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Physiological and Clinical Aspects of the flow-volume curves

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The flow-volume curve is a convenient test of lung function. When initiated after a full inspiration the maximal flow-volume curve is obtained while the partial one is recorded at lower lung volumes. The physiological basis of the curves is discussed along with the methods used for recording them The test has been found to be useful in the early detection of obstructive airways disease, in the assessment of therapeutic response to bronchodilator drugs and in detecting effect of physiological interventions on airway calibre. Some limitations of the investigation are discussed and the need to establish standard reference values using standard equipment and method in normal Indian population is stressed.

Spirometric lung function tests constituting the forced vital capacity (FVC), forced expiratory volume 1 sec (FEV_1), forced expiratory flow between the first 200 to 1200 ml of the FVC (FEF 200-1200) and the FEF 25%—75% of the FVC (MMEF-Hyatt and Black 1973) are commonly used for assessing airway calibre (Dikshit et al 1984). However these tests are not sensitive enough to detect alternations in the calibre of small airways ($<$ 2mm ; Stretton 1978) As this part of the tracheo-broncheal tree contributes to only about 20—30% of the total airway resistance (the silent zone), obstruction in the small airways may occur without clinical or spirometric manifestations (Stretton 1978) but if detected in the early stages as in smokers, could be reversible (McCarthy et al 1972). This aspect can be of considerable significance to the health of the Armed Forces personnel. Various investigations which include whole-body plethysmography, closing volume and frequency dependence of dynamic compliance are available but a comparatively simple and reliable assessment of airway calibre can be made by using the flow-volume curves.

The forced expiratory effort made in to the standard spirometer is usually recorded as a volume-time expirograph (Fig. 1a) from which various lung function indices can be calculated. By using a differentiator to obtain flow from volume, a flow-time graph or the flow-volume curve may be recorded (Fig. 1b, 1c). The shape of the curve is determined by the elastic recoil of the lungs, bronchomotor tone and the property of the respired gases the denser gases reduce air flow while the lighter ones increase it. The curve consists of an effort dependent part at high lung volumes and an effort independent part for most of the vital capacity (Stretton 1978). The expiratory airflow in the effort independent part is generated in the airways between the alveoli and the equal pressure points (which are the points at which the intra-airway pressure during exhalation equals pleural pressure). As the exhalation proceeds to residual volume the equal pressure points move peripherally (towards the smaller bronchi) and hence the airflow emerging from this part of the flow-volume curve should come from the small airways (Mead et al 1967). A reduction in these flows would then indicate small airways obstruction. The volume range on the x-axis represents the forced vital capacity (100-0%). The flow rates can be read off at any percentage of the FVC above residual volume. The commonly used variables for assessing small airways function are taken when 50%, 40% and 25% of the vital capacity remains in the chest and are termed the forced expiratory flow (FEF) 50%, 40%, and 25% (Fig. 2). The maximum mid expiratory flow normally calculated from the volume-time trace approximates FEF 50%, which is generally used as a screening index (Cotes 1979), and the peak expiratory flow rate (PEFR) measured by the usual methods is close to the highest expiratory flow on the flow-volume curve (Hyatt and Black 1973). When the inspiratory effort is recorded on the same graph, the flow-volume loop is obtained (Hyatt and Black 1973) and maximum and mid inspiratory flow rates can be read off from the trace.

The expiratory flow-volume curve obtained after a full lung inflation is termed the maximal expiratory flow-volume curve (MEFV). However, a maximum inflation preceeding the forced exhalation may induce a bronchodilatation which may raise the FEF (Wellman et al 1976, Zamel 1984 . This effect has been attributed to a reflex reduction in the bronchomotor tone which is resorted after about a minute (Green and Mead 1974), and to a mechanical stretching of the airways (Nadel and Tierney 1961). Bouhuys et al (1969) demonstrated that this bronchodilatation can be avoided by recording flow-volume curves which are initiated at about 60% of the FVC the partial expiratory flow-volume curves (PEFV). The airflow variables calculated from the PEFV curves then become sensitive indices of alterations in bronchomotor tone during physiological and pharmacological interventions (Zamel 1984) avoiding the effect of a preceeding deep inspiration.

Methods of recording the flow-volume curve

The flow-volume curves are best recorded with a volume-displacement plethysmograph but as this equipment is difficult to obtain, a dry rolling-seal spirometer with a built-in flow differentiator is more commonly used. The output can then be displayed on an XY storage oscilloscope and photographs taken for permanent records or recorded directly on to an X-Y plotter with a high frequency response. A pneumotachograph may be used to record the flow while the volume is simultaneously measured on a spirometer (Castile et al 1982). The X-Y co-ordinates may also be fed into a computer/micro-processor and later reconstructed for calculating the variables desired (Cotes 1979, Hyatt and Black 1973). The equipment selected is one of the factors which determines the extent of variability in the indices obtained and accounts for the large differences in reference values between laboratories (Cotes 1979). The recording is usually done with the subject sitting, and the values are reported at BTPS.

The maximal flow-volume curve

In one of the methods used, the subject, sitting and wearing a nose clip, breathes out to residual volume before being connected to the spirometer. He then breathes in to total lung capacity, and then exhales maximally to residual volume. Curves with forced vital capacities within 5% of the one with the maximum FVC are considered suitable (Castile et al

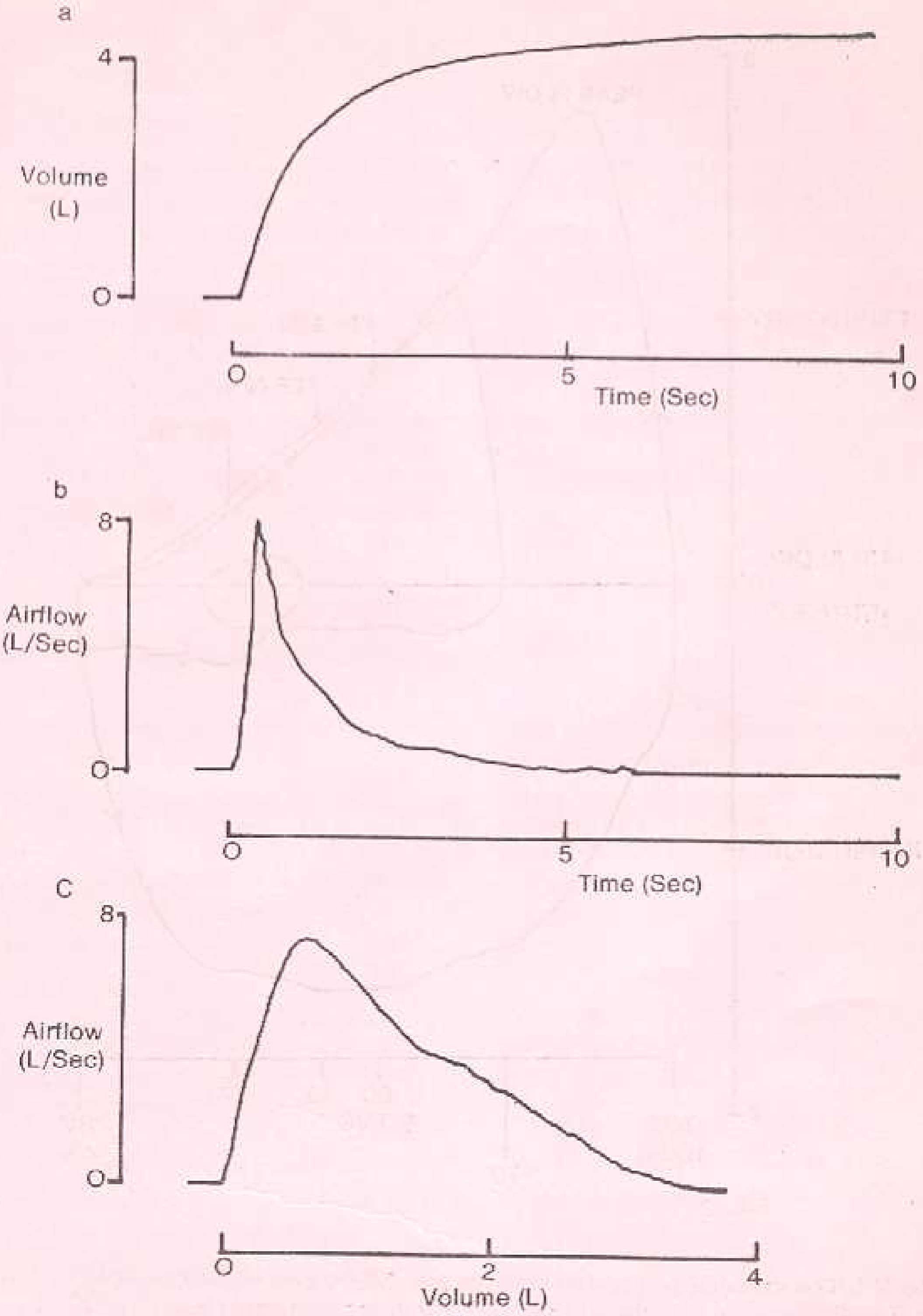

Fig. 1

Figure 1 : Instantaneous volume and airflow as functions of time (a and b). The airflow with respect to volume exhaled is recorded as the flow-volume curve (c).

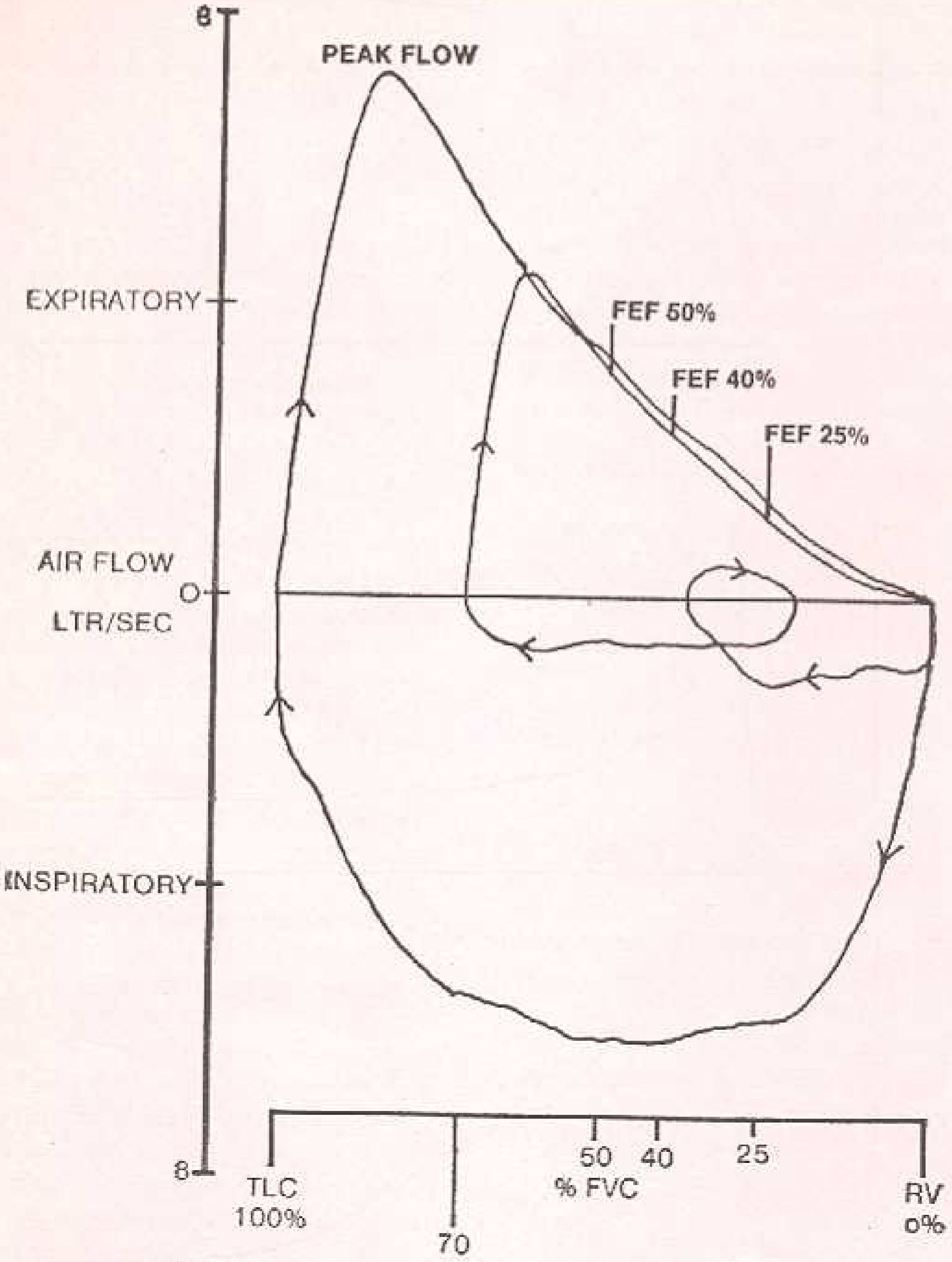

FIG. 2

Figure 2 : The maximal and partial flow-volume (MEFV and PEFV0 curves of a normal subject. The PEFV curve is initiated when 70% of the forced vital capacity (FVC) remains in the lungs. The small loop denotes the quiet breath at functional residual capacity.

1982, Schrader et al 1983). At least three such curves are recorded at one minute intervals.

The partial flow-volume curve

The PEFV curve may be initiated between 50% and 70% of the forced vital capacity above residual volume (Bouhuys et al 1969, Douglas et al 1979, Zamel 1984, Mukhtar and Patrick 1984). For valid comparisons, each curve must be initiated at about the same partial lung volume. Various methods for performing the PEFV curve are available (Bouhuys et al 1969, Douglas et al 1979, Zamel 1984). It is important that the method selected is adhered to. The following method is used in this laboratory (Mukhtar and Patrick 1984, Dikshit and Patrick 1985 a, b). The subject, sitting and wearing a nose clip, breathes out to residual volume and then connects himself to the spirometer tube. After a quiet breath or two at functional residual capacity, he breathes in slowly to the pre-determined partial volume (70% FVC) under the guidance of the observer. On reaching this volume he exhales maximally to residual volume to record the partial curve. He then performs the MEFV curve by inhaling to total lung capacity and exhaling forcibly to residual volume. In this manner both the partial and the maximal curves are obtained with a single manoeuvre and the partial curve is not proceeded by a full inspiration (Fig. 2). Subsequent pairs of forced exhalations are made at 1 minute intervals.

The following precautions are taken to achieve satisfactory results :

1. The procedure must be explained clearly to the subject. Many naive subjects/patients may find the sequence of events difficult to follow, and a number of trials may by required before satisfactory results are obtained.

2. The FVC and 70% of the FVC have to be determined on an earlier occasion, and the observer must control the subjects partial manoeuvre carefully so as to initiate the PEFV at about the same lung volume.

3. The subject/patient must be encouraged to breath out maximally to residual volume.

4. At least 3 technically satisfactory curves must be recorded. An average of the variables obtained from them is taken as the representative value. Selection of variables from the "best" out of a number of expiratory efforts gives a poor reproductibility (Schrader et al 1983).

5. If the subject is a smoker, he is instructed to abstain from smoking on the day of the test. Beverages containing caffeine are best avoided

6. Subjects recovering from viral infection of the upper respiratory tract have low flow rates up to six weeks after recovery (Picken et al 1972) and care must be exercised while interpreting results of such individuals.

7. The recording instruments must be calibrated freequently.

Application of the flow-volume curves

The curves have been used in the detection of airway calibre changes brought about by physiological interventions such as the cold pressor test, lower body negative pressure (Dikshit and Patrick 1985 a and b), cooling of the face (Mukhtar and Patrick 1984). Castile et al (1982) demonstrated the effect of a change in posture on the MEFV curves while Pyzcznski et al (1985) studied the curves during positive accelerations. The influence of vagal and beta-adrenoceptor activity in the maintenance of normal bronchomotor tone has been investigated using this technique (Douglas et al 1979, Tattersfield et al 1973).

The normal ratio of the mid-expiratory flow to the mid-inspiratory flow is about 0.9 (Fig. 3). Its alteration may be helpful in differentiating extra-thoracic airway obstruction from the intra-thoracic variety (Stretton 1983)

The variables calculated from the flow-volume curves fall with the onset of small airways obstructive disease and hence have been found to be useful in the early diagnosis of the disease process (Bake 1981, Cochrane et al 1974, Schrader et al

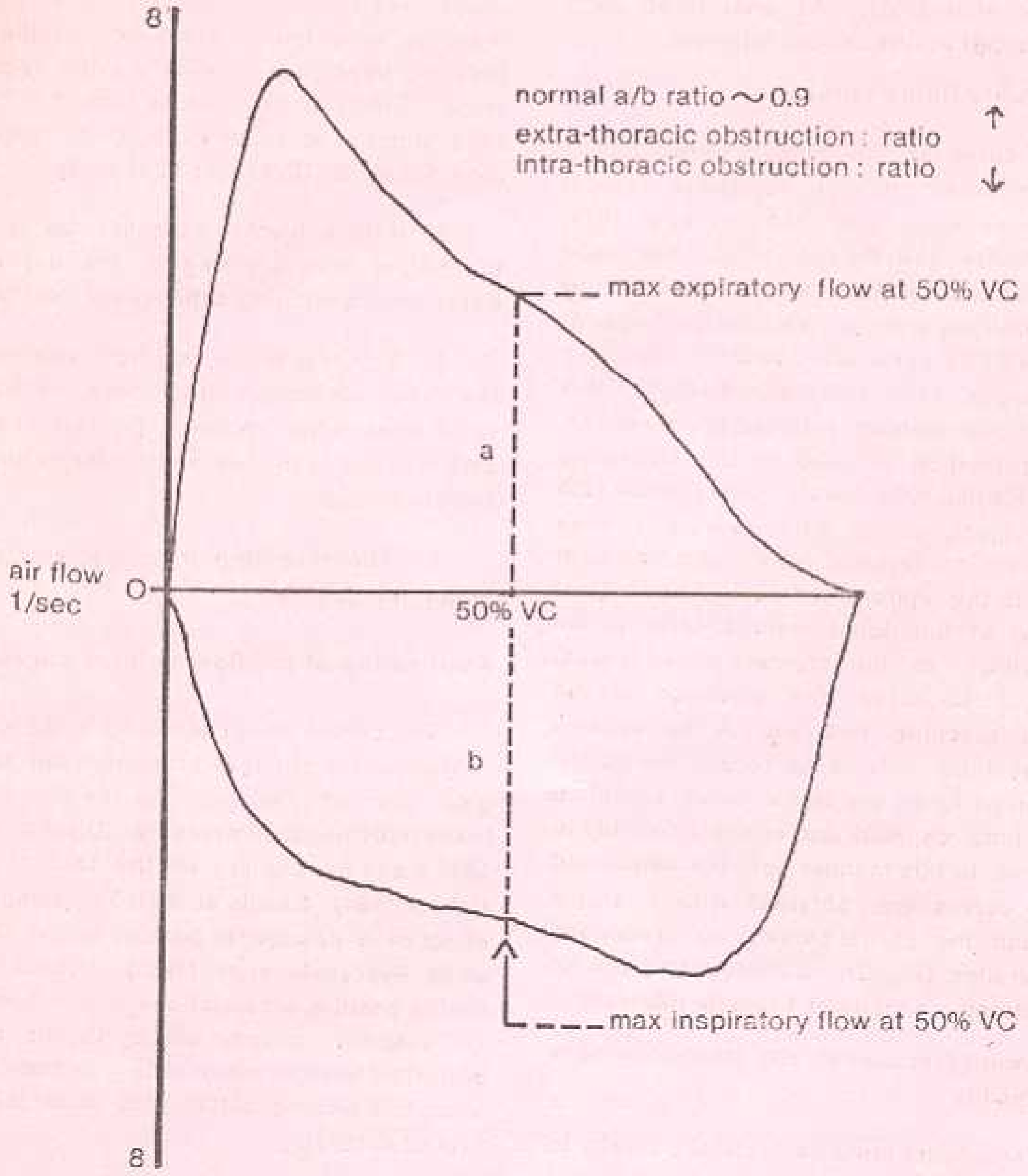

Fig. 3

Figure 3 : A method of using a flow-volume loop for differentiating between intra and extra-thoracic airway obstruction.

1983). The test can be made more sensitive by breathing helium-oxygen mixture (Dosman et al 1975). As subclinical emphysema may also result in reduction of flow rates in the effort dependent part, the test can be of use in assessing such patients (Gelb and Zamel 1973).

Limitations in the use of the flow-volume curves

The forced expiratory air flows fall with advancing age (Cherniack and Raber 1972). It is important to consider this aspect while interpreting results. Normal standards for the western population have been described by these authors but data for normal Indian subjects has yet to be reported. This is important because the normal western population has higher lung volumes as compared to Indians (Jain and Ramiah 1969). Intra-individual variability has been found in the indices calculated from the curves (McCarthy et al 1972). For greater objectivity in the diagnosis of small airways obstruction, the test is best combined with other tests like the closing volume and frequency dependent dynamic compliance. Gelb and Zamel (1973) reported a close correlation between abnormalities in closing volume and a reduction in FEF 50% while alterations in the frequency dependence of compliance has been associated with pathological changes in the small airways (Woolcock et al 1969).

There is no agreement as to the "best" measurement which can be reported from the test (Hyatt and Black 1973). Generally, airflow variables calculated at various lung volumes are used (Fig 2).

Possible future applications of the flow-volume curves

In research : It is likely that aircrew who smoke develope reversible asymptomatic small airways obstruction which may aggravate ventilation-perfusion disturbances which normally occur during exposure to positive accelaratjons (Glaister 1970). This aspect can be investigated using the flow-volume curves of such individuals to assess their lung function and later correlating the findings with their tolerance to positive accelerations. Airway calibre changes which may occur during exposure to severe heat stress because of alterations in autonomic nervous system activity can also be investigated.

In clinical assessment : The test may be effectively used in the aero-medical evaluation of aircrew patients who have been treated for obstructive airways disease by using provocative tests for inducing bronchospasm to see their bronchial reactivity. Patients undergoing hyperbaric oxygen therapy are liable to develop pulmonary toxicity. Presently the volume time expirograph is used to assess early toxicity induced changes in small airways calibre. The flow-volume curves may be found to be more suitable for this purpose.

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