Relationships between the Maximum Voluntary Ventilation and Various Expiratory Flow Rates*

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The interrelationships between different ventilatory testing procedures and the factors which influence these tests have been studied previously. If these tests have any causal relationships, they must be influenced by common factors. We have attempted to find the level of the fast vital capacity curve where maximal correlation between expiratory flow rate and maximum voluntary ventilation occurs. The significance of such a correlation can then be speculated upon in the light of ventilatory mechanics. A review of the pertinent literature is also included.

METHODS

The records of a previous study were re-examined. The population was comprised of 31 men and women volunteers aged 20-35 years. Doctors, laboratory personnel, secretaries, and nurses were included in the sample. Each subject was free of respiratory and cardiac disease and all were in good health.

Records were analyzed by delineating the total expiratory volume into ten component parts each constituting 10 per cent of the vital capacity. The slope of each 10 per cent increment of the vital capacity was measured to give us ten individual expiratory flow rates for each subject. TheMVV's were correlated first with the EFR's of the first 10 per cent increment of the VC for the entire sample. Subsequently, correlation coefficients were calculated for MVV versus EFR at each of the ten VC segments. Graphs were constructed to portray the variation of correlation (between MVV and EFR) at each position in the vital capacity curve. A second set of graphs was constructed to show the variation of correlation coefficients calculated between EFR's (at each 10 per cent increment) and percentage-of-predicted-MVV. This second set of graphs was superimposed upon the first. These graphs were constructed separately for each sex (See graphs 1 and 2).

That segment of the VC at which peak expiratory flow occurs was determined for each individual. Then the mean level at which peak EFR occurs was calculated for the entire group and separately for each sex. The mean level at which half-maximal EFR is achieved was similarly determined. The mean percentage of the VC expired in the 0.5 second and 0.75 second intervals was calculated from the sample (Table 1).

RESULTS

For normal men, MVV and EFR correlated best when approximately 85 per

<table>
<thead>
<tr>
<th>Sex</th>
<th>Number</th>
<th>Mean MEFR</th>
<th>at Per Cent VC</th>
<th>0.5 Sec EFR</th>
<th>at Per Cent VC</th>
<th>0.5 Sec Time</th>
<th>at Per Cent VC</th>
<th>0.75 Sec EFR</th>
<th>at Per Cent VC</th>
<th>0.75 Sec Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>15</td>
<td>269.3 LPM</td>
<td>21.0</td>
<td>201.9 LPM</td>
<td>60.6</td>
<td>0.54 sec</td>
<td>64.0</td>
<td>78.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>16</td>
<td>524.6 LPM</td>
<td>21.2</td>
<td>218.3 LPM</td>
<td>63.2</td>
<td>0.48 sec</td>
<td>59.2</td>
<td>76.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|          |        |           |                |             |               |              |               |             |               |              |
|          |        | 21.1      | 61.9           | 61.6        | 77.7           |               |               |             |               |              |
cent of the VC had been expelled. This transpired within the expiratory reserve volume toward the expiratory end-segment. At this level \( r = +0.68 \). Two separate levels of greatest correlation were present in women. At 35 per cent of the VC (expired) MVV and EFR have a correlation of \( r = 0.74 \). At a level of 75 per cent of the VC (expired) \( r = +0.75 \).

For men, the mean peak EFR was 525 liters per minute and for women it was 369 liters per minute. Men accomplish their peak EFR after a mean volume of 21.2 per cent of the VC has been expired. Women accomplish this with 21.0 per cent of the VC expired. Half-maximal EFR's were found after a mean of 59.2 per cent and 64.0 per cent of the VC had been expired in a mean period of 0.48 seconds and 0.54 seconds in men and women respectively. Therefore, approximately 62 per cent of the VC is expired by the time the EFR has fallen to half of its peak volume and this occurs in about 0.51 seconds.

Half-second EFR's showed mean values of 218 and 202 liters per minute after 63.2 per cent and 60.6 per cent of the VC had been expired in men and women respectively. Therefore, about 62 per cent of the VC is expired within the first half-second interval. This supports reported observations that one-half maximal EFR is achieved in the first half-second of maximal expiration. Mean 0.75 second EFR's occurred after 77.7 per cent of the VC was expired.

**DISCUSSION**

Correlation of MVV with maximal EFR would be remarkable when we take into account the variability of influence exerted by different factors upon the MVV. Factors such as: (1) training and endurance of the subjects, (2) pulmonary elastic resistance, (3) the weight, elastic resistance, muscular strength and tonus of the thorax, (4) the type of breathing and its frequency, (5) the integrity of the upper and

![Figure 1: A comparison of the segmental flow rates correlated with the per cent of maximum breathing capacity (dotted line) for normal men (upper graph) and for normal women (lower graph). The curves indicate the variation of correlation between the MBC and MEFR at each position of vital capacity (see text). The abscissa is expressed as correlates ("r")]. All subjects were between 20-35 years of age.
lower respiratory airways, and finally (6) the motivational level of the subject, all influence the performance of the subject and his results in the determination of the MVV.

Because of this variety of influences upon the MVV more than mere statistical correlations are required to link the MVV and other testing procedures. A more meaningful relationship exists when a common factor similarly influences two tests. Therefore, we have examined our data to determine whether such a common factor might be suggested by the statistical evidence. This will be discussed later.

Previous investigators have advanced prediction formulae for MVV based upon the relationship of MVV to timed vital capacity (TVC). Relationships of MVV to various space EFR's or between MVV and VC have also been reported. Leuallen and Fowler have proposed that the mid-maximal expiratory flow rate be employed because it is clinically meaningful. The flow rate of the middle 50 per cent of expired volume is considered by these authors to be the most important clinical measure of ventilatory status in patients whose primary disability stems from obstruction. The figures derived from our own study indicate that the mid-maximum EFR of Leuallen and Fowler is a rough indication of the half peak EFR in normal individuals which may give good empirical evaluation of ventilatory status. However, our data indicate that the peak EFR occurs normally after only 21 per cent of the VC is expired which would fall in the segment which was discarded by Leuallen and Fowler.

The MVV has been approximated by an empirical equation whereby MVV (estimated) = 60 x 0.5 second expiratory capacity. There are other such equations. Kennedy suggests that the MVV uses the first 0.75 second increment of the forced VC and he assumes that this coincides with a respiratory rate of 40 per minute with inspiratory and expiratory segments equal in time. If we accept this (despite the questions raised by the studies of Bernstein and Kazantzis) each complete breath can be calculated to require 1.5 seconds for 40 rapid breaths in one minute. Therefore, MVV = 40 x 0.75 second expiratory capacity. This is substantiated by the work of Stuart-Harris and Hanley in which a correlation of MVV and 40 x 0.75 second expiratory capacity (or EFR) is presented with “r” = +0.8023.

Such excellent correlations are not unexpected in light of the fact that about 77.7 per cent of the VC is delivered in the first 0.75 seconds. Therefore, if we rewrite the above equation then MVV = 40 x 77.7 per cent VC or MVV = 31.1 VC. Since 62 per cent of the VC is delivered in the first 0.5 seconds of rapid expiration, then Miller and associates' original formula can be rewritten as MVV = 60 x 62 per cent VC or MVV = 37.2 VC. These two formulae differ by a factor of about 16 per cent and so both formulae should give reasonably close results.

Guillet used a prediction formula for prediction of MVV in which MVV = 30 x one second expiratory capacity which is reducible to 30 x 83 per cent VC or MVV = 24.9 VC. Each of these three formulae gives values for MVV which fit best at differing rates of respiration.

Such equations should suffice for maximum voluntary ventilation at low respiratory rates. At high rates, MVV is more difficult to predict accurately even when the respiratory rate and the "swept fraction" of Bernstein and Kazantzis and D'Silva and Kazantzis are multiplied. In order to circumvent such difficulties, Miller and colleagues postulated a formula of MVV = 100 x 0.3 second expiratory capacity. This formula represents an effort to estimate an optimal value of MVV at high respiratory rates. They have further modified the three pre-existing formulae for precision of MVV at lower rates: MVV = 0.5 second expiratory capacity x 53; MVV = 0.75 second expiratory capacity x 46; MVV = 1.0 second expiratory capacity x 41.
Such formulae can be rewritten as follows: MVV = 53 × 62 per cent VC = 32.9 VC; MVV = 46 × 77.7 per cent VC = 35.7 VC; MVV = 41 × 83 per cent VC = 34.0 VC.

An average of the rewritten forms of these latter three equations gives MVV = 34.2 VC.

At a respiratory rate of 60 per minute, Bernstein and Kazantzis report a swept fraction of 57.7 per cent. The swept fraction x respiratory rate therefore equals 57.7 per cent VC × 60 or MVV = 34.6 VC. This is remarkably close to Miller's figures actually differing by only 1.2 per cent. We conclude from this that any prediction formula (no matter how many different factors are involved) which reduces to a vicinity of MVV = 34.4 × VC (for respiratory rates of 40-60 per minute) will give accurate estimations for normal subjects. At higher respiratory rates an increasingly greater discrepancy occurs between predicted and observed due to a greater role played by the volume loss per breath due to flow reversal.

The MVV has been correlated with the VC in studies by Gilson and Hugh-Jones ('"r"^2 = +0.826). Lyons and March derived a correlation coefficient of +0.76 when relating MVV to maximum EFR. A relationship between MVV and half maximum EFR has been discussed but does not seem to be firmly established, and such a relationship was not indicated in this study. Review of Graphs 1 and 2 reveals insignificant correlations for MVV versus the approximate one-half maximum EFR ("r"^2 = +0.54 and +0.50 for men and women respectively).

No correlation between MVV and EFR could be found for men subjects early in the forced expiration curve. However, such a relationship is found in women. This early portion of the forced VC curve is affected more by variations in intra- and extrapulmonary elastic resistance and is also considered to be completely dependent on effort.\(^{15,16,18}\) We would therefore expect variations in the chest wall strength to influence MVV greatly in early forced expiration. Such variations would also be expected to influence the MEFR or peak flow derived early in expiration. Such a common effect was found in women only for reasons which are entirely open to speculation.

However, late in forced expiration there is a considerable degree of correlation for both sexes. It is unusual that MVV and EFR should correlate well in the VC at a flow segment which is not even part of the swept fraction of the VC (i.e., at a position in the VC which is not involved in the excursions utilized in the MVV). This may reflect the large degree of influence of the lower air passages upon both the MVV and the end-expiratory segment. The work of Stuart and Collings\(^{15}\) indicates that MVV may be more strongly influenced by viscous resistance than has been previously thought. Fry and others\(^{8,10-18}\) indicate that the rate of airflow expressed low in the vital capacity is strongly influenced by the patency and viscous resistance of the lower airways and is in part effort independent. We therefore postulate that in the sample studied, lower airway resistance played a considerable role in governing MVV, since some of the best correlations of MVV and EFR were found at that region where EFR is affected by the viscous resistance of the lower air passageways. The work of Butler and Arnott\(^{9}\) strongly supports such a hypothesis since they state that at volumes of 25 per cent or less of the unexpired vital capacity, the work of breathing is mainly directed at overcoming viscous resistance.

We must conclude that though tracings obtained from a fast VC have been analyzed for MEFR, scant attention has been paid to flow rates occurring near the end of the VC. Courmand and his associates\(^{4}\) long ago discounted any possible value in the end-expiratory flow rate, but the recent studies of Fry and his co-workers\(^{5,15}\) have demonstrated its potential value.
SUMMARY

(1) Data from a previous study were reanalyzed to determine where in the VC best correlations could be found between MVV and EFR. The best correlations were generally found between 15 per cent and 25 per cent of the unexpired VC—low in the VC—for both sexes. This correlation occurs at a respiratory level where more than 75 per cent of the expiratory volume has been delivered and where the resistance of the lower air passageways strongly influences airflow. Fair correlations were also found at a level at which 35 per cent of the VC had been exhaled (for women only).

(2) The studies of correlation between half-maximum EFR and MVV are not conclusive. The MVV is best related to the swept fraction and respiratory rate with respect to prediction of expected MVV. Most prediction formulae are reducible to an approximate formula of MVV=34.4 x VC for respiratory rates between 40 and 60 per minute.

(3) The MVV is dependent upon many factors and is test of over-all ventilatory mechanics, whereas the MEFR is not dependent upon many variables. It is suggested that the lower airway resistance plays a relatively greater role in determining MVV than has been heretofore appreciated.

ACKNOWLEDGMENT: The helpful aid and suggestions toward the work and the preparation of this report rendered by Dr. Harold A. Lyons is acknowledged.

REFERENCES


3 Stuart-Harris, C. H. and Hanley, T.: Chronic Bronchitis, Emphysema and Cor Pulmonale, J. Wright, Bristol, 1957.


Two cases of Marfan's syndrome are reported. The physical signs, such as arachnodactyly, ophthalmologic lesion, as well as congenital heart disease were present in both cases. Surgical treatment was carried out under extracorporeal circulation with mild hypothermia. One patient died postoperatively by unknown reason.


PRESTENOTIC MYCOTIC ANEURYSM IN COARCTATION OF AORTA

Intravenous angiocardiography readily demonstrated a prestenotic mycotic aneurysm above the point of coarctation of the aorta in an infant and a ruptured post-stenotic mycotic aneurysm in a child with coarctation of the aorta. Excision of the prestenotic mycotic aneurysm and the narrowed segment of the aorta with end-to-end anastomosis was curative. The other case was more complicated and required replacement of the blood, resuscitative measures for cardiac arrest, and repair of the aorta with a homograft after excision of the ruptured poststenotic aneurysm and the site of the coarctation of the aorta.


MASS CYTOLGIC DIAGNOSTIC EXAMINATIONS IN EARLY DIAGNOSIS OF BRONCHIAL CARCINOMA

There are no reports in the literature of cytologic examination of the sputum as a method of mass examination for the detection of bronchial carcinoma. The author carried out such examinations in men above 40 years of age registered at the tuberculosis dispensary because of pulmonary symptoms. A total of 537 persons were examined and followed up for three years. The sputum examinations were repeated three times by Papanicolaou method. Normal cytologic findings were recorded in 289 patients. Paratypia of the cells of various degree was noted in 142 cases, i.e., pulmonary tuberculosis, sputum positive, 39 cases; pulmonary tuberculosis, sputum negative, 80 cases; silicocarcinosis, 10 cases; convalescence after pneumonia, 11 cases; lung abscess, one case; metastatic pulmonary deposits in the lungs, one case. Neoplastic cells were found in six cases. The patients were admitted to the Medical Academy Hospital and in five, primary bronchial carcinoma was found, and in one, carcinoma of the epiglottis was found.


INJECTION OF MICROSHERES OF DIVINYLBENZENE

In 15 animals, a lowered cardiac output was produced by injection of microspheres of divinylbenezene into the coronary arteries. A great improvement in blood pressure and cardiac output, measured by cardio-green dilution curves, was produced by oxygen ventilation at 3 atmospheres absolute pressure.