Direct-Writing Recorder of the Flow-Volume Curve and Its Clinical Application*


A new device for recording the flow-volume loop by direct means of pen-writing is presented. Its clinical usefulness was established by the loops recorded in 38 healthy men and 52 patients with airway obstruction. From a careful analysis of the curves flow at 25 percent VC as well as its ratio to flow at 50 percent VC was found to be sensitive for detection of airway obstruction to a milder degree.

The flow-volume curve first introduced by Hyatt and associates1,2 and Fry3 has established its physiologic basis for diagnosis and evaluation of patients with pulmonary diseases.4-6 However, the technique has not been in wide use, as information on how to use the curve is inadequate in the clinical evaluation of patients, and a convenient standard method has not been presented. The technique now available for obtaining the flow-volume loop requires a number of instruments such as Hi-Fi spirometer or flow meter with integrator and recording system in which storage oscilloscope with a Polaroid camera has been commonly used.9 These instruments are expensive and the techniques are rather complicated.

In the present study we report a new device for recording the flow-volume loop by direct means of pen-writing, and by using this machine, we obtained the loop in healthy subjects and patients with obstructive lung diseases in order to introduce a simple analytical method to evaluate its abnormalities.

Device

The ventilatory volume change was transduced to horizontal movement of the recording paper on the plate fixed at the free edge of a bellows-type respirometer specially made for the present purpose, and the galvanometer pen attached on the paper, which was designed to swing linearly, was driven with the flow signal from the tachogenerator electrically differentiating the movement of the bellows (Fig 1).

The recording paper can move 2 cm with one liter of volume change in the bellows and the pen swing ±4 cm at a maximum on the paper with three different sensitivities as 1, 2, 4 cm at one liter per second of flow. The low pass filter (fo = 6 and 10 Hz) was utilized in the electrical circuit to filter a high frequency noise on the flow signal.

The volume changes of bellows are calibrated with the conventional respirometer (Collins 13.5 liter) at room temperature. It is necessary to check frequency response of the bellows, because a transient build-up in the flow-volume loop presumably includes quite a high frequency such as up to 10 Hz at its beginning. To test the frequency response of the bellows, movement of the bellows was compared to the integrated signal of the pneumotachograph (Fleisch) with appropriate pressure transducer attached to the outlet of the bellows. Bellows movement was detected by means of a linear transducer (Sanborn) fixed at the free edge of the bellows. Volume change of about 0.5 liter at 3 to 10 Hz of frequency range was produced by means of the speaker in the box used for the oscillation technique of measuring respiratory resistance.10

Figure 2 is a diagram which shows frequency characteristics of the bellows obtained by means of the routine technique commonly used in a field of the electroengineering. As seen in the figure, difference between two volumes (gains) obtained by the different methods was found to be about 10 percent (−2 db) at 9 Hz and difference in phase lag between two volume traces in time practically insignificant being within −10. Flows are calibrated by the same pneumotachograph attached to one side of the flow meter to the outlet of the bellows, the other side being connected to the Collins respirometer which could generate rather constant flows into the bellows by pushing down the bell with various weights on its roof. The low pass filters in the flow signal were found to have practically no influence upon the flow-volume curve at the volume below 80 percent vital capacity with an exception of considerable amount of deviation at the beginning of the curve when the filter of 6 Hz used.

Application

Flow volume loops and expiratory spiromgrams during maximum forced vital capacity maneuver
were recorded simultaneously in two groups. One group of 37 healthy men who had no chest disease, worked for an electric power supply company. The ages in this group ranged from 22 to 61 years, including eight men between 20 and 29 years, nine between 30 to 39 years, nine between 40 to 49 years, and 11 between 50 and 61 years, respectively. The other group consisted of 52 patients of various ages, with chronic obstructive lung disease or diffuse pulmonary fibrosis.

In Figure 3, typical flow volume curves and vital capacity traces during maximum forced expiration in three men of the healthy group are shown with different FEV₁₀/VC ratio (FEV₁₀ percent). In the figure abscissas are expressed in time for the forced vital capacity traces, and in volume for the flow volume curves, respectively. The young subject above 80 percent of FEV₁₀ percent showed nearly linear decrease of maximum expiratory flow as lung volume decreased below 75 percent vital capacity. On the other hand, healthy elderly subjects showing FEV₁₀ percent slightly over 70 percent revealed a marked decrease of expiratory flows at lower lung volumes in spite of a spike-like increase of flows at the beginning, which resulted in curvilinear appearances in the slopes of the curves. It should be noted that among the three cases one can distinguish apparent differences by inspection in shape of the flow volume loop; on the contrary the conventional volume traces are evidently unsatisfactory for finding any definite differences among them.

In diseased subjects, shown in Figure 4, except for a patient with diffuse pulmonary fibrosis, all of the expiratory flows below 75 percent vital capacity decreased to a greater extent. This was well demonstrated in patients with chronic pulmonary emphysema who showed the maximum flow even in quiet expiration. In the asthmatic patients, the flow volume loop was characterized by a decrease of all flows along the curve including peak flow rate. Obstructive pattern of the loop seen in the bronchitic, however, was somewhat different, since a sharp inflection with a marked change in slope along the middle segment was frequently observed, as seen in the figure. Such exaggerated concavity of the expiratory curve was already reported in previous papers. Lord and co-workers⁴ described the same phenomenon, saying that as obstructive disease became more severe, the curve became more convex to the volume axis. However, this is true

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**Figure 1.** Block diagram of the apparatus.

**Figure 2.** Differences in gain (open circle) and phase lag (closed circle) between bellows movement and integrated signal of flow at the airway opening.
true that the loop is much more convenient to see what is occurring in late expired volume than a forced expiratory volume tracing which often shows a prolonged decay in obstructive disease. However, an analysis by inspection is not practical both for a comparison of various pulmonary diseases and a massive survey, and one would wish some index to characterize the individual curve such as FEV$_{1.0}$ percent as an index of obstructive change in forced expiratory volume curve. For the purpose mentioned above, maximum expiratory flow rate at different lung volumes expressed in percent VC was studied in connection with age and FEV$_{1.0}$ percent.

In the Table maximum expiratory flows at 75 percent, 50 percent and 25 percent VC measured from flow volume curves in the healthy group are shown with age. Each indicates the mean with a standard deviation. According to Zapletal and colleagues$^{11}$ who showed maximum expiratory flow rate and airway conductance to be closely related to height in children in growth, the maximum flows were normalized to correct for the differences in lung size by dividing flow by the subject's height, although the correlation coefficient between the corrected and the uncorrected flow rate is extremely high ($y = 0.95$). Following the table expiratory flow rate at 75 percent VC does not change significantly with age in this series. On the other hand the expiratory flow rates at 50 percent and to a greater extent at 25 percent (V50 and V25, respectively) show a marked tendency to decrease with age; this might be reflected by a slight obstructive change with age indicated by several investigators.$^{12,13}$

In the present study it is well recognized that flow at 75 percent VC is not effective in detecting

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**Figure 3.** Maximum expiratory volume curves conventionally obtained with the Benedict-Roth Respirometer and flow-volume loops with the new device in three healthy men.

Only in a case with relatively milder airway obstruction who has had high peak flow, since a patient suffering from severe obstruction usually tends to show less curvilinear slope, as seen in the case D, E in Figure 4. In sharp contrast to the pattern in obstructive disease, typical feature of the flow volume loop in diffuse pulmonary fibrosis was a high flow rate with the small vital capacity, characterized by a sharp rise to peak flow followed by a steep descent to the maximum expiratory position.

It is essential to recognize the flow volume curve as a pattern in various kinds of disease, and it is also

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**Figure 4.** Maximum expiratory flow-volume loops in patients with bronchial asthma (A, B), chronic bronchitis (C), chronic pulmonary emphysema (D, E) and fibrosis (F).
Figure 5. Frequency plot of V50/V25 ratio for each different age group in healthy subjects and for each FEV1.0 percent group in patients with obstructive lung disease or pulmonary fibrosis. For dotted line see the text.

Differences with age, while the flow at 50 percent VC coupled with the flow at 25 percent VC may be useful in discriminating between the young and the elderly subjects in the normal group. Previous investigations have supported the present results insofar as to utilize the flow at 50 percent VC. Hyatt has shown that comparison of maximal expiratory flows at the mid-vital capacity provides a better separation between normal and emphysematous subjects than does comparison of peak flow values. Lapp and Hyatt and recently Branscomb have preferred to apply such a relatively simple index as the flow rate at 50 percent of VC for the purpose of analyzing the flow volume loop.

From a practical point of view, however, determination of flow at a point of the volume does not necessarily require any recording of the loop, and is simply obtained from volume traces in time recorded with a conventional respirometer. Therefore, this should be discussed further. Dayman described the slope of the flow volume curve to be roughly linear over most of its volume curve; actually it was not the case in the results which he presented, and he also mentioned that in a small terminal portion of the curve which comprised approximately 10 percent, or roughly half a liter in the healthy subject, flow was too slow to be physiologically useful.

Nevertheless, it should be emphasized that the most prominent feature of the loop characterizing obstructive impairment within the lungs is its curvilinearity in the middle portion of the curve as seen in Figure 3. To convert the curvilinear pattern of the slope into a digital number, we finally chose a V50/V25 ratio as the best among a number of indexes.

Figure 5 illustrates frequency plot of V50/V25 ratio for each different age group in healthy subjects and for each FEV1.0 percent group in patients with obstructive lung disease or pulmonary fibrosis. By definition, the ratio equals two means the slope of the flow volume loop to be perfectly linear, and the greater the V50/V25 ratio the more convex downward along the curve. In the figure, it is clearly demonstrated by this index that the older subjects show more curvilinear slope than the younger group. If we accept the upper limits of this ratio in healthy young subjects not to exceed 3.0 in the figure, the older subjects over age 50 years show more or less curvilinear pattern of the loop. Furthermore, the fact that V50 can be over V25 to a greater extent in older subjects, may suggest that we can use V25 instead of V50 for an index sensitive to obstructive impairment. Conclusively, it is confirmed that augmentation of the V50/V25 ratio coupled with a diminution of V25 can better distinguish between the younger and the older persons.

In the obstructive group, the V50/V25 ratio shows a marked increase in patients with less severe airway obstruction, with a consistent tendency to decrease as FEV1.0 percent becomes greatly reduced down to around 20 percent. However, these are not unexpected findings. Because, as is mentioned previously, the slope of the flow volume curve tends to diminish its curvilinearity, with the exception of a sharp inflection with a change in slope immediately following a spike-like peak flow.

Table 1—Maximum Expiratory Flow at 75%, 50% and 25% VC Measured from Flow-Volume Curve in Healthy Men.*

<table>
<thead>
<tr>
<th>Age, Years</th>
<th>No. Subjects</th>
<th>V75/HT</th>
<th>V50/HT</th>
<th>V25/HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>8</td>
<td>5.80 ± 1.62</td>
<td>3.91 ± 0.85</td>
<td>1.92 ± 0.56</td>
</tr>
<tr>
<td>30-39</td>
<td>9</td>
<td>5.10 ± 1.00</td>
<td>3.00 ± 0.55</td>
<td>1.28 ± 0.24</td>
</tr>
<tr>
<td>40-49</td>
<td>9</td>
<td>5.03 ± 1.30</td>
<td>2.97 ± 0.80</td>
<td>1.17 ± 0.37</td>
</tr>
<tr>
<td>50-61</td>
<td>11</td>
<td>5.83 ± 1.27</td>
<td>2.63 ± 0.80</td>
<td>0.83 ± 0.33</td>
</tr>
</tbody>
</table>

*The mean value with a standard deviation corrected for height (HT, M) was demonstrated for each age group.

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at higher lung volume as obstructive disease becomes much more severe. In this regard, it should also be noted that decrease of \( V_{50}/V_{25} \) ratio may apparently be of great significance, meaning a steady constant flow along with the corresponding lung volume. According to our impression, this ratio has the possibility of separating the asthmatic patients from the bronchitis patients, in the latter supposedly the ratio representing the highest value. However, such analysis is not performed in the present study and further investigation will be necessary to confirm this fact.

In conclusion, our direct-writing machine of plotting flow against volume during the forced expiratory vital capacity maneuver has proved useful in seeing mechanical abnormalities within the lungs. With a careful analysis of the flow volume loops which were obtained by this machine in 37 healthy subjects and in 52 patients with airway obstruction or pulmonary fibrosis, it is established that \( V_{50}/V_{25} \) ratio coupled with \( V_{25} \) may give a simple tool for pattern recognition of the curve and also gives important information on obstructive impairment.

REFERENCES

14 Hyatt RE: The interrelationships of pressure, flow, and volume during various respiratory maneuvers in normal and emphysematous subjects. Amer Rev Resp Dis 83:676, 1961

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