

From the Asthma Poliklinik der Freien Universität Berlin West, Germany.

THE VALUE OF SIMPLE LUNG FUNCTION TESTS IN ASTHMATIC DISEASE

By

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During recent years there has been an increasing interest in lung function studies, and many procedures have been investigated. The more complicated tests include pressure/volume relationship, residual air, diffusion capacity and others and require much apparatus and highly skilled technical assistance. This paper deals with the simpler tests which are within the scope of the small hospital or the general practitioner.

The tests compared in the present investigation were the vital capacity, the one second forced expiratory volume ($FEV^{1.0}$, or Tiffeneau), the quotient $\frac{FEV^{1.0}}{\text{vit. capacity}}$ and the peak flow rate (or pneumometer value).

METHODS

The *vital capacity* (v.c.) was recorded on a Benedict-Roth recording spirometer in which the breathing resistance was kept at a minimum by reducing friction, wide breathing tubes and low resistance valves. The recording drum had a 2 speed arrangement (15 mm and 300 mm/min). O_2 was continuously supplied to the spirometer bell through a flow meter which was adjusted to admit the amount of O_2 used by the subject. In order to record the v.c., the subject was asked to exhale fully but not forcibly from tidal air level, and then to breathe normally again. A few breaths later or, in some cases immediately, he was asked to inhale fully. Expiratory reserve, tidal air and inspiratory reserve were added up to give the v.c. This mea-

surement was repeated several times at intervals of 1–2 min., until the 3 last values lay within a range of not more than 150 cc ($\pm 1.5 - \pm 5\%$). The mean of these 3 values was used.

The $FEV^{1.0}$ was recorded with 300 mm/min drum speed. The subject was asked to inhale fully and then to exhale as quickly and forcibly as possible. Often several attempts were necessary to fulfil this requirement. If the (expiratory) forced v.c. was required, the expiration was not broken off after one second but continued to maximum expiration. In some patients maximum flow could not be achieved right at the beginning of the first second. This could be easily detected, because the expiratory line did not begin as a straight line but reached its greatest slope only after a fraction of a second. In these cases the $FEV^{1.0}$ was measured from the beginning of the greatest slope.

The quotient $\frac{FEV^{1.0}}{v.c.}$ was calculated in the present investigation with the expiratory forced v.c., because most of the earlier investigators have used this measurement. As will be shown later, the expiratory (forced) v.c. leads to errors, and it therefore appears preferable in future to use the ordinary v.c. in this quotient. The scatter of the quotient in normals was small. Five replicate determinations were made in each of 15 healthy subjects, 8 men and 7 women, mostly laboratory workers. The mean of these subjects varied between 96 % and 73 %, and the standard deviation between 1.7 and 3.6. In 14 of the 15 subjects the standard deviation varied between 1.7 and 2.8.

The *peak flow rate* was measured with the Wright peak flow meter in litres/min. Here also a certain amount of training is required until a subject learns to exhale not fully but as quickly as possible. We have investigated the peak flow of 17 apparently healthy subjects. The absolute values varied apparently with age, sex and body build, between 315 and 640 l/min, as was to be expected from the literature. (Wright & McKerrrow, 1959, Thomson & Hugh-Jones, 1958, Tinker, 1961, Shephard, 1962).

Even when the peak flow was measured up to 10 times at

TABLE 1
Comparison of peak flow and pneumometer readings.

Normal subjects no.	Peak flow 1/min.		Pneumometer 1/min.	
	Mean of 3 readings		mean of 3 readings	
1	585		514	
	610	602	630	622
	610		642	
2	420		378	
	400	413	408	400
	420		414	
3	670		690	
	680	683	690	690
	700		690	
4	460		480	
	490	482	456	466
	495		452	
5	320		270	
	325		270	
	330	330	330	285
Asthmatics no.	345		270	
	140		162	
	160	152	192	174
6	155		168	
	290		318	
	290	292	330	328
7	295		336	
	85		120	
	80	82	108	110
8	80		102	
	160		138	
	140	145	138	142
9	140		150	
	460		480	
	465		456	
10	460	466	468	468
	480			
	140		96	
11	130	142	96	99
	155		105	

TABLE 2

Comparison of (expiratory) forced vital capacity and inspiratory vital capacity.

	Before Inhalation of isoprenaline aerosol N = 45	After 36
F.E.V. mean ($\bar{X}$) lower than insp. v.c. mean by	9.3 %	2.8 %
Standard deviation	6.4	4.7
Standard error of mean	0.96	0.78
P	<0.001	<0.01

different times of the day or on different days of one week in the same subject variations were sometimes considerable. In one trained subject, for instance the peak flow varied within 1 hr between 415 and 470 l/min. In view of this, one must expect that in patients, whose condition is less stable, the scatter will be greater still. In our patients the peak flow measurements were repeated at intervals of about 30–60 sec., until stable values resulted. If this could not be achieved, the mean of the three highest readings was used.

The pneumometer of Wyss & Hadorn (Hadorn, 1942; Wyss, 1950) seems to test the same part of the expiration as the peak flow meter, but it is read in liters/sec. Eleven subjects—normal and asthmatics—breathed with both instruments and the results were compared. They were not identical but very similar (Table 1)¹.

In order to compare the lung function in various degrees of asthmatic obstruction, a small number of patients with mild asthma received a 3 % histamine aerosol in a closed circuit spirometer (Herxheimer, 1949); this is known to increase the obstruction (Curry 1946, Herxheimer 1952). As soon as the vital capacity fell and the necessary measurements had been made, 2 % isoprenaline was nebulized into the circuit immediately relieving the obstruction. The measurements were then repeated.

¹ I am obliged to Professor K. Holldack of the Krankenhaus Neukölln, Berlin (West) who kindly permitted me to use his pneumometer for this comparison.

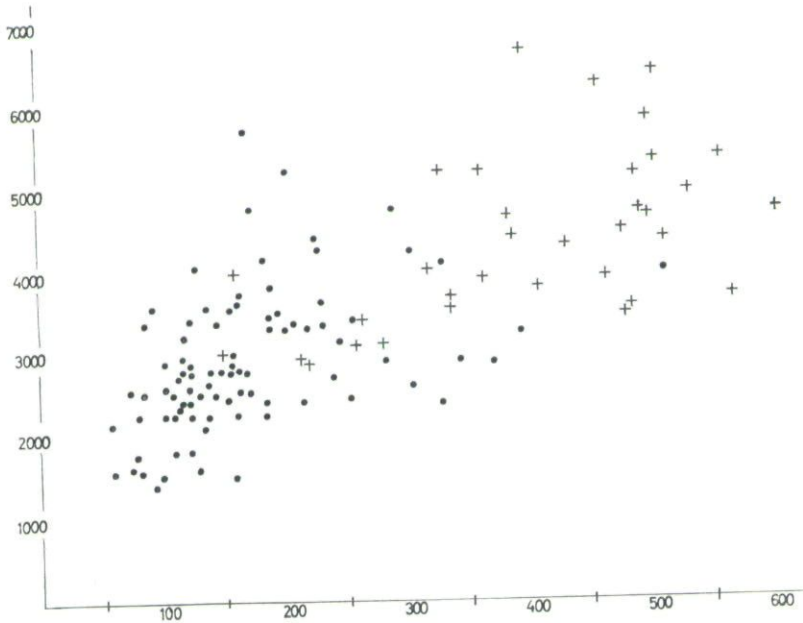


Fig. 1.

Relationship of peak flow and vital capacity in severe chronic asthma (●) and mild acute asthma during the free interval (+).

RESULTS

Inspiratory Vital Capacity and (Expiratory) Forced Vital Capacity.

A comparison of both values is given in table 2. It will be seen that the forced expiratory values are significantly lower than the inspiratory v.c. Under the antispasmodic influence of isoprenaline inhalation most of this difference disappears. The inspiratory v.c. is also shown in fig. 1 where it is plotted against the peak flow.

The values are given separately for patients with moderate to severe chronic asthma and for mild intermittent¹ asthma

¹ Patients with severe chronic asthma were those who continuously had bronchial obstruction with reduction of lung function. In mild intermittent asthma there were long free intervals. There were no children among the patients, and no patients of very high or low body length or weight. Their measurements and

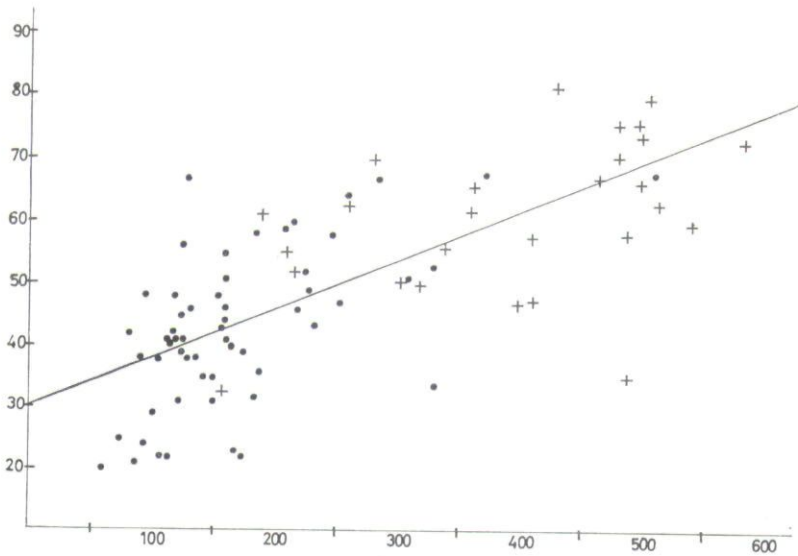


Fig. 2.

Relationship of FEV Quotient and Peak Flow in severe chronic asthma (●) and mild acute asthmatics in their free interval (+).

during the asthma-free interval. They show that in most severe patients (●) the v.c. is reduced, whilst in the milder cases (+) it lies within the normal range. There are, however, a few chronic patients with a large v.c. or peak flow obviously within the normal range.

Quotient $\frac{FEV^{1.0}}{v.c.}$. Fig. 2 shows the quotient in all the patients with chronic asthma (●) and mild intermittent asthma (+). Most values are the mean of several determinations. It can be seen that all chronic asthma patients lie below 70 %, and even in the intermittent cases very few (6) are within the normal range above 70 %. There are some asthmatics with a quotient as low as 20 %, and a line fitted through the points of the graph shows that the quotient increases by as little as 8 % for every 100 l/min peak flow.

Peak flow. Fig. 1 shows the peak flow in relation to the v.c.,

ages are not given, as the normal scatter of the v.c. is very great and that of the peak flow not sufficiently known.

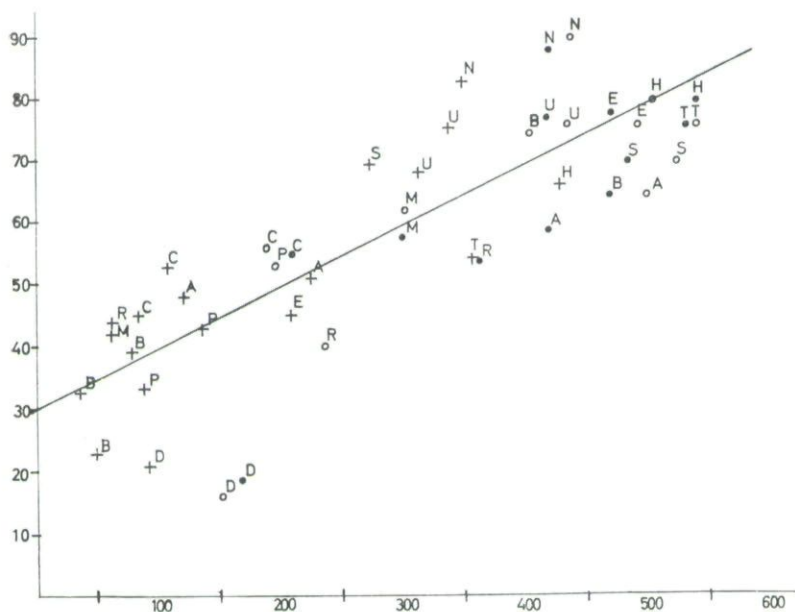


Fig. 3.

Relationship between Peak flow and FEV quotient in a number of asthmatics at rest (o), after histamine (+) and after isoprenaline (●). In some of the subjects, for instance C, D, N, R, S, U, the quotient is hardly affected although the peak flow is. Letters indicate subjects. In some instances several experiments with the same subjects are plotted, as no histamine obstruction of uniform degree could be achieved.

figs. 2 and 3 in relation to the FEV quotient. Only a few patients, most of them mild asthmatics, have normal peak flows; the majority of the chronic patients have peak flows in the neighbourhood of 150 l/min.

The changes in $\frac{FEV^{1.0}}{v.c.}$ and peak flow with varying degrees of obstruction are shown in fig. 3. It can be seen that, with severe histamine obstruction, the peak flow becomes very small. The quotient, nevertheless, often changes very little, and sometimes hardly at all. If a line is drawn through the points of this graph, it runs at the same angle as in fig. 2, showing that for every 100 l peak flow the average FEV percentage changes by only 8 %. This means that the peak flow is a much more

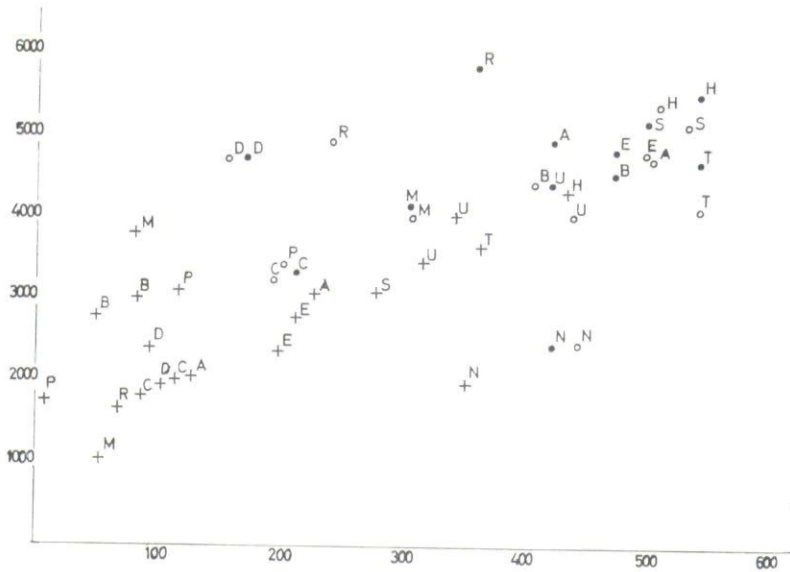


Fig. 4.

Relationship between Peak Flow and vital capacity in a number of asthmatics at rest (o), after histamine (+) and after isoprenaline (●). In some subjects (D,R) the v.c. is more affected by the changes than the peak flow.

Letters indicate subjects.

sensitive indicator of a change in lung function than the FEV quotient.

DISCUSSION

The purpose of such simple tests as have been investigated is to find out whether ventilation is unimpaired or whether obstruction to the free flow of air to the lungs exists. Previous observers have confined themselves to a comparison of methods in a number of different normal subjects and patients. It seemed reasonable to investigate the sensitivity of these methods by varying the condition of the same patient. The drastic changes which can be induced by histamine and isoprenaline in the same patient have been found most suitable for comparing measurements of ventilation.

Of the tests investigated the v.c. is the oldest. Its diagnostic value is impaired by 2 disadvantages: One is the large scatter

of its normal values which are, as a rule, calculated from weight, height or surface area. The v.c. measured often differs enormously from the values so calculated, as it varies with length and shape of the thorax, state of training and age. A scatter of $\pm 20\%$ is not rare. I have examined a relatively untrained rugby player who weighed 70.0 kg and was 190 cm tall. His v.c. was 7700 cc which, if the v.c. were calculated from his body surface, is 40 % above the normal value. With such variations, it will be rarely possible to say whether the v.c. of a patient as measured is "normal". Only if it is observed over a period will it be possible to say that a certain volume is the normal one for this subject. It may then become a fairly accurate measure of increasing or decreasing obstruction.

The second disadvantage of the v.c. is that it does not measure the time required for a certain ventilated volume. If obstruction slows down airflow, a single expiration may take so long that the patient has an overpowering urge to take a fresh breath instead of utilizing his full v.c. This does not mean that measuring the v.c. is useless. Obviously, a large v.c. indicates a better function than a small one. A v.c. of 5000 ml will permit a one sec. breath of 1000 ml even with the minimum F.E.V. quotient of 20 %, and an asthmatic will be rarely in difficulties if he has a v.c. of 3500 or 4000 ml, which enables him to ventilate at least 20 l/min. Moreover, it is easy to see even on a slow drum whether there is delay in late expiration, for, in this case, the expiratory trace does not descend vertically but is curved in its last quarter, thus increasing the distance of its straight part to the following inspiratory trace which is always straight upwards. Thus, the recorded v.c. permits the diagnosis of expiratory slowing although not of its degree, and the recorded v.c. is therefore not a pure volumetric method.

On the other hand, the v.c. has certain advantages. The subject does not see his recording; he cannot guess whether his breathing volumes are greater or smaller than before, and his reaction to a given influence (for instance a drug) usually follows a specific time course which the patient never and the ex-

perimeter seldom can anticipate. In view of this, the method can be regarded as "blind". I have used it during the past 20 years as a measure of bronchial obstruction in numerous experiments on the influence of inhaled allergens, histamine, acetylcholine, antihistamines aminophylline and other bronchodilators (Herxheimer 1949, 1951, 1952). In all these experiments the v.c. has been shown to be a very sensitive measure of the ventilatory state of the lungs. It usually was also in agreement with the subjective sensation of the patients. A change in the v.c. of less than 5 %–6 % is not, as a rule, noticed by the patient, but greater changes are usually correctly commented upon as "easier" or "tighter". How quickly the v.c. responds to changing ventilatory conditions can be seen from the experiments with histamine and isoprenaline (fig. 4).

The $F.E.V.^{1.0}$ is a direct measure of the ventilatory capacity in relation to time. It increases and decreases with the v.c. *and in rough proportion to it*, (see Table 3), but it does not indicate bronchial obstruction unless it is very much reduced. In contrast, the quotient $\frac{F.E.V.^1}{v.c.}$ does not permit a conclusion about

the ventilatory capacity. The quotient may be as low as 20 %, and it may still be possible for the patient with a large v.c. to reach a very satisfactory minute volume of 30 ml. Some examples for this are included in fig. 2. On the other hand, the quotient is a very sensitive test for the degree of bronchial obstruction, as all chronic asthmatics and most mild asthmatics in their intervals have a decreased quotient (below 70 %). The quotient is therefore most useful for detecting an impairment of ventilation not easily shown by the vital capacity, namely a degree of bronchial obstruction which is not felt at rest but with exertion. It must not be forgotten, however, that the $F.E.V.^1$ is an artificial test, as a patient rarely will be compelled to exhale as forcibly as this test demands. It is possible that the expiratory force in itself increases bronchial obstruction and thus exaggerates the results. It appears that in spite of this disadvantage the quotient is a useful measurement complementary to the v.c. The $F.E.V.^1$ considered alone has no par-

ticular merits and can be omitted, as all the information derived from it can also be derived from the v.c. and the quotient $\frac{\text{F.E.V.}^1}{\text{v.c.}}$. This can be seen from table 3, in which the decrease of the forced expiratory v.c. and the F.E.V.¹ after histamine inhalation is compared. These decreases are of similar extent, particularly in the 4 subjects, in whom the histamine decrease of the v.c. was more than 60 % of the basal value.

TABLE 3
Histamine Experiments.

Subject	Expiratory forced vital capacity (ml)		F.E.V. ¹ (ml)		Decrease in % of	
	Before	After	Before	After	Expiratory forced v.c.	F.E.V. ¹
	Histamine		Histamine		After histamine	
A	4840	2500	3240	1270	48 %	61 %
		2560		1220	47 %	63 %
B	4290	2510	3675	980	42 %	73 %
	4470	1380	2900	450	69 %	84 %
C	3110	1700	1760	900	45 %	49 %
		1570		700	49 %	60 %
D	4770	1520	820	340	86 %	59 %
		1500		300	69 %	63 %
E	4770	2710	3640	1220	43 %	66 %
F	5320	4250	4265	2800	20 %	34 %
G	3970	930	2450	430	76 %	82 %
H	3230	1930	1710	520	40 %	70 %
I	4610	1550	1840	680	66 %	63 %
K	5110	2840	3600	1870	44 %	48 %
L	4240	3660	3230	1990	14 %	38 %
M	4190	3520	3190	2400	16 %	25 %

Although the quotient differentiates easily between the degrees of obstruction in different patients, it does not easily register changes in obstruction in the same patient. We have observed a number of patients whose v.c., peak flow and subjective condition have changed considerably without much change in the quotient. Sometimes, only drastic improvement

or deterioration cause it to change, as can be seen from the histamine and isoprenaline experiments plotted in fig. 3. But even here the change may remain within a range of 15 %. This relative constancy of the quotient has been described by Dulfano, Herschfus & Segal (1955), Thomson & Hugh-Jones (1958) and Shephard (1962) who comments on its lack of correlation with the peak flow. Thomson & Hugh-Jones believe that its change in serial observation would indicate improvement, but our histamine experiments confirm this for a few patients only, not for the majority.

Another disadvantage of the quotient is seen if it is calculated from the forced (expiratory) v.c. instead from the inspiratory v.c. The forced (expiratory) v.c. produces lower values (table 2). This phenomenon has been known for a long time; it has been described by Christie (1934) as "distension" phenomenon. More recently it has been explained by "air trapping". Some observers have come to the conclusion that the very high intrathoracic pressure in the course of a forced expiration closes some of the bronchi, particularly when the tissue structure of the lungs is weakened by emphysematous changes, and, by their closure, would prevent full expiration. There are 2 reasons why this explanation cannot be correct. First the phenomenon also occurs in young people with a short history of asthma, in whom structural changes as they occur in emphysema are highly improbable. Second, the phenomenon disappears under the influence of isoprenaline (Table 1). This shows without any doubt that the reduction shown by forced expiration is caused by active bronchial spasm, which is probably induced by the violent expiratory movement. This is confirmed by my earlier observation (Herxheimer, 1952) that forced expiration may affect bronchial tone in some patients for up to half an hour. One also frequently observes that violent coughing fits accompanied by high intrathoracic pressures cause an increase in bronchial spasm.

This side effect makes the forced expiratory v.c. an unsuitable procedure in subjects inclined to bronchial spasm, that is, in all patients with asthma, bronchitis or emphysema. It is

not quite certain whether the same disadvantage is present if the forced expiration lasts only one second or a little more. We have not sufficient evidence on this point. The full forced expiration, in any case, should be avoided. It is therefore suggested that the F.E.V.^{1.0} should be related to the inspiratory v.c. instead of to the forced expiratory v.c.

In contrast to the FEV quotient the *peak flow* appears to measure bronchial obstruction quantitatively. As with the quotient, all chronic asthmatics and most mild asthmatics in the asthma-free interval have a diminished peak flow, but this measurement also gives a useful estimation of the degree of the obstruction. As can be seen from the histamine and isoprenaline experiments (fig. 3), the range from 475 l/min to 100 l/min fully demonstrates the degree of change in obstruction. Compared with the F.E.V. quotient the peak flow increases by 100 l/min for every 8 % of the quotient. An increase by 100 l/min is far beyond its normal scatter as far as it is known and therefore signifies improvement, whilst an increase of 8 % in the F.E.V. quotient is, in our experience, of doubtful significance.

Whereas serial observations by the peak flow method are a useful measure of the changes in bronchial obstruction in the same subject, the peak flow values show a great variation from subject to subject (Wright & McKerrow, 1959). Tinker (1961) measured the peak flow of 462 men between 30 and 59 years and found an enormous scatter, the flows for the oldest group, for instance, lying between 200 and 700 l/min, 51 % of all values lying between 450 and 599 l/min. Thus it seems that the variability of individual peak flow values is at least as great as that of the vital capacity, and that it depends, perhaps, on the same factors, namely age, sex, height and shape of the chest, training and cooperation. A single measurement of the peak flow therefore, at present, permits the diagnosis of impairment of the ventilation as little as does the v.c., unless it is excessively low. A definite opinion on this, however, must be deferred until determinations for peak flow have been carried out on a very large scale.

Two other simple tests, the maximum breathing capacity and the mid-expiratory flow rate have not been included. The first which had been the fashion for a number of years has now been abandoned by many because it is an artificial measurement requiring a unusual degree of cooperation from the patient, and because it tends to aggravate bronchial obstruction. The mid-expiratory flow rate has been recommended by Leuallen & Fowler (1955), and a modification of it, the flow rate in the third quarter of expiration, by Franklin & Lowell (1961). There is one slight advantage in these flow-rates compared with the FEV¹, namely that they avoid the first small fraction of the first expiratory second; some subjects cannot manage to exhale right from the start at top speed; therefore their one second volumes include a first fraction with submaximal flow and are too small. This error can easily be avoided, if the one second expiration is measured by omitting the initial slow fraction, if any. The disadvantage of the mid-expiratory flow rates is that in patients with moderate disability the mid-expiratory flow may be slowed down out of proportion to their disability. This disproportion will increase towards the end of the mid-expiratory period: for during the last fraction of the expiration the flow decreases to almost nil (the slope becoming shallow) whether the bronchial obstruction is mild or severe. The measurement therefore loses what quantitative character it had during the first second and becomes purely qualitative.

SUMMARY

1. The simple lung function tests described in this paper investigate different functions. None of them gives a complete picture of lung function.
2. Those tests giving absolute volume values (all except the quotient $\frac{\text{FEV}^1}{\text{v.c.}}$) vary considerably with age, sex, height and shape of the thorax, training and cooperation of the subject. Normal values based on weight or surface area are therefore of little use.

3. The inspiratory vital capacity is a very sensitive measure of the ventilatory capacity. If it is recorded on a fast drum, it also shows expiratory slowing by obstruction. It is most useful for following up in the single subject changes in ventilatory capacity caused by environmental influences or by drugs.

4. The (expiratory) forced vital capacity is a useless test, because it causes additional bronchial obstruction in many patients. It thus gives an exaggerated picture of the bronchial obstruction quite apart from causing discomfort to the patient.

5. The one second forced vital capacity does not seem to have these disadvantages. It is a good measure of the subject's ability to ventilate sufficiently for moderate exertion. It does not permit any conclusion as to bronchial obstruction unless very low.

6. The quotient $\frac{FEV^1}{v.c.}$ is an excellent qualitative test for bronchial obstruction. Values over 70 % in chronic asthma have not been seen in this series, and they are rare even in the asthma-free interval of mild asthmatics. On the other hand, the quotient indicates little about the severity of the condition or about improvement or deterioration. Of 13 of our patients subjected to severe histamine obstruction, the quotient hardly decreased at all in five, a little more in four others, whilst vital capacity and peak flow fell sharply.

7. The peak flow appears to be a sensitive measure of bronchial obstruction. Its relation to the actual ventilatory capacity and its scatter must be explored further.

ACKNOWLEDGEMENT

The author is indebted to Dr. E. Stresemann for statistical advice.

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