Clinical Application of the Flow-Volume Loop

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A convenient method for recording pulmonary function which allows for rapid graphic bedside analysis was presented. The method involves recording flow-volume (V-V) loop, in correct alignment to a previously determined FRC. FRC was measured by a rapid nitrogen dilution method. This method of recording pulmonary function affords a composite of TLC and all subdivisions with corresponding flow which can be recorded in a patient's chart similar to ECGs. Normal and pathologic loop patterns are illustrated. A high statistical correlation of volumes and flows by the method was found when compared to conventional spirometers in 90 patients.

In 1958 Hyatt and Fry1 first described the flow-volume (V-V) loop technique. This and subsequent work by these authors2,3 clearly demonstrated the interrelationships of transpulmonary pressure, respiratory gas flow, and degree of lung inflation to the resultant V-V loop form. Their work along with the work of Dayman4 provided an analytic approach to the expiratory portion of the V-V loop. The V-V loop technique has been proved to be a useful clinical test of dynamic pulmonary function. Lapp's5 study found the V-V loop effective in distinguishing normal subjects from patients with pulmonary disease. Branscomb6 found the technique to be rapid, reliable and well suited for an epidemiologic survey. Bartlett7 suggested the V-V loop as a method of monitoring pulmonary function in aerospace flights. In spite of its apparent clinical applicability and advantages the V-V loop method has not received wide usage. Perhaps this is because a standard convenient method has not been presented.

Hyatt8 emphasized the value of relating maximum expiratory flow to absolute thoracic gas volumes. This was considered by him to be particularly important in disorders with abnormal residual volumes such as chronic obstructive emphysema and restrictive diseases. A practical clinical technique of recording V-V loops in correct relationship to a patient's thoracic gas volume has not been described.

The purpose of this report is to present: (1) a simple accurate method of recording the flow-volume loop (V-V) in correct alignment to previously determined functional residual capacity (FRC); (2) a rapid method of measuring FRC which facilitates precise positioning of the loop; (3) the applicability of the V-V loop to rapid visual analysis; (4) the statistical correlation of the V-V loop method with more conventional methods of spirometrics; and (5) a valuable graphic reproduction for displaying the loop in patient's medical charts.

MATERIAL AND METHODS

Subjects for this study were all patients referred to the cardiopulmonary laboratory for pulmonary function analysis over a six-month period. One hundred and twelve studies involving 90 patients were performed. There were 79 men and 11 women with a mean age of 42 years.

Functional residual capacity (FRC) was first determined by a nitrogen dilution closed system technique. A waterless spirometer,* filled with 100 percent O₂, a CO₂ absorber, and a gas circulating motor blower were used. The initial N₂ concentration was assumed to be 80 percent in the lung (which is deemed close enough for clinical purposes) and approximately zero in the spirometer. The initial volume of gas in the lung (FRC) was unknown. The subject

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*Hi-Fi Spirometer System, Model 470 by Med-Science Electronics, St. Louis, Missouri
then began rebreathing into the system from an end tidal expiratory position. A nitrogen meter continuously sampled the gas until equilibration of $N_2$ was reached, i.e., the concentration of $N_2$ was the same in both the lung and the spirometer. The volume of the system was maintained constant by adding $O_2$ to replace the $CO_2$ absorbed and the $O_2$ utilized. The FRC was calculated by the formula: FRC $\times N_2$ concentration in the lung before rebreathing + volume of gas in the spirometer (Vs) $\times N_2$ concentration in the spirometer before rebreathing = (FRC + Vs) $\times$ final $N_2$ concentration of the system.

Since FRC and final $N_2$ concentration are the unknowns in the above equation, they were used as variables in a linear equation to construct a permanent straight line graph. A volume scale was placed on the ordinate and a scale of $N_2$ concentration was drawn on the abscissa. A straight line graph was drawn after several points were determined by equilibrating known volumes of gas containing approximately 80 percent $N_2$ (room air) with the spirometer. The coordinates of the known volumes and their corresponding equilibrated $N_2$ concentrations intersected to locate the points for the straight line. An unknown FRC can be rapidly read from the graph by knowing the final $N_2$ concentration ($N_2$ concentration after rebreathing).

The V-V loops were obtained by feeding the transduced signals of flow and volume from the waterless spirometer through differential amplifiers** to the X and Y axis respectively of a storage oscilloscope.† A tidal volume V-V loop was initially obtained. It was aligned on the volume axis by utilizing the previously measured FRC to determine the end tidal level (Fig 1). Both FRC and V-V loops were recorded at ambient temperature and pressure saturated with water (ATPS). The subject was then instructed to perform a maximum effort vital capacity maneuver, i.e., a forced expiratory VC effort followed by a forced inspiratory effort. The pattern was then photographed with a Polaroid camera.† Figure 2 represents a diagram of the V-V loop and some of the measurements which can be made from it.

**Differential Amplifier Type 2A63 by Tektronics, Beaverton, Oregon.
†General Purpose Storage Oscilloscope Type 564 by Tektronics
†Trace Recording Camera Type C-12 by Tektronics

Standardized calibrations for flow and volume are essential for consistency in pattern analysis. One centimeter deflection on the oscilloscope equivalent to 1 liter on the volume axis and equivalent to 2 liters/sec on the flow axis were used in this study.

Each study included a V-V loop analysis and spirometry performed with a 13.5 liter Collins spirometer§ on the same day. The FRC for the conventional spirometry was measured by closed circuit helium dilution technique. At least three V-V loops and three spiromgrams were determined on each subject. The maximal performance with each method was selected for analysis.

A coefficient of correlation between the vital capacities by the two methods was calculated. The conventional maximum midexpiratory flow (MMF) as described by Bates and Cristie§ was correlated with the MMF measured from the V-V loop.

** Results and Comments **

Comparison of the V-V Loop Method with Conventional Spirometry

The mean VC by the V-V loop method was 4,203 ml (BTPS) SD ± 1,283. The mean VC measured with the Collins Respirometer was 4,035 ml (BTPS) SD ± 1,261 ml ($r = +0.96$). The slightly higher volumes measured by the V-V loop method probably reflected the technician's ability to more closely approximate maximum patient effort while simultaneously monitoring the loop pattern inscribed on the oscilloscope. A slight variation in apparatus calibration cannot be excluded.

The mean MMF by the V-V loop method was 132 liters/min, SD ± 75 liters/min. The mean MMF by the conventional spirometer was 141 liters/min, SD ± 102 liters/min ($r = +0.98$). The different mean MMF by the two methods re-

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**Figure 1. Adjustment of the tidal volume V-V loop to FRC: Step 1, illustrates movement of oscilloscope beam by the horizontal adjust knob as subject performs tidal volume loops. The end tidal level of the loop is aligned with the FRC level (2,000 ml). Step 2 once tidal V-V loop is aligned at the FRC level tracings are erased and single tidal V-V loop is formed (the storage oscilloscope retains an image for more than 30 minutes unless erased). Step 3 illustrates inscription of complete V-V once the tidal volume loop has been formed.**

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reflects the fact that the V-V loop MMF is an instantaneous flow at mid VC whereas the conventional spirometric MMF is an average flow.

The V-V loop, when aligned in correct relationship to FRC, represents a composite of many elements of pulmonary function which contribute to a characteristic loop pattern. The pattern lends itself to rapid visual analysis and as shown by Bartlett and Phillips10 is reproducible from day to day in a subject with stable respiratory function. Furthermore the major pathophysiologic disorders of pulmonary function produce characteristic loop patterns.

In obstructive disorders the pattern demonstrates: (1) a shift of the loop to the right on the volume axis due to hyperinflation; (2) exaggerated concavity of the expiratory curve; and (3) reduced expiratory flow peaks. Figure 3 illustrates the loop in chronic obstructive emphysema. Reversal of an obstructive loop pattern toward normal after bronchodilatory therapy allows for rapid recognition of bronchospastic disorders (Fig 4).

Restrictive disorders display (Fig 3): (1) a tall narrow loop shifted toward the left on the volume axis and the expiratory portion of the loop is flat; (2) reduced expiratory flow peaks; and (3) normal inspiratory flow peaks. This pattern reflects reduced compliance and decreased intrinsic PEEP (Fig 5). Figure 4. Example of pulmonary function report form and mounted V-V loop: This is a patient with asthma reflecting an obstructive pattern relieved by a bronchodilator drug. The prenebulization loop has superimposed maximum voluntary ventilation loops. The spike noted on the postnebulization loop was produced when the patient coughed during the maneuver. The loops and FRC are recorded at ATPS whereas the tabulated volumes have been corrected to BTPS.

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axis; (2) straightening of the last half of the expiratory curve; and (3) high expiratory flow peaks.
Lack of maximal effort due to malingering, or failure to understand the procedure is readily apparent and indicated by one or more of the following (Fig 3): (1) failure to close the loop; (2) inconsistent loop pattern; and (3) convexity of the last half of the expiratory phase of the loop. In this context Burger and Bartlett and associates aluded to the potential value of using a "cough loop" as a means of increasing the objectivity of V-V loop analysis in selected cases. The subject is instructed to inspire fully followed by a series of coughs. The expiratory phase of the loop can be outlined and the V-V loop is analyzed in the usual manner.

Methods of Display

Once the V-V loop is photographed, the Polaroid print can be glued to a grid printed on a pulmonary function report form. The abscissa of the grid is graduated into liters (volume) and the ordinate into liters/second (flow). This method of mounting is similar to that used to mount ECGs. A completed pulmonary function form and mounted V-V loop pattern can be duplicated by most of the commonly employed copying methods (Fig 4).

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REFERENCES


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