Maximum Flow Ratios at Mid-Vital Capacity in Young Healthy Adults*

P. McLean, M.D.; and Noe Zamel, M.D., F.C.C.P.

Upper airway obstruction is usually diagnosed by visual examination of maximum expiratory and inspiratory flow-volume curves and by calculating a ratio of expiratory to inspiratory flow at 50 percent of vital capacity (mid-vital capacity flow ratio); however, reference values of this ratio have not been well established, and considerable variability exists. The purpose of this study was to examine the range of mid-vital capacity flow ratios in a group of healthy subjects and to determine if some of the variability is accounted for by different maximum inspiratory pressures. We measured (1) maximum expiratory and inspiratory flows at 50 percent of vital capacity from the flow-volume curves, and (2) maximum inspiratory pressures in a group of 60 healthy nonsmokers (30 men and 30 women) whose ages ranged from 21 to 40 years. We found that mid-vital capacity flow ratio (mean ± SD) was 0.72 ± 0.19 in men and 0.77 ± 0.18 in women. The coefficient of variation of the mid-vital capacity flow ratio was 23 percent for men and 23 percent for women. The 95 percent confidence limits for the mid-vital capacity flow ratio were 0.65 to 0.79 for men and 0.70 to 0.84 for women. Maximum inspiratory pressures (mean ± SD) were 129 ± 30 cm H2O in men and 91 ± 16 cm H2O in women, not significantly different from previous studies. Normalizing maximum inspiratory flow for maximum inspiratory pressure did not reduce the coefficient of variation, which became 29 percent in men and 30 percent in women. We conclude that the range of mid-vital capacity flow ratios is wide, and it cannot be reduced by standardizing it for maximum inspiratory pressure.

The use of maximum expiratory and maximum inspiratory flow-volume curves for the diagnosis of upper airway obstruction was first described by Jordanoglu and Pride,† subsequently by Miller and Hyatt.‡ The latter authors introduced the use of the ratio of maximum expiratory to maximum inspiratory flow at 50 percent of vital capacity (mid-vital capacity flow ratio) to differentiate between a fixed and variable (extrathoracic and intrathoracic) upper airway obstruction. Since then, the mid-vital capacity flow ratio has been used to diagnose upper airway obstruction in a number of diverse diseases, such as tracheal stenosis,§ asthma,‖ and, most recently, obstructive sleep apnea.¶

Nevertheless, if we examine the sources from which the reference values of the mid-vital capacity flow ratio were derived, surprisingly few studies have been done.¶†‡§ The studies in which the mid-vital capacity flow ratio was found to be quite variable, with the coefficient of variation (defined as the percentage ratio of standard deviation to the mean) ranging from 23 to 30 percent. One reason for this variability may lie in the heterogeneity of the subjects studied; little or no information as to the age, gender, and smoking history was provided. Another possible reason is variable effort during the generation of maximum inspiratory flow-volume curves, which would introduce variability in the measurement of maximum inspiratory flow.

In the present study, we examined these factors by (1) selecting a well-defined group of young male and female healthy nonsmoking adults, and (2) by attempting to standardize the maximum inspiratory flow by maximum inspiratory pressure.

Materials and Methods

We studied 60 young healthy adults, 30 men and 30 women. Their ages ranged from 21 years to 40 years. None had any history of respiratory disease, and all were lifelong nonsmokers.

In all subjects, we measured maximum inspiratory and expiratory flow-volume curves using a dry rolling-seal spirometer (Cardio-Pulmonary Instruments 220) equipped with an X-Y recorder (Hewlett-Packard 7045A) and a timer to give the forced expiratory volume in one second (FEV1). Three reproducible curves were required, and ones with the highest expiratory and inspiratory flows at 50 percent of vital capacity were selected for analysis. From the flow-volume curve, we obtained forced vital capacity (FVC), FEV1/FVC, maximum expiratory (Veexp) and maximum inspiratory (Veins) flows at 50 percent of vital capacity and calculated the mid-vital capacity flow ratio (Veexp/Veins).

Maximum inspiratory pressures were measured using a standard mouthpiece and a pressure transducer (Validyne) located just distal to the mouthpiece and connected to it via a 20-gauge needle. After inhaling to total lung capacity (TLC), the subjects were instructed to exhale to near residual value (RV) and then asked to inhale maximally against an obstructed airflow. Three such maneuvers were performed, and the subjects were coached to improve the effort. The best (most negative) value of maximum inspiratory pressure (MIP) was used for analysis.

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RESULTS

The characteristics of the subjects and the results of pulmonary function are shown in Table 1. We note that none of the subjects had evidence of obstruction of the lower airways (as manifested by normal values of FEV/FVC ratio and normal expiratory flow rates when referred to VC). Women had significantly lower VC than men (p<0.001) and significantly higher expiratory flow (when expressed in VC/sec); V_{exp} was 1.0 ± 0.2 VC/sec (mean ± SD) for men and 1.2 ± 0.2 VC/sec in women (p<0.01). Inspiratory flow was similar in women (1.6 ± 0.3 VC/sec) and in men (1.5 ± 0.4 VC/sec).

Table 2 summarizes the maximum inspiratory pressures, calculated values of the mid-vital capacity flow ratios (V_{exp}/V_{ins}), and the ratios obtained after standardizing inspiratory flow for maximum inspiratory pressure (V_{exp}/V_{ins}MIP). There was no significant difference in the mid-vital capacity flow ratios between men (0.72 ± 0.19) and women (0.77 ± 0.18). The 95 percent confidence limits for the mid-flow ratio were 0.65 to 0.79 for men and 0.70 to 0.84 for women. Coefficient of variation was 28 percent for men and 23 percent for women. When inspiratory flow was standardized for MIP, the mid-vital capacity flow ratio became 90 ± 26 for men and 71 ± 22 for women, and this difference was statistically significant (p<0.01); however, the coefficient of variation remained essentially unchanged at 29 percent for men and 30 percent for women.

Maximum inspiratory pressures were significantly higher in men (129 ± 30 cm H2O) than in women (91 ± 16 cm H2O; p<0.001). We found no significant correlation between the maximum inspiratory flow and MIP for women; linear regression analysis showed that for women the correlation coefficient was r = 0.13; however, for men the correlation coefficient was highly significant (r = 0.62; p<0.001). When linear regression analysis was carried out for the whole group, the correlation coefficient was statistically significant (r = 0.65; p<0.001).

DISCUSSION

There are few reported measurements of the normal mid-vital capacity flow ratio in healthy individuals in the literature. In this study, we have established the standard reference values for the mid-vital capacity flow ratios in a large group of normal subjects. While similar measurements have been performed previously, the subject groups were not well defined with respect to age, gender, smoking history, and pulmonary function.2,16,18 We hypothesized that one reason for the large variability of the mid-vital capacity flow ratio found in the previous studies may be due to the nonhomogeneous population studied by these investigators. In the present study, we attempted to remedy this by selecting a well-characterized group of subjects. An important feature of this group is their relatively young age and complete absence of smoking history or any other pulmonary disease.

Similar to Miller and Hyatt,4 we found that men have lower mid-vital capacity flow ratios than women. Despite a carefully selected group of subjects, our study also demonstrated significant variability in the mid-vital capacity flow ratio (Table 3), with the coefficients of variation between 20 and 30 percent. The actual values of the mid-vital capacity flow ratio measured by us are somewhat lower than in the previous studies, perhaps reflecting the difference in the studied population, as discussed previously, and the differ-

Table 1—Characteristics of Subjects and Pulmonary Function Data*

<table>
<thead>
<tr>
<th>Data</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subjects</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Age, yr</td>
<td>30 ± 5</td>
<td>27 ± 5</td>
</tr>
<tr>
<td>VC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>5.4 ± 9</td>
<td>3.8 ± 0.5</td>
</tr>
<tr>
<td>Percent of predicted</td>
<td>104 ± 12</td>
<td>96 ± 10</td>
</tr>
<tr>
<td>FEV/FVC, percent</td>
<td>0.83 ± 0.07</td>
<td>0.87 ± 0.04</td>
</tr>
<tr>
<td>Inspiratory V-exp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L/sec</td>
<td>7.7 ± 1.4</td>
<td>6.1 ± 1.1</td>
</tr>
<tr>
<td>VC/sec</td>
<td>1.5 ± 0.4</td>
<td>1.6 ± 0.3</td>
</tr>
<tr>
<td>Expiratory V-exp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L/sec</td>
<td>5.3 ± 1.1</td>
<td>4.6 ± 1.0</td>
</tr>
<tr>
<td>VC/sec</td>
<td>1.0 ± 0.2</td>
<td>1.2 ± 0.2</td>
</tr>
</tbody>
</table>

*Mean ± SD.

Table 2—Mid-Vital Capacity Flow Ratios and MIP*

<table>
<thead>
<tr>
<th>Data</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP cm H2O</td>
<td>129 ± 30</td>
<td>91 ± 16</td>
</tr>
<tr>
<td>Mid-vital capacity flow ratio</td>
<td>0.72 ± 0.19</td>
<td>0.77 ± 0.18</td>
</tr>
<tr>
<td>Normalized mid-vital capacity flow ratio</td>
<td>90 ± 26</td>
<td>71 ± 22</td>
</tr>
</tbody>
</table>

*Mean ± SD.

Table 3—Published Values for Mid-Vital Capacity Flow Ratio

<table>
<thead>
<tr>
<th>Reference</th>
<th>No. of Subjects</th>
<th>V-exp/V-ins</th>
<th>Coefficient of Variation, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miller and Hyatt4</td>
<td>20</td>
<td>0.91</td>
<td>23</td>
</tr>
<tr>
<td>Men</td>
<td>16</td>
<td>0.99</td>
<td>23</td>
</tr>
<tr>
<td>Women</td>
<td>15</td>
<td>0.90</td>
<td>30</td>
</tr>
<tr>
<td>Botman et al16</td>
<td>20</td>
<td>0.57</td>
<td>30</td>
</tr>
<tr>
<td>Owens and Murphy18</td>
<td>30</td>
<td>0.72</td>
<td>28</td>
</tr>
<tr>
<td>Present study</td>
<td>30</td>
<td>0.77</td>
<td>23</td>
</tr>
</tbody>
</table>

Maximum Flow Ratios in Young Healthy Adults (Hoffstein et al)
ence in the methodology. In the previous studies, flow-volume loops were measured using the body box, which may result in higher $V_{\text{exp}}$ than in our study using the spirometer to record changes in pulmonary volume. Since most of the clinical laboratories use spirometric, rather than plethysmographic, flow-volume curves, we decided for the spirometric method, in spite of the well-known gas compression artifact.

Having found just as large variability in the mid-vital capacity flow ratios as in the previous studies by other investigators, we further hypothesized that it may be possible to reduce this variability by taking into account the effort exerted by the subjects in generating maximum inspiratory flow. Because maximum inspiratory flow is dependent on effort, we attempted to quantitate the degree of effort exerted by our subjects, as well as to ensure that maximum effort was attained, by measuring maximum inspiratory pressures.

The values of maximum inspiratory pressures obtained in the present study fall within the range of measurements quoted in the literature.4,8 We found that for men, MIP was 129±30 cm H₂O, while for women, MIP was 91±15 cm H₂O. Review of the literature indicates that for men, published values of MIP range from 89 to 146 cm H₂O, while for women the range is from 63 to 113 cm H₂O. As discussed by Smyth et al.,4 comparison between different published studies must be approached with caution due to differences in the methodology. We believe that the maximum inspiratory pressures measured in our group of subjects reflect primarily their motivation, rather than other factors such as fast transients, lack of inspiratory leak, or use of cheek muscles against closed glottis.

After standardizing the mid-vital capacity flow ratio by MIP, we found that the variability remained unchanged, and the coefficient of variation for the standardized flow ratio remained 29 percent for men and increased to 30 percent for women.

This may be in part due to the fact that MIP is a static measurement and does not represent the driving pressure responsible for generating inspiratory flow at 50 percent of VC. In addition, it was measured at RV, instead of at mid-vital capacity; the reason for measuring at RV was to compare it with other studies employing similar techniques. Furthermore, MIP reflects muscular strength, rather than the driving pressure which causes maximum inspiratory flow; however, we reasoned that a relationship between MIP and $V_{\text{ins}}$ exists so that the higher the MIP, the better the effort in the given person during maximum inspiratory flow, and the higher the $V_{\text{ins}}$. Failure to reduce the variability of the mid-vital capacity flow ratio by normalizing it for MIP may be due to the rather remote relationship between MIP and maximum inspiratory flow, as illustrated by the lack of correlation between these two parameters in women; however, in men, even though we found a significant correlation between $V_{\text{ins}}$ and MIP, the coefficient of variation for the mid-vital capacity flow ratio remained high. This implies that other factors may be important in determining the flow ratio, such as maximum expiratory flow, tracheal area, and tracheal compliance.4

In summary, we have established reference values of the mid-vital capacity flow ratio for healthy young adults. We found that this flow ratio is highly variable and that the variability cannot be reduced by standardizing it for MIP. We therefore conclude that the reliance on the flow ratio alone in diagnosing upper airway obstruction is unjustified. The entire flow-volume loop must be visually examined in order to decide whether upper airway obstruction is present.

REFERENCES

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99:696-702

Thoracic Imaging, 1987
The Society of Thoracic Radiology will present this annual postgraduate course February 16-19 in Orlando, Florida, at the Wyndham Sea World. For information, contact R. Dawne Ryals, PO Box 920113, Norcross, GA 30092-0113 (414:641-9773).

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The Lung Association of Montana will present this conference February 22-25 at Big Sky Resort, near Yellowstone National Park. For information, contact Mr. Earl W. Thomas, ALA of Montana, 825 Helena Avenue, Helena, MT 59601 (406:442-6556).