Bronchodilatation and the Inspiratory Flow Volume Curve*

Raju Reddy, MD; Timothy Cook, MD; and Michael F. Tenholder, MD, FCCP

The inspirational flow volume curve is included in the spirometric tracing provided by most pulmonary function laboratories and is useful in assessing upper airway abnormalities. We analyzed the changes in peak inspiratory flow (PIF), forced inspiratory flow at 50% (FIF50), and forced inspiratory vital capacity (FIVC) that occur with bronchodilator challenge testing (3 puffs of a β-agonist by metered-dose inhaler without a spacer device) in 145 consecutive patients. Fifty-five patients responded to bronchodilators with either a 12% or 200-mL change in FEV1 or FVC. All of these subjects produced forced expiratory maneuvers that fulfilled American Thoracic Society criteria or acceptability. The FIVC was the only inspiratory parameter that consistently showed a similar correlation to the bronchodilator responsiveness demonstrated by the FEV1 or FVC. With the reduction in air trapping, a 12% or 200-mL change in the FIVC is additional confirmatory evidence of bronchodilator responsiveness.

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Key words: bronchodilatation; challenge testing; inspiratory flow

Abbreviations: ATS = American Thoracic Society; FIF50 = forced inspiratory flow at 50%; FIVC = forced inspiratory vital capacity; PIF = peak inspiratory flow

The value of flow volume loops in assessing the magnitude of upper airway obstruction is well recognized.1 Analysis of these curves is a useful adjunct to other methods being employed for such evaluation. The flow volume loop is produced by continuously recording the flow and volume by an electronic spirometer during a forced inspiratory and expiratory maneuver. Characteristic patterns are seen in obstructive and restrictive diseases of the airways of different etiologies.2 Flow volume loops are sensitive and have a characteristic expiratory "scooped out" pattern in patients with airway obstruction. In most obstructive diseases, however, the appearance of the inspiratory flow loop is believed to be well preserved with minimal distortion.

Significant improvements in the FEV1, FVC, and peak expiratory flow rate can be seen on computerized spirometry following inhalation of a bronchodilator. Traditionally, attention has been focused on the expiratory flow volume loop in patients with obstructive diseases and few have studied the inspiratory flow loop, especially after inhalation of a bronchodilator. The American Thoracic Society (ATS) criteria for a meaningful response to a bronchodilator require that it should augment the FEV1 and FVC by at least 12% of the baseline and increase either of these by at least 200 mL.3 We applied similar criteria to the inspiratory loop to measure bronchodilator response.

Materials and Methods

All patients at the VA Medical Center in Memphis, Tenn, who had a pulmonary function test that included bronchodilator testing were considered eligible for inclusion into the study. Patients without expiratory airflow obstruction were not given bronchodilators. There were no other exclusion criteria for this prospective study. Spirometry and lung volumes were performed on a spirometer (Sensormedics 2100 Spirometer; Yorba Linda, Calif) and a computer (IBM Personal System/2 model 30 2886 Computer; Armonk, NY). The spirometry was done according to ATS standards using Knudson race-adjusted normals.4, 5

All pulmonary function tests were performed by the same qualified technician in precisely the same format. Patients were first asked to take in a deep breath followed by a forceful expiratory maneuver lasting 6 s. If all ATS criteria were met for an adequate testing,6 patients were then given three puffs of a β-agonist by metered-dose inhaler (without a spacer device). After a 15-min rest period, the flow volume loop, inspiration followed by expiration, was repeated three times. The best inspiratory effort was coupled with the best expiratory effort for analysis of flow volume characteristics.8

Statistical Analysis

Data are presented as the mean±SEM under each column in the expiratory/inspiratory flow/volume loop tables. Data obtained from pulmonary function testing, both prebronchodilution and postbronchodilution, were compared by a two-tailed Student’s t test for paired observations. A value of p<0.05 was taken as the level of statistical significance.

*From the Department of Medicine, Division of Pulmonary and Critical Care Medicine, University of Tennessee, Memphis. Manuscript received February 6, 1996; revision accepted May 30.

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RESULTS

A total of 145 patients were tested. Fifty-five patients performed acceptable (ATS criteria) expiratory flow loops before and after bronchodilator administration and had a 12% or 200-mL increase in FEV1 or FVC. These bronchodilator-responsive patients had a mean age of 63.4 years. All were male smokers; 34 were white and 21 were black. The mean tobacco history was 44 pack-years.

Table 1 shows the expiratory bronchodilator responsiveness of the entire group, the nonresponders and the responders. Table 2 represents the relationship of the (forced inspiratory flow at 50% (FIF50), forced inspiratory vital capacity (FIVC), and peak inspiratory flow (PIF) to bronchodilator responsiveness. There was no correlation except for the FIVC which mirrored the performance of the FVC and FEV1. When the 55 bronchodilator-responsive subjects were analyzed, the FVC (>12% and 200 mL), standing alone, identified 43 of the 55. The FEV1 (>12% and 200 mL), standing alone, identified 42 of the 55. The FIVC (>12% and 200 mL) also showed bronchodilator responsiveness in 42 of the 55 when analyzed alone. The combination of the FVC and the FIVC demonstrated a positive bronchodilator response in 30 of the 55 subjects, while the FEV1 and FIVC combined was positive in the other 25. This can be compared to the positive response seen on both the FVC and the FEV1 that occurred in 28 of the 50 patients. Twenty-one subjects were positive on all three parameters (FVC, FEV1, FIVC). The FIVC (>12% and 200 mL) independently identified 9 subjects whose FVC and/or FEV1 percentage change was less than 12% (mean, 6 to 9%). These subjects had fulfilled the 200-mL volume change criteria for bronchodilator responsiveness.

DISCUSSION

Since the early description of the flow volume curve by Hyatt and Black, the main focus has been on the characteristics of the expiratory limb. However, an analysis of flow limitation during both inspiration and expiration can be made. The pattern of the inspiratory limb is a well-established tool used in the diagnosis of upper airway obstruction that may limit inspiratory or expiratory flow, or both, and produce symptoms that can be confused with refractory asthma. There is now increased emphasis on performance and selection criteria for the inspiratory curve.

In a previous study of the inspiratory flow volume curve, we demonstrated that it is more appropriate to generate an inspiratory flow volume curve prior to or without an antecedent forced expiratory maneuver in patients with upper airway obstruction. We found a substantial increase in the FIVC (about 170 mL) in patients with obstructive disease when the forced expiratory maneuver followed the inspiratory flow curve. We suggested the following criteria for accepting, reporting, and displaying the “best” inspiratory flow volume curve data: (1) the acceptability criteria would require that the FIVC be equal to or greater than the FVC and that the FIF50 should be at least 95% of the PIF; (2) the best data selected for numeric tabulation and ratio determinations should be the largest FIVC, FIF50, and PIF from all trials; (3) The “best” inspiratory flow volume curve for printing and interpretation should be the curve with the largest sum of the FIVC+FIF50+PIF and paired with the best expiratory flow volume curve. Bolliger and colleagues studied 18 patients with asthma and COPD to test the hypothesis that forced inspiration is reproducible, contains the same information, and is less strenuous than forced expiration. Correlations between inspiratory and expiratory variables were very good for FVC/FIVC (R=0.99), FEV1/FIVC (R=0.66), and peak expiratory flow/PIF (R=0.70). Patients with COPD found the expiratory maneuver much more stressful. Their study, like ours, demonstrated that the FIVC clearly outperformed the FIF50 (R=0.40) and the PIF (R=0.70) in COPD patients. Further work has been performed by Hnatiuk and Slade to characterize the quality of the inspiratory flow curve. They analyzed the inspiratory curve of 122 subjects with no pulmonary

### Table 1—Expiratory Flow/Volume Loop Parameters

<table>
<thead>
<tr>
<th></th>
<th>FVC</th>
<th>% Change</th>
<th>p Value</th>
<th>FEV1</th>
<th>% Change</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients (n=145)</td>
<td>3.13±0.85</td>
<td>7.46±10.4</td>
<td>NS</td>
<td>1.63±0.65</td>
<td>10.7±10.7</td>
<td>NS</td>
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<tr>
<td>Nonresponders (n=90)</td>
<td>3.18±0.93</td>
<td>1.70±6.54</td>
<td>NS</td>
<td>1.75±0.68</td>
<td>4.97±7.51</td>
<td>NS</td>
</tr>
<tr>
<td>Responders (n=55)</td>
<td>3.03±0.70</td>
<td>16.9±8.36</td>
<td>&lt;0.0006</td>
<td>1.45±0.57</td>
<td>19.9±8.90</td>
<td>&lt;0.02</td>
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### Table 2—Inspiratory Flow/Volume Loop Parameters

<table>
<thead>
<tr>
<th></th>
<th>FIF50</th>
<th>% Change</th>
<th>p Value</th>
<th>FIVC</th>
<th>% Change</th>
<th>p Value</th>
<th>PIF</th>
<th>% Change</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients (n=145)</td>
<td>3.30±1.41</td>
<td>9.67±30.2</td>
<td>NS</td>
<td>2.94±0.90</td>
<td>8.20±13.7</td>
<td>NS</td>
<td>3.62±1.39</td>
<td>7.53±21.8</td>
<td>NS</td>
</tr>
<tr>
<td>Nonresponders (n=90)</td>
<td>3.25±1.47</td>
<td>6.75±30.1</td>
<td>NS</td>
<td>3.00±0.95</td>
<td>2.51±12.2</td>
<td>NS</td>
<td>3.62±1.44</td>
<td>4.49±21.5</td>
<td>NS</td>
</tr>
<tr>
<td>Responders (n=55)</td>
<td>3.35±1.31</td>
<td>14.4±30.3</td>
<td>NS</td>
<td>2.85±0.80</td>
<td>17.4±10.9</td>
<td>&lt;0.005</td>
<td>3.62±1.31</td>
<td>12.5±21.6</td>
<td>NS</td>
</tr>
</tbody>
</table>
disease and normal results of expiratory spirometry. As in our previous study, they also found that using the “best effort” expiratory curve missed a significant portion of maximal midinspiratory flow rate (MIFR) and FIVC50 values. They have proposed that an acceptable inspiratory flow volume curve should include FIVC50 of 95% or greater MIFR, FIVC greater than or equal to forced expiratory vital capacity, or a parabolic shape with only one inflection point.

We have shown that analysis of the “best” inspiratory curve, using either our previously published criteria or those of Hnatiuk and Slade, provides additional information about bronchodilator responsiveness. We propose that a 12% increase or 200-mL increase in FIVC be incorporated into the positive predictive factors for bronchodilator responsiveness. Because our study is limited to a homogeneous group of male smokers, further analysis of inspiratory limb characteristics, with and without bronchodilators, awaits confirmation by broader population studies. We hope that when new ATS criteria for spirometry are published, the performance and reporting guidelines for the inspiratory limb will be addressed.

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REFERENCES

10 Hnatiuk OW, Slade AR. Characterization of the inspiratory flow-volume curve in asymptomatic patients with no known pulmonary disease and normal expiratory spirometry. Chest 1995; 108(suppl):1S7S