be within 3% or 50 ml when gas is injected at any rate between 0,2 and 12 l/s.

2. The instrument must be capable of accumulating volume for at least 10 seconds.

3. Resistance should be less than 1,5 cm H<sub>2</sub>O/l/s at a flow rate of 12 l/s.

4. Flow should be measured within 5% over a range of 0,12 l second.

To this we would add that real-time viewing of the curve on the computer screen and the facility to store and recall the registered curves facilitate the selection of the 'best' repeatable curve.

All equipment should be calibrated with a 3 - 5-litre syringe.

The concept of *accuracy* implies that there is a 'correct' value about which repeat measurements scatter in a random Gaussian manner. The closer the mean of these measurements is to the correct value, the greater the accuracy. Accuracy of a measuring device is usually ensured by meticulous attention to the calibration procedures. *Precision* is an index of reproducibility of repeated measurements, regardless of how close the mean value is to the 'correct' value. The standard deviation or coefficient of variation (SD/mean x 100) of repeated measurements is commonly used as an estimate of precision; the smaller the standard deviation or coefficient of variation, the greater the precision. The assessment of precision is an essential component of quality control programmes. It serves to define not only the capabilities of the instrument but also those of the technologist and the subject during the entire testing procedure. In the determination of instrument precision, the use of devices such as large syringes for simulating forced expirations clearly offers the advantage that repeated test 'samples' will be more reproducible than the repeated forced expirations of a subject whose possible fatigue, airway spasm, and lack of co-operation will adversely affect the magnitude of random error of measurements with a specific spirometer or pneumotachograph.<sup>10</sup> Even though the accuracy and precision of a particular instrument may be within acceptable limits, significant problems in accuracy and precision can occur as the result of faulty techniques and non-compliance of the subject. Few other laboratory tests are so dependent on subject co-operation as this.

### Evaluation of the maximal expiratory flow/volume (MEFV) curve

#### Time factors in relation to the MEFV curve

Although the MEFV curve is a plot of flow against volume, the FEV<sub>1</sub> can also be measured by adding a 1-second time signal on the volume axis or by computer programming techniques. In order to determine the beginning of expiration or zero time, back extrapolation (as described for volume/time curves<sup>2,11</sup>) is not practical for flow/volume curves. Time zero can be defined as the time at which flow exceeds a threshold value (e.g. 50 ml/s) or when a threshold volume (25 - 100 ml) has been delivered. These measures provide values that are similar to those obtained by extrapolation when effort is optimal, but smaller values are obtained when initial effort is submaximal.<sup>11</sup> If the subject hesitates after the initial commencement of the test, the FEV<sub>1</sub> may be smaller (Fig. 3).

The FVC manoeuvre is considered at an end when either the volume change is less than 25 ml or the flow rate is less than 0,05 l/s with a half-second interval. If this end-point has not been reached, recording should continue for at least 10 seconds. Many expiratory efforts are terminated before full expiration is reached (Fig. 4) and this has an influence on several measurements derived from or expressed in terms of the FVC, including the forced expiratory flow at 50% (FEF<sub>50</sub>) and 75% (FEF<sub>75</sub>) of the expired volume and the FEV<sub>1</sub>/FVC ratio<sup>11</sup> (Fig. 4).

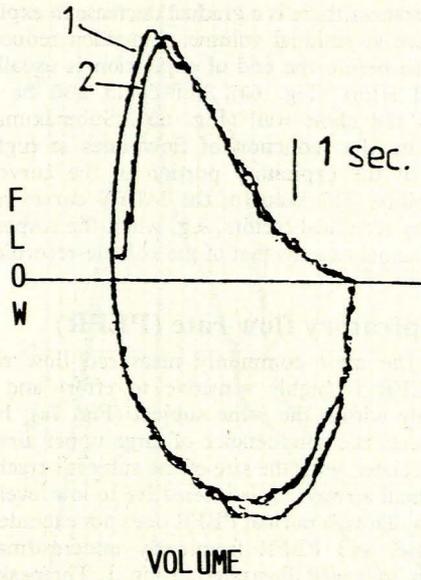


Fig. 3. The importance of point zero. The FVCs of both curves are similar, but in curve 2 there was a slight hesitation on the ascending part of the curve. The FEV<sub>1</sub> of curve 1 is 2,85 l and that of curve 2 2,45 l.

**Shape of the MEFV curve**

The shape and size of the MEFV curve vary considerably among both healthy subjects and patients with lung disease and no simple mathematical expression fits all the variations. Three patterns describe the majority of curves in healthy subjects, i.e. (i) in young persons the descending portion of the curve is approximately linear or slightly concave to the volume axis (Fig. 5a); the latter shape is more frequently obtained from young females; (ii) in older persons the descending part of the curve, especially near residual volume, is slightly convex to the volume axis (Fig. 5b); (iii) some young and healthy subjects have a small intermediate plateau ('knee') on the curve at high lung volume<sup>12</sup> (Fig. 5c); this is thought to result from a shift in the site of flow limitation from extrapulmonary to intrapulmonary airways.<sup>13</sup>

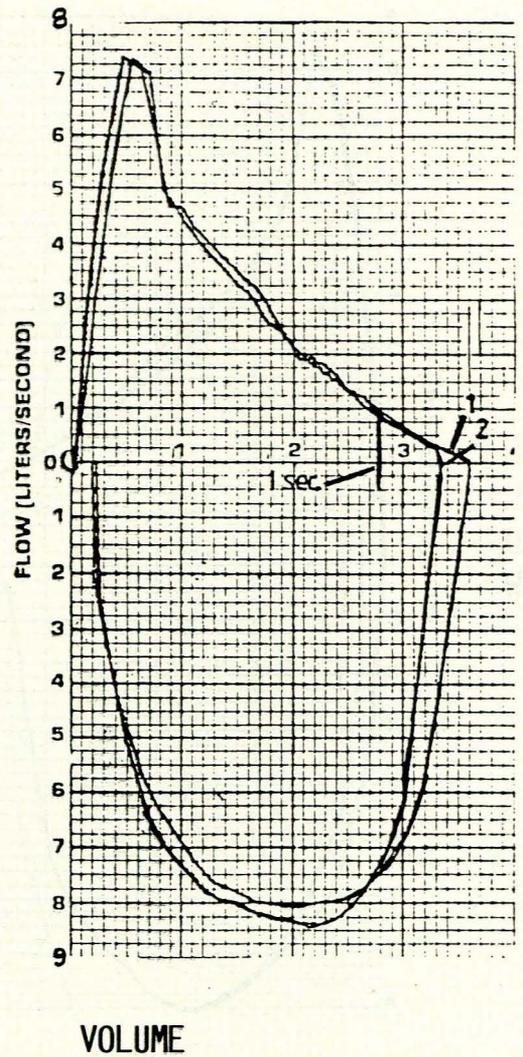


Fig. 4. Expiration in curve 2 was terminated before RV had been reached. It is clear that FEV<sub>1</sub>, expressed as a ratio of the FVC of curve 1 will differ from the ratio with the FVC of curve 2. Maximal flows at 50% and 75% of the expired volume of the two curves will also be different.

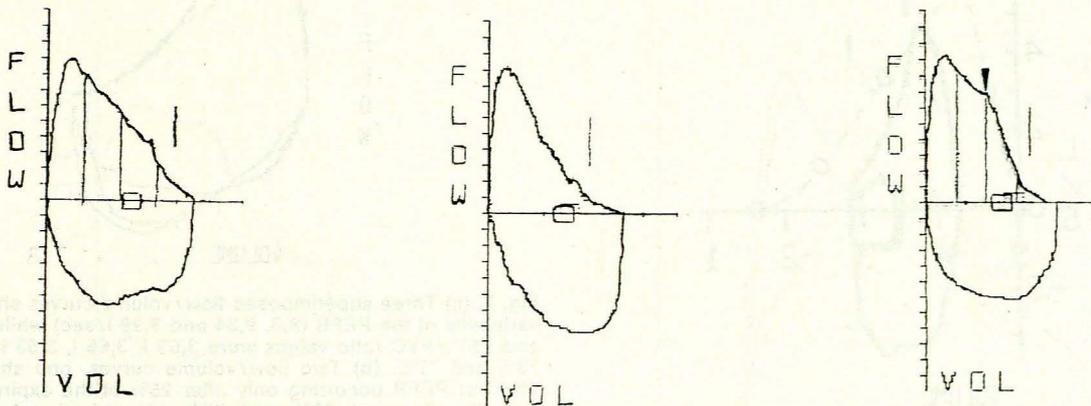


Fig. 5. (a) Flow/volume curve of a healthy male non-smoker aged 24 years, showing a descending portion of the curve that is straight or slightly concave to the volume axis and decreasing progressively to zero at RV. (b) Flow/volume curve in a healthy non-smoker of 60 years, showing the descending portion of the curve convex to the volume axis. (c) Flow/volume curve in a healthy 23-year-old non-smoker, showing the 'knee' or 'shoulder' on the descending portion of the curve. Note that the descending part of the curve always reaches zero flow gradually and not abruptly.

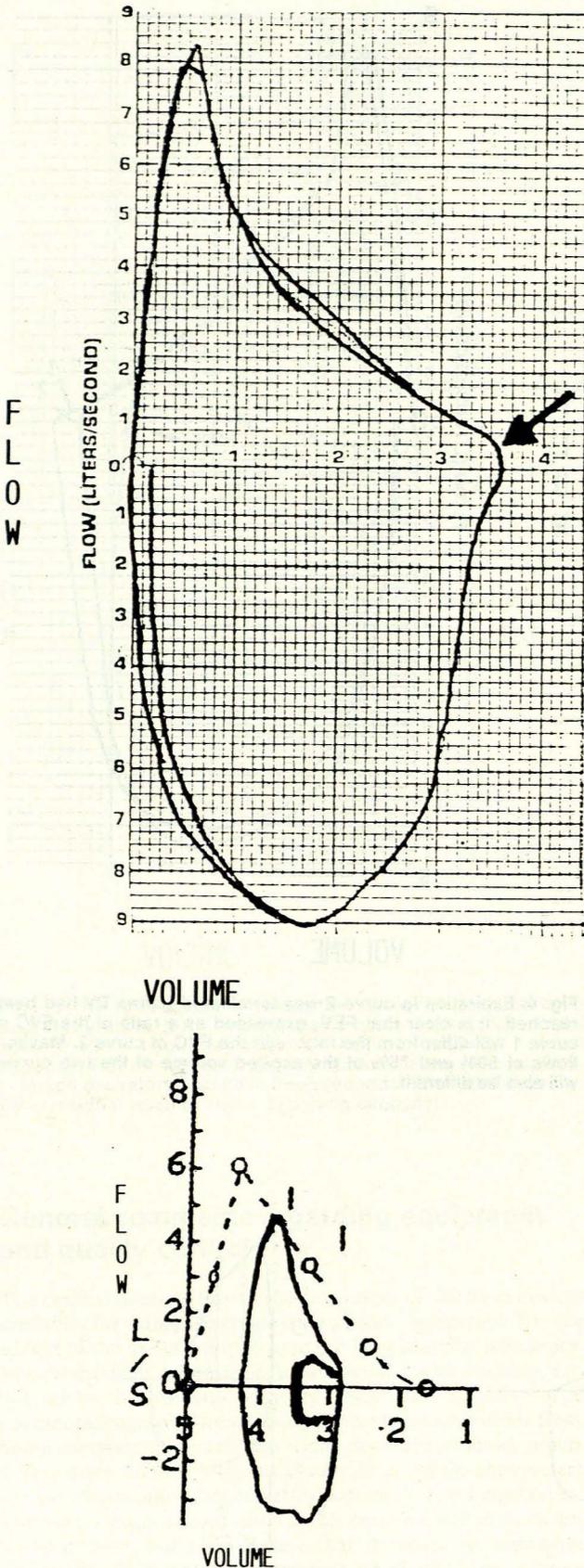


Fig. 6. (a) Flow/volume curve showing an abrupt cessation of flow due to the subject not exhaling to RV. (b) Flow/volume curve in a patient with a relatively 'stiff' chest wall due to a thickened pleura on the left, not being able to exhale completely, thus resulting in an abrupt end of the descending curve.

In all instances there is a gradual decrease in expiratory flow towards zero at residual volume. A sudden reduction of the flow to zero before the end of expiration is usually due to a suboptimal effort (Fig. 6a), but could also be caused by rigidity of the chest wall (Fig. 6b). Submaximal effort is suggested by the reduction of flow rates at high volumes, flattening of the expiratory portion of the curve and poor reproducibility. The shape of the MEFV curves may also be distorted by technical factors, e.g. when the response time of the flow channel exceeds that of the volume-recording channel.

**Peak expiratory flow rate (PEFR)**

One of the most commonly measured flow rates is the PEFR. PEFR is highly sensitive to effort and may vary considerably within the same subject (Fig. 7a). In addition, PEFR reflects the conductance of large upper airways and is largely associated with the size of the subject's trachea<sup>14</sup> rather than the small airways. It is insensitive to low levels of airway obstruction. Thus, a normal PEFR does not exclude significant lung disease, and PEFR frequently underestimates airway obstruction, as is well illustrated in Fig. 1. The peak expiratory flow should be produced within the first 15% of the volume expired from maximum inspiration and sustained for 10 milliseconds.<sup>11</sup> Although the PEFR can usually be reached within the first 15% of the FVC, it is our experience that a significant number of normal subjects have difficulty in achieving this and as long as PEFR is reached before 25% of expired volume, it does not appear to influence other measurements. When PEFR is reached after 25% of expired volume, the MEFV curve must be rejected (Fig. 7b). Pneumotachograph-derived signals virtually eliminate the measuring device as a source of this distortion. A PEFR which is not easily identified or which is delayed and reduced in amplitude may indicate upper airway obstruction (Fig. 7c) or poor initial effort (Fig. 7d). If the latter is the case, instantaneous flows occurring later in the same curve may be higher than on a true maximal expiratory curve because dynamic airway compression is less (Fig. 7e). Apart from a submaximal effort, PEFR can also be reduced if the manoeuvre was not started from total lung capacity (TLC), as maximal flow is also volume-dependent (Fig. 7f). A clue to the existence of this latter problem is a forced inspiratory vital capacity immediately after the MEFV which exceeds the forced expiratory vital capacity.

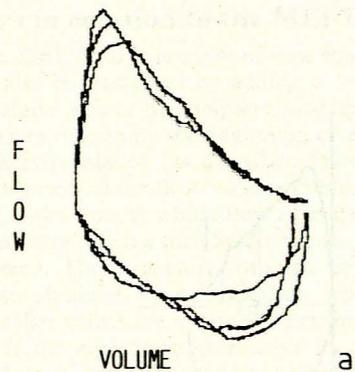
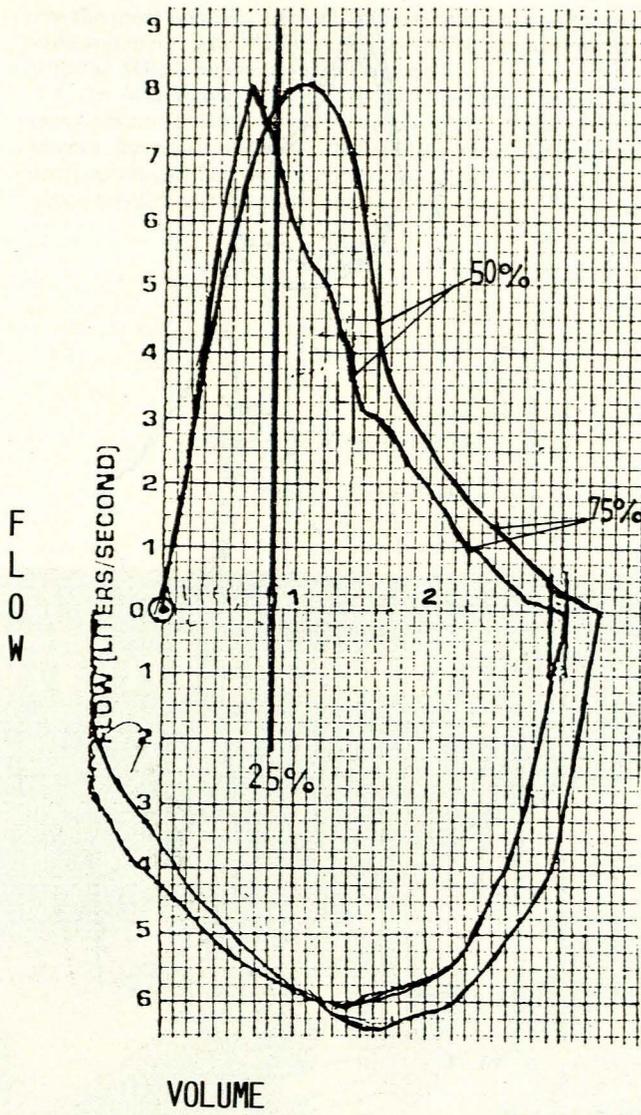
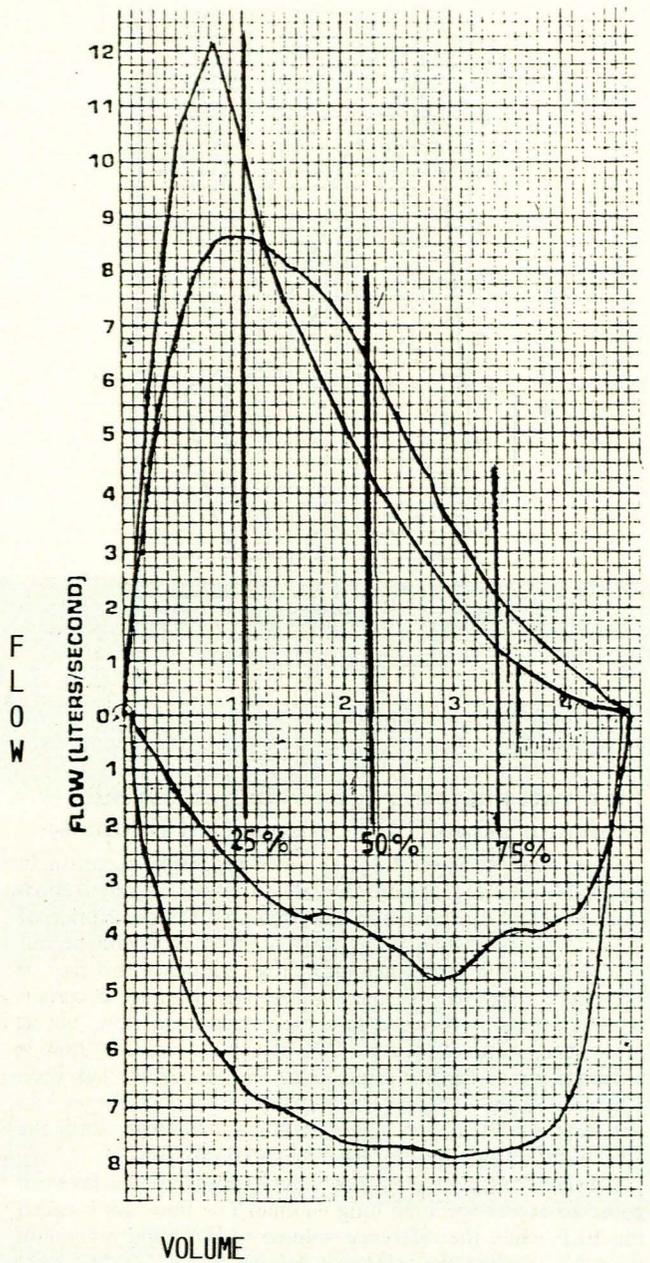


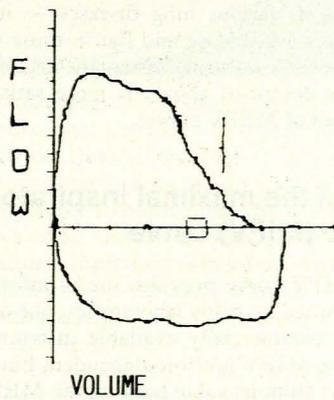
Fig. 7. (a) Three superimposed flow/volume curves showing the variability of the PEFR (8.3, 9.34 and 9.99 l/sec) while the FEV<sub>1</sub> and FEV<sub>1</sub>/FVC ratio values were 3.69 l, 3.66 l, 3.63 l and 74%, 73% and 77%. (b) Two flow/volume curves, one showing the effect of PEFR occurring only after 25% of the expired volume with the flows at 50% and 75% of expired volume being erroneously high. (c) Flow/volume curve in a 26-year-old smoker with airflow limitation, the FEV<sub>50</sub> differing 5% (2.15 and 2.05 and predicted normal being 4.73 l/s) and the FEV<sub>75</sub> 26% (0.76 and 0.72 and predicted normal being 1.98 l/s) between efforts. When the measurements are small, small differences result in large percentage differences. (d-f) see text.



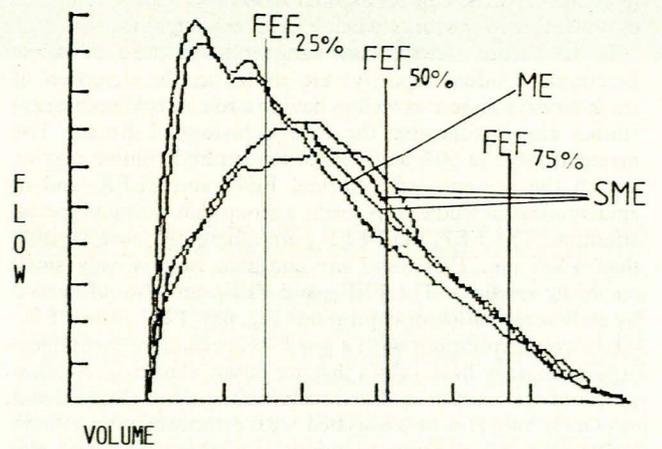
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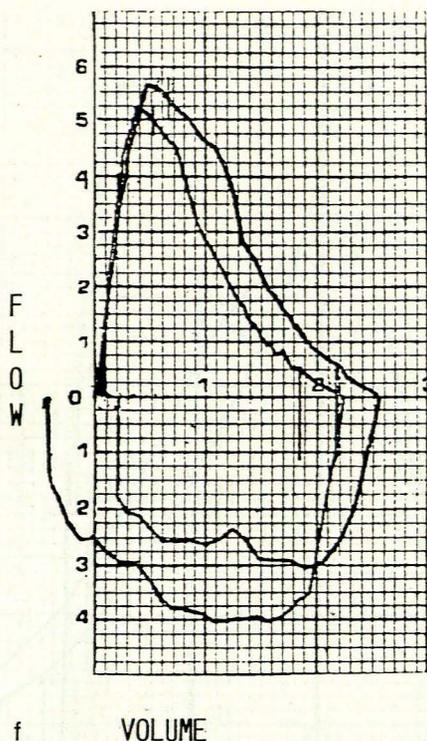
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e



**Flow rates at lower lung volumes (forced expiratory flow (FEF) at specified volumes)**

Flow rates at lower lung volumes are often surprisingly repeatable in spite of considerable variation in initial effort (Fig. 8a). This phenomenon has prompted the description of the descending portion of the curve as effort-independent, but this term is confusing since effort does influence this part of the curve (Fig. 6a, 7d and 7e). At any volume, a certain minimal effort is required to achieve maximum flow, but at lower lung volumes (beyond 25% of expired volume) flow is independent of further effort once this minimum has been attained. At high volumes isovolume pressure flow curves<sup>11</sup> do not show plateaux, and flow continues to increase until the limit of expiratory muscle power has been reached.

When flow is plotted against volume, instantaneous flow can be noted at any specified lung volume. The flow rate is called the FEF when the reference volume is FVC and maximum flow ( $\dot{V}_{max}$ ) when the reference volume is TLC.<sup>11</sup> The most commonly reported FEFs are at 50% (FEF<sub>50</sub>) and 75% (FEF<sub>75</sub>) of FVC and at 60% of TLC. By consensus, these percentages refer to the volume of air expired when FVC is the reference or remaining in the lungs when TLC is the reference.<sup>11</sup>

Instantaneous flows at low lung volumes (near or below functional residual capacity) are useful in the detection of small-airways disease as well as having a role in epidemiological studies and in following the natural history of disease. The maximal flows at 50% and 75% of the expired volume may be low in the presence of a normal FEV<sub>1</sub> and PEFr, and in epidemiological studies this forms a group that warrants special attention. The FEF<sub>50</sub> and FEF<sub>75</sub> are inherently more variable than FVC and FEV<sub>1</sub> and are sensitive to relatively small recording artefacts. The FEF<sub>50</sub> and FEF<sub>75</sub> are also influenced by early termination of expiration (Fig. 6a) (FEF<sub>50</sub> and FEF<sub>75</sub> taken from expirations with a low FVC because of incomplete expiration, may have values that are falsely elevated). Another source of 'inaccuracy' is less forceful initial effort (Figs 7d and e), which may also be associated with erroneously high flows at 50% and 75% of expired volume. It is, therefore, absolutely essential to obtain the best repeatable MEFV curve when

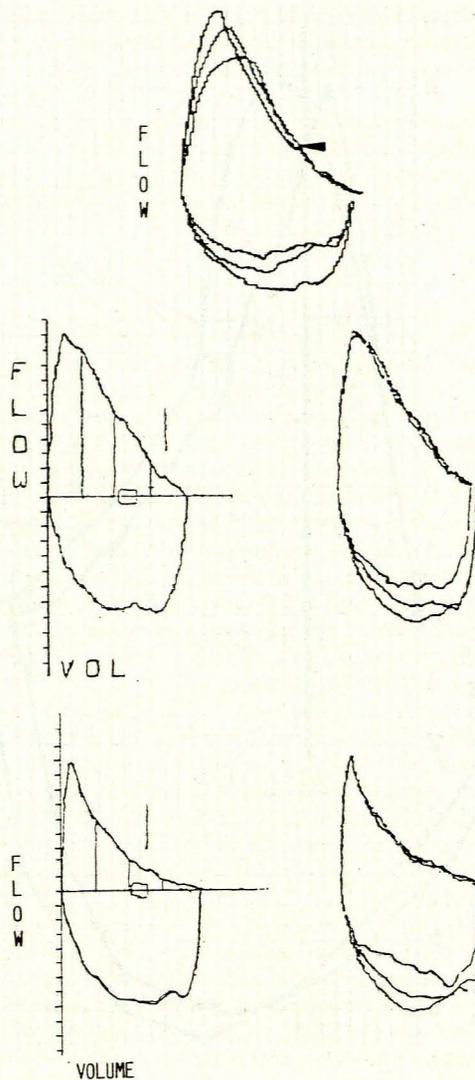


Fig. 8. See text.

instantaneous flows are measured. Careful attention to these factors can improve the reproducibility of the FEF<sub>50</sub> and FEF<sub>75</sub> to near 5% (Fig. 8b), even when airway obstruction is present (Fig. 8c).

The slope of the descending portion of the MEFV curve shows differences in various lung diseases — it is steep in patients with restrictive disease and flat in those with airways obstruction. However, measuring instantaneous flow at specific volume levels, as described above, is more satisfactory than assessing the slopes of MEFV curves.

**Evaluation of the maximal inspiratory flow/volume (MIFV) curve**

Although the MIFV curve provides useful information, it is not routinely recorded by many laboratories, one of the reasons being that most commercially available instruments do not allow for this. The MIFV is effort-dependent but in itself this should not detract from its value because the MEFV curve *per se* is also effort-dependent, although possibly not to the same degree. It is, however, true that many subjects have more difficulty in performing a maximal inspiratory effort from residual volume than the maximal expiratory effort from TLC.

For the more accurate interpretation of lung function there are valid arguments why MIFV curves should be recorded together with the MEFV on every subject tested:

1. An MIFV loop can provide that first 'clue' or the most easily obtained confirmation of an obstructive process in the trachea, larynx, or pharynx.<sup>11</sup> Different types of upper airways obstruction can be recognised by flow/volume loops, two of which are demonstrated in Figs 9a and b.

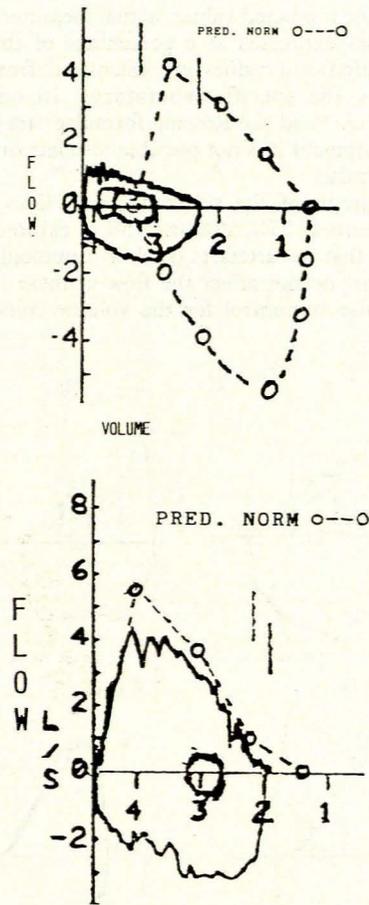


Fig. 9. (a) Flow/volume curve of a 17-year-old boy who inhaled sulphuric acid and had severe stenosis of the trachea and both main bronchi. (b) Flow/volume curve of a 49-year-old female with paralysis of the left vocal cord.

2. Although most of the present standard values have been calculated from the FVC, it is of value to register the slow expiratory vital capacity. In standard spirometry the subject expires slowly to residual volume before taking a deep inspiration to TLC and then performs the FVC manoeuvre. The inspiratory vital capacity thus measured may be equated to the slow expiratory vital capacity. The same procedure can be followed with the flow/volume curve. When the curves thus obtained are monitored on an oscilloscope or computer screen, it helps the operator to ensure that the subject exhales totally and to detect early closure of airways. If FEVC < FIVC, when the maximal inspiratory manoeuvre preceded the maximal expiratory manoeuvre, the early closure of the airways is indicated. Unfortunately, most instruments allow inspiration only after forced expiration.

3. Changes in inspiratory versus expiratory flow may be used to separate emphysema from chronic bronchitis.<sup>11</sup> The rationale is that the mechanism for airway obstruction in chronic bronchitis (secretions, inflammatory thickening of the bronchial mucosa) will affect inspiratory flow (Fig. 10a) more than the prevailing mechanism for obstruction in emphysema.

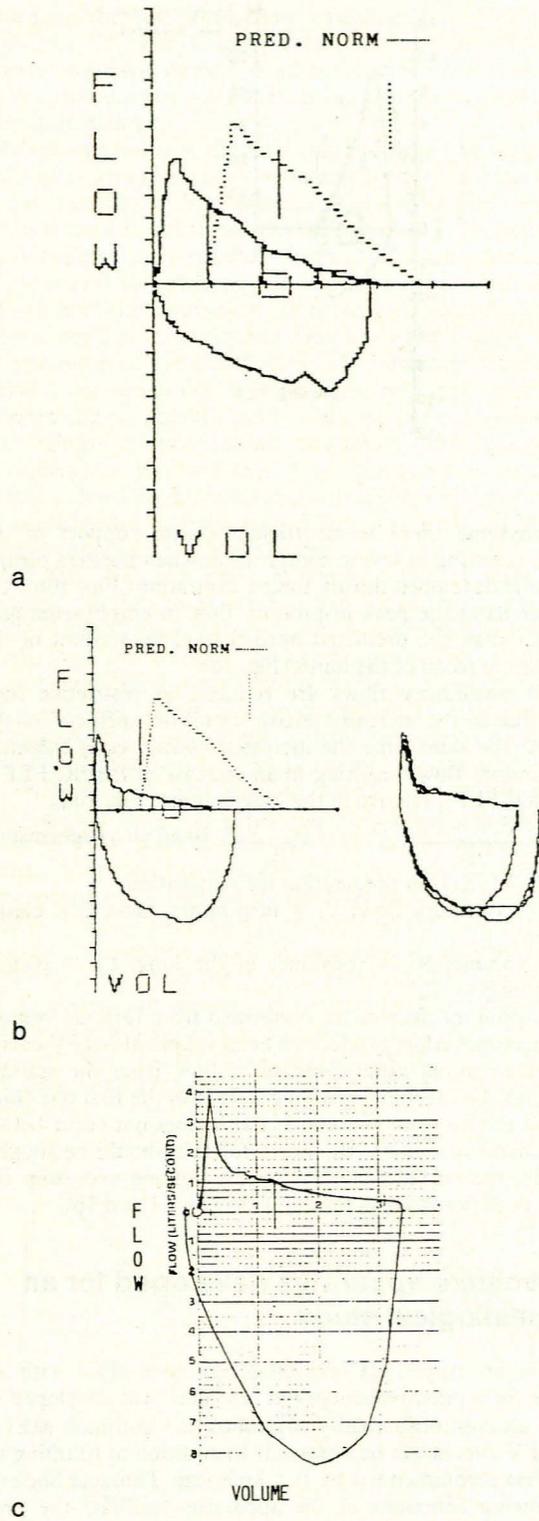
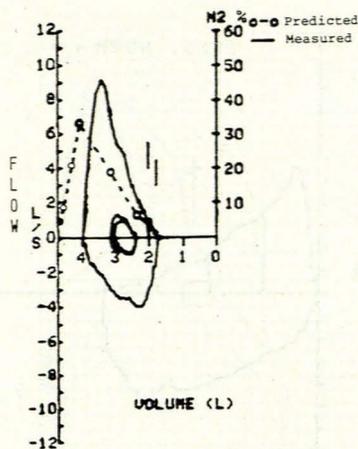


Fig. 10. (a) Flow/volume curve in a 35-year-old male smoker with limitation of airflow due to chronic bronchitis with PEFR 77%, PIFR 70% of predicted normal, FEV<sub>1</sub>/FVC ratio 56%, FEV<sub>50</sub> 36% and FEV<sub>75</sub> 55% of predicted normal. (b) Flow/volume curve of a 38-year-old male with the clinical and radiological features of emphysema, the MIFR being 47% higher than MEFV. (c) The flow/volume curve of a 37-year-old female with advanced emphysema due to alpha-1-protein inhibitors deficiency, MIFR being 153% of predicted normal. (d) A flow/volume curve showing the reduced inspiratory flows (PIFR 57% of predicted value) with the increased expiratory flows (FEV<sub>50</sub> 135%, FEV<sub>75</sub> 157% and PEFR 139% of predicted values), as seen in restrictive lung disease.



In emphysema there is insufficient elastic support of the airways, resulting in severe compression when positive pleural pressure is developed during forced expiration (Fig. 10b). On the other hand the peak inspiratory flow in emphysema may be higher than the predicted normal level on account of the loss of elastic recoil of the lungs (Fig. 10c).

4. All inspiratory flows are reduced in restrictive lung disease due to the increased elastic recoil or 'stiffness' of the lungs. At the same time the increased elastic recoil enhances the expiratory flow, resulting in an increase of PEFR, FEF<sub>25</sub>, FEF<sub>50</sub> and FEF<sub>75</sub> relative to the lung volume (Fig. 10d).

$$[\dot{V}_E = \frac{E.V + P_{pl}}{R_L}; \dot{V}_I = \frac{P_{pl} - E.V}{R_L}]$$

based on a mathematical model which is in preparation for publication.

$\dot{V}_E$  = expiratory flow;  $\dot{V}_I$  = inspiratory flow; E = elastic recoil;

V = volume;  $R_L$  = resistance of the lung;  $P_{pl}$  = pleural pressure.]

An inspiratory manoeuvre performed from residual volume with a maximal effort produces a hemi-elliptical MIFV curve. There is an initial rapid increase in flow from the starting point at residual volume, reaching MIFR in the first one-third to half of the inspired volume. If PIFR does not occur before 50% of inspired volume, the cause for this should be sought. Typically, the curve is concave to the volume axis from the point of peak flow to zero flow at TLC (Figs 1 and 5b).

### Flow volume apparatus developed for an epidemiological study

Based on an Apple IIE personal computer (PC) with an interface for a pneumotachograph, a system was developed to simplify and optimise quality control so that optimum MEFV and MIFV curves can be obtained. In addition to fulfilling all the criteria recommended by the American Thoracic Society, the following functions of the apparatus facilitate the procurement of the best, satisfactory repeatable curve and will promote quality control.

1. The inspiratory and expiratory graphs are displayed in real time.

2. If the curve is acceptable, it is stored and if not it is rejected.

3. These curves can be stored or rejected according to the quality of the effort.

4. When 3 acceptable curves have been obtained, it is possible for the operator to recall each individual curve separately on the screen or superimpose them whenever it is thought necessary in order to select the best curve.

5. The following measurements of all three efforts are displayed on the screen: FVC, FEV<sub>1</sub>, FEF<sub>25</sub>, FEF<sub>50</sub>, FEF<sub>75</sub>, PEFR, FIVC, and PIFR.

6. The manoeuvre with the largest sum of the FVC + FEV<sub>1</sub> and the largest inspiratory vital capacity (FIVC), which may not come from the same manoeuvre, are indicated on the screen. If all other criteria are met, these curves are selected. The operator should have the option to overrule the computer.

7. The selected MEFV and MIFV curves must be printed together with the predicted values, actual measured values and measured values expressed as a percentage of the predicted values. (The predicted values are calculated from formulae decided on by the specific laboratory.) In our case the Schoenberg *et al.*<sup>15</sup> and the Rössing formulae<sup>5</sup> are being used. With some equipment it is not possible to select or change the prediction formulae.

8. On the graph of the selected curve, lines are drawn through the points at 25%, 50% and 75% of expired volume in order to check that the artefacts (such as commonly occurring flow oscillations) do not affect the flow at these points (Figs 11a - c) and also to control for the volume coinciding with PEFR.

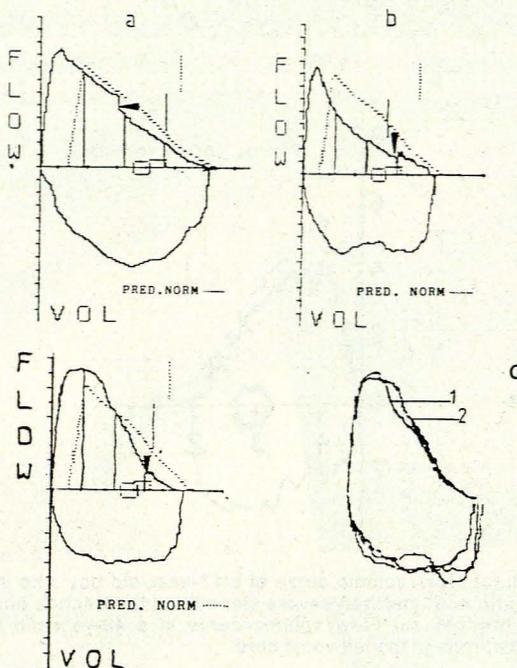


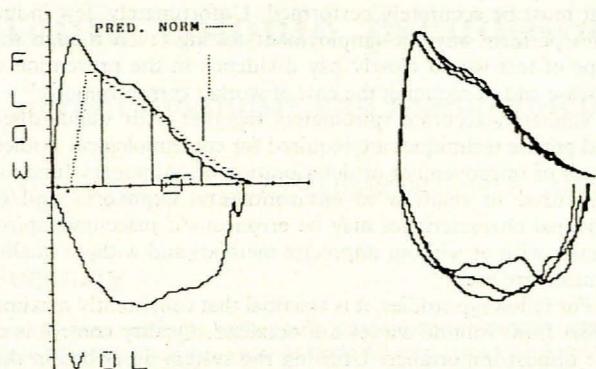
Fig. 11. (a), (b) and (c) show artefacts in relation to the cutpoints at 50% and 75% of expired volume. In (a) the artefact does not affect the FEF<sub>50</sub> but in (b) and (c) the artefacts do affect the FEF<sub>75</sub>. In addition, it can be seen in (c) that the operator chose the wrong curve (No. 2), the sum of FVC and FEV<sub>1</sub> being the highest, but curve 1 is the better one as the PEFR is easily identifiable and is also reached earlier.

9. In the final report all three curves are also superimposed and printed to the right of the selected curve, together with their actual values of the measurements as specified above.

10. A hard copy of the curves and all measurements is printed out and all the information stored on a disk (Figs 12a and b).

### Procedure for MIFV and MEFV curves

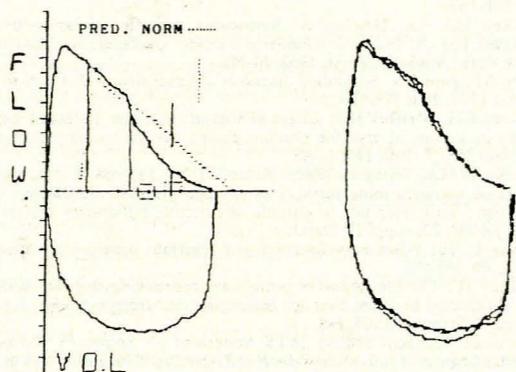
Maximising the repeatability and usefulness of flow/volume curves depends not only on the equipment used but also on the adoption of a consistent and meticulous technique when



	R-PRED	S-PRED	MEAS	S-%	TEST 1	TEST 2	TEST 3
FVC	4.57	4.97	5.51	111	5.34	5.51	5.41
FIVC		4.97	5.34	107	5.28	4.92	5.34
RV		1.63	1.63	100			
TLC		6.60	7.14	108			
RV/TLC		24.69	22.98	93			
FRC		3.27	3.57	109			
FEV1	3.65	3.86	4.22	109	4.31	4.22	4.16
FEV1(FVC)		77.79	75.59	98	80.71	76.59	76.89
FEV15(FVC)		77.79	75.03	101	81.63	85.77	77.90
FEF25		6.63	7.58	114	7.98	7.58	7.66
FEF50	4.27	4.57	5.33	117	5.69	5.33	5.60
FEF75	1.59	1.78	1.58	89	1.95	1.58	1.67
PEFR	8.82	7.96	10.15	128	10.24	10.15	9.66
PIFR	6.5	7.29	7.98	109	7.49	6.66	7.98
RAE		1.28	0.35	27			
KST(L)		0.13	0.12	92			
T @50%		0.54	0.52	96			
T @75%		0.70	0.67	124			

FUNCTIONAL CLASSIFICATION:  
 A 0 (FVC, FEV1, FEV1/FVC%)  
 B 0 (PEFR, FEF50, FEF75, FEF75-85)  
 C 0 (RV, TLC, RV/TLC%, FRC)  
 E 0 (EST RAW, EST KST(L), T @ FEV50%, T @ FEV75%)

Lung mechanics are within normal limits.  
 Interpretation is not based on derived values. Derived values RV, TLC, FRC, Raw, KstL, dependent on satisfactory MAXIMAL inspiratory and expiratory efforts. Abnormal values calculated according to prediction tables of Schoenberg are indicated by \*.  
 DERIVED VALUES NOT CALCULATED IF INSPIRATORY EFFORT INADEQUATE



	R-PRED	S-PRED	MEAS	S-%	TEST 1	TEST 2	TEST 3
FVC	4.33	4.98	5.44	109	5.29	5.25	5.44
FIVC		4.98	5.52	111	5.44	5.45	5.52
RV		1.24	1.81*	146			
TLC		6.22	7.33	118			
RV/TLC		19.94	24.71	124			
FRC		2.90	3.79*	131			
FEV1	3.64	3.88	4.10	106	4.15	4.13	4.10
FEV1(FVC)		79.22	75.37	95	78.45	78.67	75.37
FEV15(FVC)		79.22	74.28	93	76.29	75.78	74.28
FEF25		6.31	8.23	132	8.85	8.54	8.32
FEF50	4.69	4.69	5.04	107	5.71	5.43	5.04
FEF75	2.11	2.06	1.22*	59	1.49	1.67	1.22
PEFR	8.07	7.58	9.68	120	10.07	9.76	9.68
PIFR	7.47	7.55	9.49	126	10.24	9.57	9.49
RAW		1.45	0.35	24			
KST(L)		0.12	0.14	117			
T @50%		0.53	0.54	102			
T @75%		0.60	1.11	185			

FUNCTIONAL CLASSIFICATION:  
 A 0 (FVC, FEV1, FEV1/FVC%)  
 D 1 (PEFR, FEF50, FEF75, FEF75-85)  
 C 2 (RV, TLC, RV/TLC%, FRC)  
 E 0 (EST RAW, EST KST(L), T @ FEV50%, T @ FEV75%)

Clinical assessment and further investigations are indicated.  
 Interpretation is not based on derived values. Derived values RV, TLC, FRC, Raw, KstL, dependent on satisfactory MAXIMAL inspiratory and expiratory efforts. Abnormal values calculated according to prediction tables of Schoenberg are indicated by \*.  
 DERIVED VALUES NOT CALCULATED IF INSPIRATORY EFFORT INADEQUATE  
 R-PRED = ROSSING PREDICTEDS. S-PRED = SCHOENBERG PREDICTEDS.  
 S-% = MEASURED % OF SCHOENBERG PREDICTEDS.

Fig. 12. (a) and (b). Two curves with all values as printed on the hard copy, as suggested in the text.

performing the test. Important guidelines are given in the literature.<sup>1,8,11,16</sup> For a specific laboratory, especially when follow-up tests will be performed and compared, it is essential that the procedure be standardised and performed consistently in the same manner.

We recommend that the following procedure be adopted: a period of quiet breathing is maintained until a constant tidal point is reached for three consecutive breaths. The subject is then instructed to exhale slowly and maximally. When expiration is maximal, i.e. residual volume has been reached, the subject is told to inhale as fast and as deeply as possible to TLC, to hold the inspiratory effort for 1 - 2 seconds, then to exhale as rapidly, forcefully and completely as possible.

A minimum of three acceptable FVC manoeuvres must be obtained. An acceptable FVC manoeuvre has a 'crisp', unhesitating start; smooth, continuous expiration; absence of cough, glottis closure, second inspiration, leak (e.g. at the mouthpiece), or blockage (e.g. by the tongue); and complete expiration. Early termination of effort can be easily missed and will affect the FEV<sub>1</sub>/FVC ratio, FEF<sub>50</sub> and FEF<sub>75</sub>. The same principles apply for the MIFV curve.

Both the FVC and FEV<sub>1</sub> in the best two of these three acceptable tracings must agree within 5% of the largest value or 100 cc, whichever is the greater. A workable definition of the best curve is that it has the largest sum of FVC and FEV<sub>1</sub>, and in which PEFR occurs within the first 25% of the expired FVC; the curves must also be acceptable in all other ways outlined above. Furthermore, at least two curves should be virtually superimposable (Figs 12a and b). A single best curve thus defined can be selected and stored. Provided the efforts agree within acceptable limits (about 5%), there is little practical difference if one curve is chosen as 'best' and all measurements reported from this, even if the FVC or FEV<sub>1</sub> is marginally larger on another effort. All flow rates, whether mean or instantaneous, are calculated from this best curve.<sup>11</sup>

Submaximal efforts result in inconsistent, varying curves, the last usually being the best (Figs 13a and b). In patients with hyperreactive airways, inhalation to TLC may trigger bronchoconstriction, so the maximal flow on the first effort may be greater than in all subsequent efforts<sup>17</sup> (Figs 14a and b). In this case all the curves are of clinical interest and should be stored.

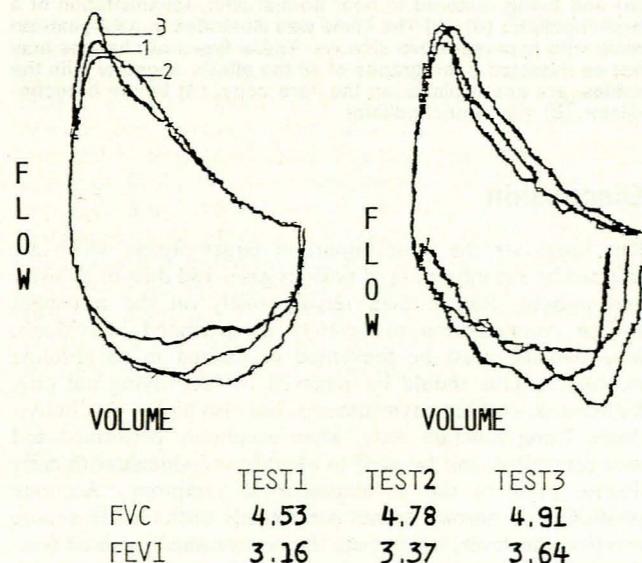


Fig. 13. (a) Submaximal expiratory efforts numbered according to efforts 1-3, the last (No. 3) being the best. In this patient the effects of the submaximal efforts are only seen in the PEFR and in the first 25% of expired volume. (b) Three submaximal efforts in a different patient with test 3 being the best. Here the effects of the submaximal efforts are seen in all the measurements.

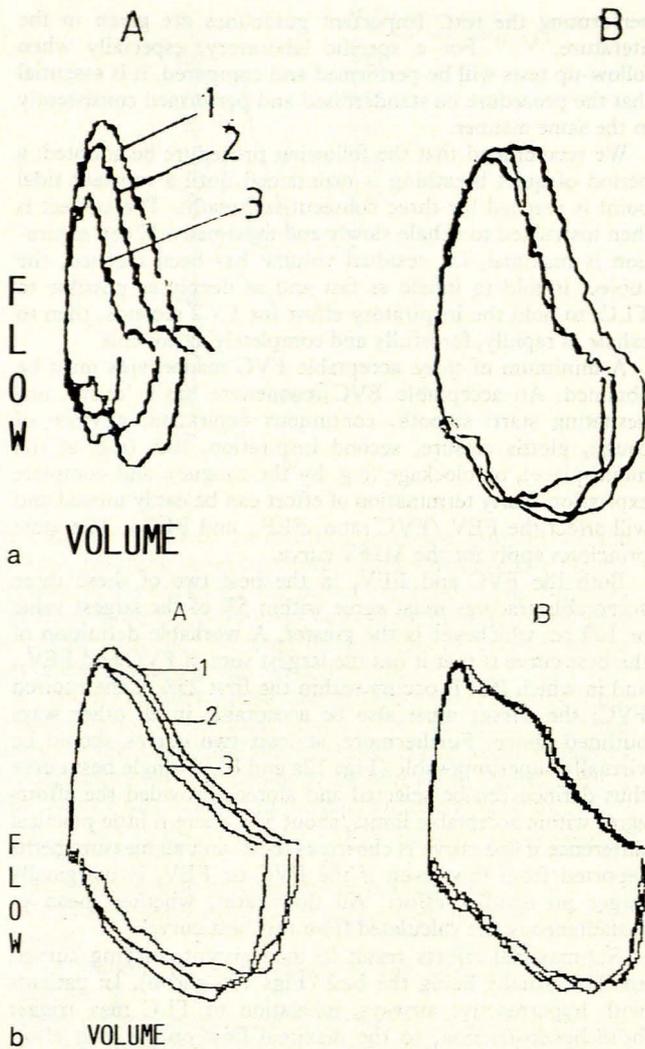


Fig. 14. (a) Flow/volume curve in a 32-year-old male with hyper-sensitive airways becoming progressively smaller blow after blow (A) and being restored to near normal after administration of a bronchodilator (B). (b) The same was illustrated in a 29-year-old male with hypersensitive airways. These types of changes may not be detected if the graphs of all the efforts, together with the values, are not available on the hard copy. (A) before bronchodilator, (B) after bronchodilator.

**Discussion**

The lungs are the most important target organs which are affected by the inhalation of noxious gases and dust in industry and mining. Rather than relying solely on the treatment and/or compensation of severely incapacitated individuals, lung damage must be prevented or limited to an absolute minimum. This should be achieved by identifying not only higher-risk working environments, but also higher-risk individuals. Lung function tests, when accurately performed and well controlled, can be used to identify individuals with early disease prior to the development of symptoms. Accurate prediction of 'normal' values is extremely difficult.<sup>5</sup> It is more practical, however, to estimate the occupationally caused fractional loss in the individual, rather than comparison with population norms. Estimation of pre-exposure values is easy

but must be accurately performed. Unfortunately, few industries perform any pre-employment testing (even though this type of test would clearly pay dividends in the prevention of disease and in reducing the cost of worker compensation).<sup>18</sup>

Similarly, accurate spirometers together with standardised and precise techniques are required for epidemiological studies. Rates of improvement or deterioration of pulmonary function measured in relation to environmental exposures and/or personal characteristics may be erroneous if inaccurate spirometers with or without unprecise methods and without quality control, are used.<sup>16</sup>

For follow-up studies, it is essential that consistently maximal effort flow/volume curves are obtained. Quality control is of the utmost importance. Utilising the system described in this article, operator error has been reduced from more than 16% to almost zero. The recorded graphic curves should be inspected by a physician experienced in lung mechanics. Forms with only the numbers of the tests filled in by the technologist are unsatisfactory and unacceptable. Epidemiologists not experienced in lung function and doing studies in which spirometry is used, should involve a pulmonary physician with experience in this field. To provide a mine or factory with a pulmonary function apparatus to be operated by a nurse untrained in pulmonary function testing and the absence of quality control, is at best only cosmetic and may even have the adverse effect of giving rise to a false sense of security.

(A copy of the instructions based on the principles discussed in this paper and in use at the Rössing Uranium Mine at Swakopmund, SWA/Namibia is available on request.)

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