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Errors in the measurement of vital capacity

A comparison of three methods in normal subjects and in patients with pulmonary emphysema

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Hutchison, D. C. S., Barter, C. E., and Martelli, N. A. (1973). *Thorax*, **28**, 584–587. **Errors in the measurement of vital capacity: a comparison of three methods in normal subjects and in patients with pulmonary emphysema.** Three methods of measuring the vital capacity have been compared in six normal subjects and in six with pulmonary emphysema, according to a randomized design. The methods were (*a*) the inspiratory vital capacity (IVC), (*b*) the expiratory vital capacity (EVC), and (*c*) the forced vital capacity (FVC).

In normal subjects, there was a small but significant difference between the methods. The residual standard deviation derived from analysis of variance was 94 ml (coefficient of variation 1.7%). A slight but significant rise in vital capacity with repeated effort was observed.

In emphysematous subjects, there was no significant difference between the IVC and EVC methods. The FVC gave values which were, on average, approximately 0.5 litre less than those obtained by the other methods. The standard deviation in all three methods was substantially greater than for the normal subjects.

The FVC is not a suitable method for the measurement of vital capacity in patients with pulmonary emphysema. The EVC is satisfactory, provided it is used with caution, but in practice the IVC is the preferred method.

Hutchinson (1846) defined the vital capacity as the volume of gas displaced from the lungs by the 'greatest voluntary expiration following the deepest inspiration', and although this is probably the method most commonly used, the procedure is not infrequently carried out in the reverse order. There seems no obvious reason why the two methods should yield differing results, provided that the manoeuvres are performed without undue speed. It has become common practice, however, to make the measurement at the same time as the forced expiratory volume, though this procedure may underestimate the true vital capacity in subjects with severe airflow obstruction (Gilson and Hugh-Jones, 1949).

In the present study, three variations on the measurement of vital capacity have been assessed: 1. the expiratory vital capacity, here abbreviated to EVC; 2. the inspiratory vital capacity or IVC; and 3. the forced vital capacity or FVC. The object of the study was to compare the three methods in normal subjects and in patients with pulmonary emphysema. A randomized design was used, provision being made for the detection of time related effects, such as fatigue or training.

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SUBJECTS AND METHODS

SUBJECTS The six normal subjects were healthy male members of the hospital staff, their ages ranging from 25 to 35 years. All were apparently free from pulmonary disease, with forced expiratory volume (FEV_1) and vital capacity within the expected normal range. Normal values were obtained from Cotes (1968).

The six emphysematous subjects (E1 to E6) all suffered from severe dyspnoea on exertion; in all six, attenuation of the peripheral pulmonary vessels (Laws and Heard, 1962) was observed on the chest radiograph, and the FEV_1 and the single-breath transfer factor for carbon monoxide (TF) were considerably less than the expected values (Table I). In patients E1, E3, E4, and E6, emphysema was associated with α_1-antitrypsin deficiency; these correspond to patients 4, 5, 7, and 6 respectively of a previous report (Hutchison *et al.*, 1971). The nature and purpose of the procedure were explained to each patient.

LABORATORY METHODS The spirometer conformed to

TABLE I

MEASUREMENTS OF PULMONARY FUNCTION IN PATIENTS WITH EMPHYSEMA

Patient	Age	FEV_1 (% predicted)	VC[1] (% predicted)	TF (% predicted)
E1	46	25	106	29
E2	57	24	75	25
E3	50	21	101	45
E4	39	14	65	12
E5	45	16	85	48
E6	52	21	97	21

[1] VC=vital capacity: mean of all values for EVC and IVC
Predicted values from Cotes (1968)

the design of Bernstein, D'Silva, and Mendel (1952). It was calibrated by displacement of air in steps of 1 litre from an accurately machined syringe and its response was linear over the range used. The record was inscribed in ink on squared paper fixed to a rotating drum, adjusted so that the initial horizontal and vertical reference lines were parallel to the grid-lines on the paper. The paper speed was 2 cm/sec during the performance of the FVC, and 0·2 cm/sec for the IVC and EVC. The deflections were measured to the nearest millimetre and converted to litres BTPS. One millimetre was equivalent to a volume of 44 ml.

The tests were performed with the subject seated. The mouthpiece was inserted during tidal breathing and the manoeuvre was closely observed to ensure that there was no leakage round the mouthpiece or noseclip. During each test the subjects were encouraged to give a maximal response.

The EVC was measured by a slow expiration after the deepest possible inspiration. The IVC was measured by a slow inspiration after the deepest possible expiration. The FVC was measured by expiration with maximal force after the deepest possible inspiration. The time interval between each test was two minutes in the normal subjects and three minutes in the emphysematous subjects.

FEV_1 was measured from the same spirogram as the FVC, the zero point for time and volume being obtained by extrapolation of the steepest part of the downward slope of the spirogram to a horizontal line through the maximum inspiratory plateau (American College of Chest Physicians, 1963). The transfer factor for carbon monoxide was measured by the single-breath method of Ogilvie, Forster, Blakemore, and Morton (1957), except that the breath-holding time was calculated as suggested by Jones and Meade (1961) and the alveolar volume was obtained from the simultaneous dilution of helium.

PLAN OF STUDY The study was carried out in 'sessions', each session consisting of nine 'tests', each test being one performance of either the EVC, the IVC or the FVC. The three types of test were each performed three times during one session, the order being determined on a Latin square basis.

The emphysematous patients completed one session only and so performed each type of test three times. The normal subjects each completed three sessions, separated by one to two weeks, and so performed each type of test nine times in all.

RESULTS

NORMAL SUBJECTS The mean values for vital capacity obtained by the three methods were very similar (Table II), and the standard deviations (within subjects) were small. Analysis of variance showed that there was a small but significant difference between the methods ($P<0·05$), and that there was a significant linear regression of volume on time ($P<0·01$), the values being greater towards the end of each session. There was no consistent rank order with respect to method, though the IVC was not the greatest in any subject.

TABLE II

VITAL CAPACITY (LITRES BTPS) MEASURED BY THREE METHODS IN NORMAL AND EMPHYSEMATOUS SUBJECTS

	No. of Sub-jects	IVC Mean	IVC SD	EVC Mean	EVC SD	FVC Mean	FVC SD
Normal	6	5·59	0·081	5·61	0·116	5·63	0·087
Emphysema	6	3·97	0·189	3·91	0·217	3·48	0·340

IVC, EVC, and FVC For definition see text.
BTPS=body temperature and ambient pressure, saturated
SD=within subjects standard deviation

EMPHYSEMATOUS SUBJECTS The means and (within subjects) standard deviations for the three methods are shown in Table II. The standard deviations for all three methods were significantly greater than in the normal subjects; this effect was apparently greater for the FVC, though the range of values was particularly large in one patient (E5).

Analysis of variance showed that there was a highly significant difference between the methods ($P<0·01$); there was no significant regression of volume on time. There was a significant patient-method interaction ($P<0·05$) showing that the differences between the methods were not consistent from patient to patient, an effect largely due to patient E3. The results in individual patients were therefore analysed in greater detail.

The values for the three methods in each patient are shown diagrammatically in the Figure. The rank order was more consistent than in the normal subjects, the IVC being the greatest (or equal greatest) and the FVC the smallest, in five subjects. The rank order was reversed in subject E3, though in this particular case there was no significant difference between the three methods.

In view of the apparent similarity between the IVC and the EVC, these two methods were compared by the *t* test in each emphysematous individual, no significant difference at the 5% level being

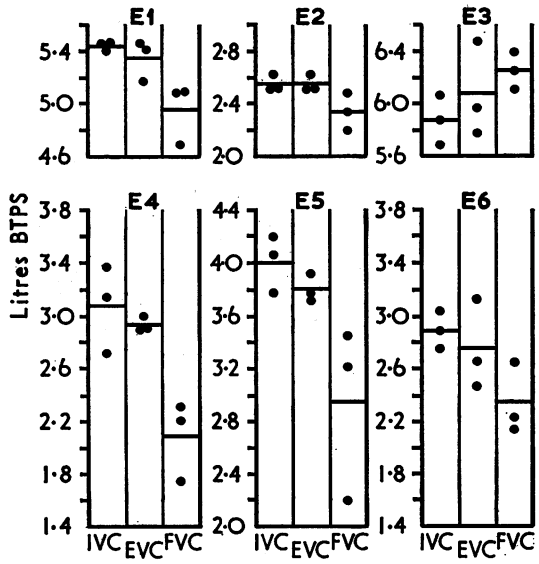

FIGURE. *Vital capacity measured by three methods in six patients with pulmonary emphysema. IVC=inspiratory vital capacity; EVC=expiratory vital capacity; FVC=forced vital capacity. Horizontal bar: mean.*

found in any subject. A *t* test was then carried out to compare the FVC with the pooled EVC and IVC; FVC was significantly smaller in all cases except E3, where no difference was found.

DISCUSSION

The most important finding to emerge from this study was the extent to which the FVC method may underestimate the vital capacity in patients with severe emphysema, when compared with either of the 'slow' methods, the IVC and EVC, the results of which were much alike. The reproducibility of all methods was poor in the patients with emphysema, as compared with the normal subjects. The discrepancies between the methods in normal subjects were very small and the residual standard deviation derived from the analysis of variance was 94 ml. This figure is very similar to that obtained by Gilson and Hugh-Jones (1949) and by Dawson (1966), and is not a great deal larger than the error of the method. A fourth variation in which the vital capacity is obtained from the sum of the separately measured inspiratory capacity and expiratory reserve volume has not been considered in this report.

The vital capacity has been measured in normal subjects by a number of authors in order to develop regression equations for the prediction of normal values. Needham, Rogan, and McDonald (1954) and Berglund *et al.* (1963) measured both EVC and FVC and chose the larger value in each subject. Kory, Callahan, Boren, and Syner (1961) measured vital capacity by all three methods but based their equations upon the 'slow' methods, having found a very high degree of correlation between the EVC and the IVC; these methods were not compared with the FVC, however. The FVC was used by Miller, Johnson, and Wu (1959) to establish normal values for the ratio of forced expiratory volume to vital capacity (FEV/FVC), which is widely used as an index of airflow obstruction. We are not aware that any systemic comparison of the three methods has appeared in the literature, but in normal subjects the results presented here suggest that the differences between the methods are relatively slight and that the use of the FVC as a measurement of vital capacity is not likely to lead to serious errors. In pulmonary emphysema, there would be little to choose between the IVC and the EVC provided that the latter test is not performed too quickly; in practice, however, this may be difficult to prevent, so that the IVC seems to be the preferable method if there is any possibility of emphysema being present.

The volume of gas within the lungs at the limit of inspiration (that is, at total lung capacity) is that present when the 'sum of the elastic recoils of the lung and of the thoracic cage is equal and opposite to the maximum inspiratory effort' (Cotes, 1968); the volume at the limit of expiration (residual volume) is determined by the balance between the forces maintaining airway patency (the recoil pressure and the intraluminal pressure) and the intrapleural pressure, which tends to produce airway closure. An increase in voluntary effort applied near to full inspiration may therefore increase the measured vital capacity but may actually reduce it when applied near to full expiration. During the FVC, the rapid imposition of a high positive intrapleural pressure may bring about closure of lung units which would otherwise remain patent, and it seems clear that neither the FVC nor the FEV/FVC can be valid or reproducible measurements in patients with pulmonary emphysema. A warning to this effect was given by Gilson and Hugh-Jones (1949), who pointed out that 'a very rapid expiration may give a figure for the vital capacity which is too low'. The warning was repeated by Gandevia and Hugh-Jones (1957) and again by Cotes (1968), who suggested that the IVC is the preferred method in patients with lung disease. The FVC continues to be widely used, however, particularly to estab-

lish the ratio FEV/FVC, and the assumption that the FVC is uninfluenced by airflow obstruction is not true of severe emphysema on the evidence of the present study. The validity of the FVC in other types of airflow obstruction, moreover, has yet to be demonstrated.

It has been common practice, following the example of Hutchinson (1846), to record the largest value from any series of successive measurements as the true vital capacity, on the ground that a lack of voluntary effort is the only limiting factor; Gilson and Hugh-Jones (1949) pointed out that by this procedure other sources of error were ignored, and that use of the mean value was therefore more logical. It is clear, furthermore, that in some circumstances an increase in voluntary effort may actually produce a smaller result. Because of the large standard error found in emphysema, even with the more satisfactory 'slow' methods, it might prove more useful to take the mean rather than the largest value as the final result, particularly as this is already common practice with other subdivisions of the total lung capacity.

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