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DYNAMIC SPIROMETRY STUDIES IN PATIENTS WITH LUNG DISEASE

IV. Ventilatory Capacities obtained from Forced Expirograms and from Maximal Voluntary Ventilation¹ of various Frequencies¹

By

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Several studies have shown a good correlation between forced expiratory capacities of various time durations (FEV) and volumes obtained from maximal voluntary ventilation tests (MVV). (4, 8, 10, 43, 52, 67, 90). The ventilatory parameters are easily studied from single breath expiratory and inspiratory tracings, which are the elements composing the MVV.

In the present study frequencies and volumes obtained in MVV_F were compared with those achieved at a fixed rate of forty per minute (MVV₄₀). The forced expiratory volume in one second (FEV_{1.0}) was correlated to MVV₄₀ in patients with broncho-pulmonary diseases; the latter study was briefly reported in *Nordisk Medicin*, 1960:63:374.

MATERIAL

A. In the comparison between ventilation tests with free rate, MVV_F, and with a fixed rate of 40/minute, MVV₄₀, 66 patients with various bronchopulmonary diseases were studied. Seventeen of the patients had generalized airways obstruction.

¹ For terminology see page 330.

References after article no. VI.

The patients were divided in two groups, each consisting of 33 subjects. The average ages in the two groups were 53 years (range 29–75) and 46 years (range 27–67). In one group MVV_{40} was made as the first test and in the other group MVV_F was the first. In the latter group three subjects had made MVV_{40} on a previous admission one year earlier, while the rest had never performed any MVV test.

B. For regression of MVV_{40} to $FEV_{1.0}$, the values from 52 females and 110 males were used. The mean age in the female group was 47 years (range 21–84), in the male group 50 years (range 19–74 years). More than $\frac{1}{3}$ of the patients had generalized airways obstruction and $\frac{1}{3}$ had pulmonary tuberculosis. Twenty-seven subjects had tumours, 6 granulomatous or fibrotic pulmonary diseases, and the rest had other intrathoracic affections. The $FEV\%$ values in the female group were 34–99 % (mean 71 %) and in the male group 26–92 % (mean 61 %).

METHOD AND PROCEDURE

The *forced expiratory spiograms*, FES, were obtained with the spirometers and methods which were reported in paper I. The maximum voluntary ventilation, MVV , was made after 4–5 FES. The maximal volumes were recorded.

MVV_{40} was obtained by breathing maximal tidal volumes for about 15 seconds to the beats of a metronome, giving a breathing rate of 40 breaths per minute. The subject was helped into the rhythm by the test conductor, who shouted "IN" and "OUT" and beat with the arm in sight of the patient. When the patient could follow the rhythm, 2–4 MVV tracings were made with some rest between. Usually the subject had no difficulty in following the metronome rate.

MVV_F was obtained 2–4 times with the subject breathing for 15 seconds as fast and as deeply as he could. No conductance or exhortation was given during the performance, as this would not result in a true free rate.

A test of *maximal expiratory pressure*, MEP, was made,

as a possible parameter of respiratory muscular strength. The subject blew maximally in a mouth-piece used for the Wright Peak Flow Meter (91). The mouth-piece was attached to a brass fitting, which was provided with a small leak to make closure of the glottis impossible (82). The aneroid manometer attached was calibrated against a mercury manometer. In four trials, the largest value kept for more than one second was recorded.

CALCULATION

That part of the MVV tracing corresponding to 10–15 seconds was selected, where the largest and most even excursions were found. The inspiratory volumes were measured by means of a transparent ruler and added. The ATPS¹-volumes were converted to BTPS² values by multiplying with the constant 1.1 (22).

Standard methods were used for calculation of sample regressions and correlation coefficients. See Snedecor, Chapter 7 (83). Level of significance: $P < 0.05$.

RESULTS

A. The frequencies chosen in *MVV* performed with free rate, MVV_F , are shown in Table 1. The average rate was 28, range 17–44. The true breathing rate in MVV_{40} in 25 controlled subjects averaged 40.2, with a scatter between 38–43 breaths/minute. Regardless of the order of the tests, the voluntary selected mean rate was thus lower than 40. The difference in breathing rates gave a *significant difference in ventilatory volumes* with greater values for MVV_{40} , $P < 0.001$.

B. The regressions for $MVV_{40}/FEV_{1.0}$ are seen in Figs. 1 and 2. The regression line for males (Fig. 1) crosses the X-axis close to zero ($MVV_{40} = 1.9$ litres). For the females the regression line is steeper and crosses the X-axis at the value

¹ Ambient Temperature, Pressure, Saturated with water.

² Body Temperature and Pressure, Saturated with water.

TABLE 1
Comparison between volumes obtained in MVV_F and MVV_{40} .
66 patients with broncho-pulmonary disease.

Order of measurements	No. of subjects	FEV ₀ %	"Free rate" breaths/min.	MVV_F Litres BTPS	MVV_{40} Litres BTPS
MVV_{40} first	33	69	28	62.5*	76.6*
MVV_F first	33	73	29	64.9†	74.0†

* † $P < 0.001$.

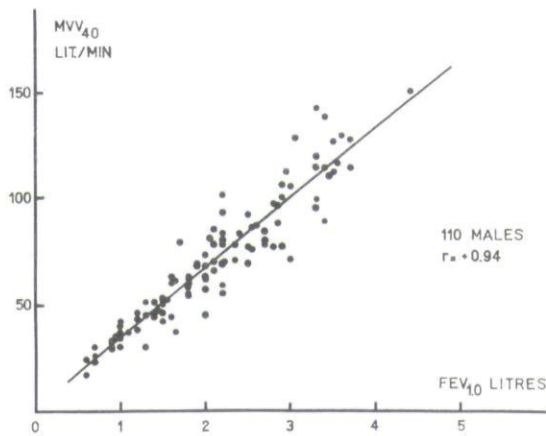


Fig. 1.
 MVV_{40} plotted against $FEV_{1.0}$ in male patients.
Regression equation and correlation coefficient (r):
 $MVV_{40} = 32.7 \times FEV_{1.0} + 1.9$
 $r = +0.94$

$MVV_{40} = 13.4$ litres (Fig. 2). The coefficient of correlation for the males was $+0.94$, for the females $+0.89$. Patients with pure obstructive and pure restrictive ventilatory impairment fell in the same area.

The MVV_{40} for the *male* patients can be roughly predicted from the $FEV_{1.0}$ by multiplying it by 33; the difference from the regression formula is then between -4% and -0.02% for $FEV_{1.0}$ volumes of 1-4 litres.

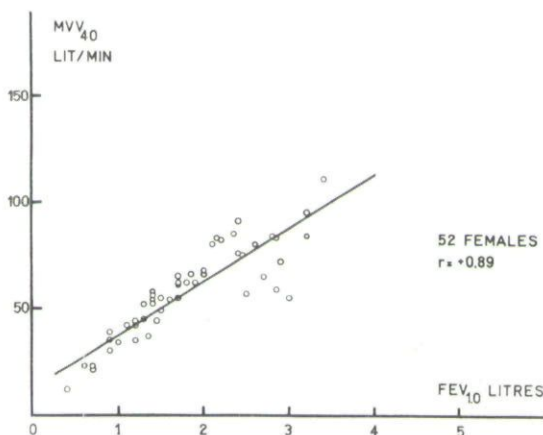


Fig. 2.

MVV₄₀ plotted against FEV_{1.0} in female patients.
Regression equation and correlation coefficient (r):

$$\text{MVV}_{40} = 24.5 \times \text{FEV}_{1.0} + 13.4$$

$$r = +0.89$$

For the *female* patient group a multiplication of FEV_{1.0} by 2.5 and addition of 13 litres gives a rough estimate of MVV₄₀; this will result in an error of from 0 % to +1 % for FEV_{1.0} volumes of 1–4 litres.

DISCUSSION

A. In the present study of *Maximal Voluntary Ventilation* with free rate, the patients chose an average breathing rate of 28–30/minute. Average frequencies recorded in other studies have been in the vicinity of 40/minute but with large inter-individual and intra-individual differences (9, 54, 86). *Miller et al.* thus found the mean “free” frequency for females to be 90 and for males 103 breaths/minute in a normal group; the rate averaged 74 in an obstructive group and 95 in patients with restrictive ventilatory impairment (67). These subjects might have been coached to high rates “on training” or during the test.

With high internal or external inspiratory resistance the inspiratory time increases, which may prevent fast rates when

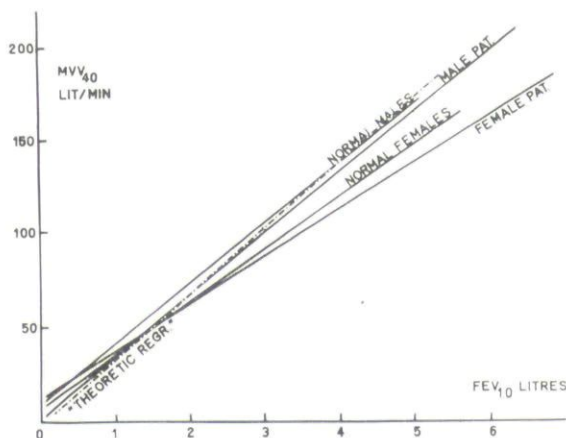


Fig. 3.

Regression lines for normal males and females according to *Birath et al.*, and for male and female patients from this study.

Broken line represents "Theoretical" regression.

using older types of spirometers with high flow resistance and heavier bells (61).

B. *Correlation between MVV_{40} and $FEV_{1.0}$.* In the present study the correlation coefficients for $MVV_{40}/FEV_{1.0}$ in the male and female groups were $+0.94$ and $+0.89$ respectively. *Birath et al.* found correlation coefficients of $+0.91$ for normal males and $+0.89$ for normal females (10), the two regressions being different. In Fig. 3 this normal material can be seen together with the present material. Thus, using a fixed frequency, the correlations are equally good for normal subjects and patients with lung disease. The correlation coefficient for $MVV_F/FEV_{1.0}$ is considerably lower (43).

Bernstein and Kazantzis found a high correlation between forced expiratory volumes, corresponding to the time necessary for expiration during each breathing cycle at the respiratory rates, and the total volumes recorded at that breathing rate; they obtained $r = +0.93$ when correlating $FEV_{1.0}/MVV_{30}$ and $r = +0.90$ for $FEV_{0.6}/MVV_{50}$ (8). *Miller et al.* correlated $FEV_{0.50}$, $FEV_{0.75}$ and $FEV_{1.0}$ to MVV obtained with

"free" rate (67). The correlations between MVV_F and $FEV_{0.50} \times 60$ ($R = +0.922$) and $FEV_{0.75} \times 40$ ($r = +0.917$) were "significantly better" than for $FEV_{1.0} \times 30$ ($r = +0.909$).

Thus, a high correlation factor is always obtained when relating FEV to MVV. To obtain maximal fitting, however, all the subjects should use the same breathing rate in the MVV. Ideally, MVV should be compared to the FEV obtained with the time index corresponding to the rate used in the MVV (8). This index is dependent upon the time relationship between inspiration and expiration; the former is considered prolonged to a greater extent in the MVV than the latter when internal air flow resistance is increased (3). A correlation between forced inspiratory volumes (FIV) and MVV thus might be a better choice at high internal flow resistance or at high rates.

The ability to reveal airways obstruction seems equal for the $FEV_{1.0}$ and MVV_{40} . If other segments of the single forced ex- or inspirograms are studied, more information about the physical properties of the airways may be gained (49, 56).

A theoretical formula for predicting MVV_{40} from $FEV_{1.0}$.

During the MVV test the "swept fraction"—i.e., the part of the vital capacity used as tidal volume—decreases with faster breathing rates (8). At a rate of 30/minute about 85 % of the FVC is normally used as tidal volume; at 80/minute only 45 % is used. The reduction of the part used is mainly in the expiratory reserve.

The time used for expiration is about half that of the total cycle. Then MVV_{30} would be the "ideal" MVV corresponding to $FEV_{1.0}$. At this rate the tidal volume used by non-obstructive subjects is 85 % of the FVC; the upper 2 % of the forced expirogram is not used, but the first 85 % of the FVC can be considered to represent the swept fraction (4, 8, 29).

The tidal volume in MVV_{40} would correspond to $FEV_{0.75}$. The "swept fraction" in normals at this rate is 75 % of the FVC; the upper 5 % of the forced expirogram is not used, but the first 75 % of the FVC may be considered to represent the swept fraction. The tidal volume used in MVV_{40} is that part of $FEV_{1.0}$ expelled during 0.75 seconds or $75/85 \times FEV_{1.0}$.

There is presumably increased "flow reversal" loss of volume at higher respiratory frequencies due to deceleration occurring between inspiration and expiration (4). At 30 breaths per minute the loss is negligible, and at 40 per minute the loss in normals is about 0.09 litres/breath, which must be subtracted

from the recorded $FEV_{1.0}$. At high resistances the flow reversal loss tends to be smaller.

Then, the "theoretical" formula for predicting MVV_{40} from $FEV_{1.0}$ would be:

$$MVV_{40} = 40 \times (75/85 \times FEV_{1.0} - 0.09)$$

or

$$MVV_{40} = 35.2 \times FEV_{1.0} - 3.6.$$

A comparison between the volumes obtained according to this formula and the regression lines actually obtained is shown in Fig. 4. The formula resembles the regression line obtained in the male group in the present study, $MVV_{40} = 32.7 \times FEV_{1.0} + 1.9$.

Muscular strength—a possible cause of the different regressions for $MVV/FEV_{1.0}$ in males and females.

Recently *Birath et al.* found a difference in the regression of $MVV_{40}/FEV_{1.0}$ for normal males and females similar to the one reported here (10). On the assumption that this difference might be due to a difference in muscular strength, the maximal expiratory pressures in males and females were compared.

Eight pairs of males and females, each pair with equal $FEV_{1.0}$, were compared. Six of the $FEV_{1.0}$ pairs were larger than 1.60 litres, the point where the male and female regression lines cross. The males were selected as having much higher maximal expiratory pressure (MEP) than the corresponding females. The difference in MEP between the groups was 7 cm. of mercury. See Table 2. The MVV_{40} recorded in the male group were significantly larger than MVV_{40} for the females ($P < 0.025$). The male mean MVV_{40} was 5 % larger, the female 9 % smaller than the average volume estimated from the theoretical formula.

The difference in MVV_{40} obtained in males and females with equal $FEV_{1.0}$ but with different MEP supports the suspicion that the MEP may be an index of muscular power as exerted during maximal breathing. McGregor found a significant correlation between MEP and MVV_F in pulmonary diseased subjects, while *Matheson et al.* found no relationship between these two parameters in normals (60, 62). Campbell

considers muscular strength to be no limiting factor for the Maximal Breathing Capacity (MBC) without considerable muscular weakness, and doubts that the MEP is a reliable index of muscular strength. A reflex mechanism elicited from the thoracic wall or the lung may inhibit the applied forces when the resulting effort grows too large (17).

TABLE 2
Recorded and predicted volumes of maximal voluntary ventilation.

8 males and 8 females with the same forced one-second volumes but different maximal expiratory pressures.

Male subjects							Common		Female subjects					
Subj.	Age	EEV%	MEP cmHg	MVV ₄₀ Rec.	MVV ₄₀ Est.	FEV _{1.0} Lit.	MVV ₄₀ Theor.		Subj.	Age	FEV%	MEP cmHg	MVV ₄₀ Rec.	MVV ₄₀ Est.
RJ	69	69	10.5	118	105	3.15	107.3		Be	44	78	3.0	95	78
TM	76	76	10.0	66	57	1.74	57.6		VF	57	57	3.5	58	56
BK	26	53	12.0	37	38	1.16	37.2		AA	54	75	5.0	45	40
LP	43	55	6.5	47	44	1.28	41.4		AN	73	73	2.5	34	43
SJ	47	82	11.0	97	70	2.09	70.0		RN	51	72	5.2	68	63
AW	48	72	17.0	61	72	2.15	72.1		SL	66	72	5.0	54	63
GL	48	71	13.0	60	76	2.26	75.9		EA	51	73	4.5	52	69
HJ	61	76	8.0	81	76	2.26	75.9		LS	54	81	3.0	76	57
Mean	52	69	11.0	70.8*	67.2	2.01	67.2			56	73	4.0	60.2*	58.6

* Diff. $P < 0.025$.

Females with the same FEV_{1.0} as males have a lower FVC than the males, and with the same FEV% they have a larger airway resistance than males (31). The elastic breathing work in females thus must be greater, because they use a greater part of their vital capacity as tidal volume during the MVV than males with corresponding tidal volumes. This may be a further cause of the differences in regression lines noted.

SUMMARY AND CONCLUSION

In sixty-six subjects with various broncho-pulmonary diseases the MVV_F was lower than the MVV_{40} , regardless of the order of the tests. The average breathing rate chosen was 28/minute.

In 110 males and 52 females with various bronchopulmonary disorders a highly significant correlation was found between MVV_{40} and $FEV_{1.0}$. The regression was somewhat different in the two sexes. The relation between the MVV and the maximal expiratory pressure was studied. The difference in muscular power may be part of the cause of the lower MVV obtained by females, even with the same $FEV_{1.0}$ as males.

The good correlation between MVV_{40} and $FEV_{1.0}$ theoretically makes the two parameters of comparable value. Clinically, however, $FEV_{1.0}$ seems to be the preferable as being more easy to repeat and as having a low variation in contrast to the more tiresome MVV test with its lower reproducibility. The good correlation can be valuable for revealing malingerers.

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