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Characteristics of the Vitalograph spirometer

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The characteristics and performance of the Vitalograph dry spirometer were studied using the criteria suggested by the International Labour Organisation (I.L.O.) Report on the standardization of respiratory function tests in pneumoconiosis. Comparison was also made with the Bernstein spirometer. The recorder speed, activation volume, and accuracy of volume calibration and linearity comply with most of the suggestions in the I.L.O. Report. The combined resistance and inertia of the Vitalograph exceed the limits cited in the report, however, and are also greater than those reported for the Bernstein and other spirometers. Nevertheless, the Vitalograph calibrates well against the Bernstein for vital capacity and FEV_1 measurements made in normal subjects and in patients with obstructive airways disease. It is therefore suggested that it may be suitable for the assessment of forced expiratory volume and vital capacity in patients and normal subjects, or in population survey work. The fact that it is lightweight, portable, and robust is also an advantage.

The widespread use of the Vitalograph dry spirometer for assessments of ventilatory capacity in hospital patients, out-patients, or general practice surgeries (*British Medical Journal*, 1968) and population surveys (Lowe, Pelmear, Campbell, Hitchins, Khosla, and King, 1968), and the absence, as yet, of any published report on this patented instrument[3] led to this critical study of its performance. The investigation was undertaken along the lines suggested in the International Labour Organisation (I.L.O.) Report (Cotes, 1966) in connexion with proposals for the standardization of lung function tests. In particular, some aspects of the Vitalograph's performance were compared with those of the Bernstein low-resistance water-sealed spirometer (Bernstein, D'Silva, and Mendel, 1952). The two instruments are illustrated in Figures 1 and 2. Some comparisons of their dimensions and other physical characteristics are shown in Table I, which shows that the Bernstein spirometer achieves its high performance by eliminating inertia and resistance by the extremely small mass of its recording members and its large-bore tubing. The Vitalograph utilizes a different physical principle, compensating for the effects of inertia and resistance by spring forces controlling mass and mass movement.

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METHODS

RESISTANCE AND INERTIA EFFECTS The combined effects of the resistance and the inertia of the instruments were determined by measuring the back-pressure generated during the FEV_1 test at the 5-litre level. Pressure measurements were made at a known distance from the mouth during 20 FEV_1 manœuvres of the same healthy male subject. A Statham P23D6 strain gauge and a Hellige electromanometer were used for the recording.

RECORDER SPEED The same observer compared the time recorded on the trace during 30 consecutive FEV_1 tests, using a fast stop-watch (Smith's) accurate to within 0·01 second.

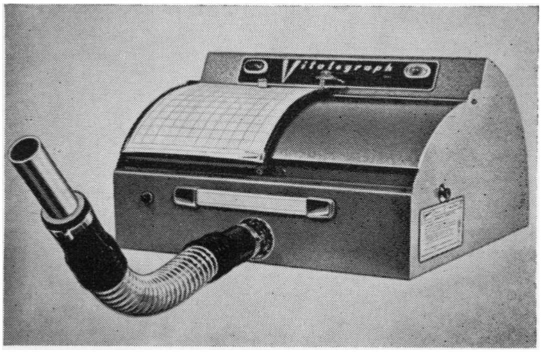

FIG. 1. *The Vitalograph spirometer.*

ACTIVATION VOLUME The minimum volume required to move the time scale was determined. Small volumes of room air were introduced into the instrument through an air-tight syringe or Wright's respirometer.

LEAKAGE TEST A 300-g. weight was attached to the base of the Vitalograph recording arm. The mouthpiece was occluded after introducing known volumes of air into the spirometer, and the rate of leakage was recorded.

BIOLOGICAL CALIBRATION Fifteen normal subjects and 15 patients with airways obstruction compared their vital capacities and FEV_1 on both instruments.

VOLUME CALIBRATION AND LINEARITY The Vitalograph was tested for accuracy of linearity and calibration over the range 0 to 6,000 ml. ATPS at 20° C., using the water displacement technique.

RESULTS

RESISTANCE AND INERTIA EFFECTS The pressures shown in Table II reflect the combined resistance and inertia encountered in each instrument. The dynamic backpressure at 3·5 cm. from the mouth using the Vitalograph spirometer exceeded 5 cm. H_2O during the initial rapid phase of a 5-litre FEV_1 manœuvre for up to 70 milliseconds. During

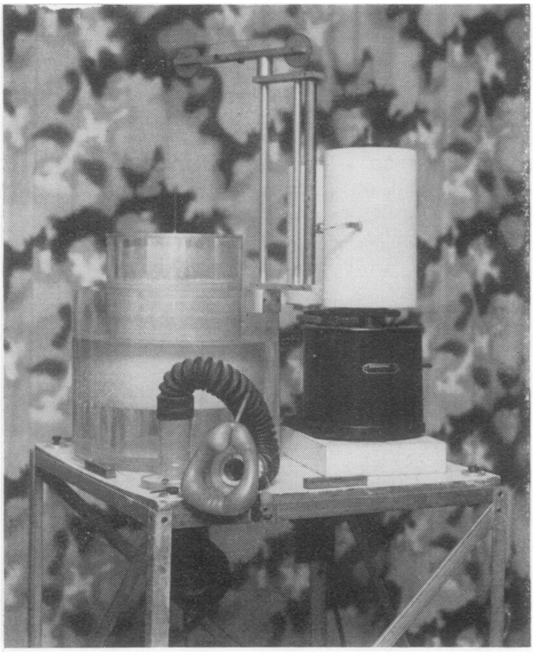

FIG. 2. *The Bernstein spirometer.*

TABLE I
SOME COMPARATIVE PHYSICAL DATA OF THE BERNSTEIN AND VITALOGRAPH SPIROMETERS

Specification	Bernstein	Vitalograph
Volume measuring member:	Metal bell	Wedge type plastic bellows
Material	Aluminium	Plasticized PVC
Wall thickness	0·3 mm.	0·254 mm.
Size	28·8 × 23·1 cm. diameter	33 × 18 cm., 6 gussets
Usable capacity	9,000 ml. BTPS	6,612 ml. BTPS
Weight	250 g.	171 g.
Inertia and acceleration:	No specific elimination	Elimination by spring forces, positive/negative acting
Counterbalance	200 g. weight	Initial tension 3/16 in. lb., fractional increase rate 5/8 in./lb.
Suspension	Thin cord, negligible weight	
Pulleys	2, each 3 × 60 mm. diameter	None
Pulley weight, each	22·5 g.	None
Moment of inertia	314 g./sq. cm.	Negligible initially, increasing in proportion to brake requirements of mass acceleration
Recording system:	Indirect-writing	Direct-writing
Driving unit	Synchronous geared motor and drum	Shaded pole synchronous motor and rack and pinion driven platform
Pen type	Ink pen	Inkless stylus
Pen friction	Negligible	Eliminated, 1 : 100 leverage
Recording paper	Continuous-feed mm.-sq. with good dimensional stability at average humidity levels	Calibrated 20 × 20 cm. waxed charts with exceptional dimensional stability over wide range of humidity and temperature levels; accuracy of ruling ± 0·127 mm.
Resonant frequency response at 2·8 l./cycle		Not measurable in this system; calibrated for single-breath, one-way operation
Linear up to	56 cycles/minute	
Linear +2% at	60–75 cycles/minute	
Linear +3% at	80–90 cycles/minute	
Overall size and weights:	With kymograph	With built-in recorder
Overall size	90 × 90 × 120 cm. height	39·5 × 38 × 24 cm. height
Weight (ready for use)	35 kg. (77 lb.)	5·6 kg. (12½ lb.)
Portability	Not portable	Fully portable

TABLE II
BACKPRESSURES DISPLAYING SPIROMETER INERTIA AND RESISTANCE AT FEV_1 OF 5 LITRES

Spirometer	Duration of Backpressure Greater than 5 cm. H_2O	Maximum Initial Back-pressure	Maximum Sustained Back-pressure
Vitalograph (3·5 cm. from mouth)	70 milliseconds	11·75 cm. H_2O	1·63 cm. H_2O
Bernstein (1·5 cm. from mouth)	0	4·9 cm. H_2O	0·68 cm. H_2O

the sustained phase, the static backpressure exceeded 1·5 cm. H_2O. Both pressure values were greater than those obtained with the Bernstein spirometer (Table II). It is interesting to note that they exceeded the values suggested by Cotes (1966)—namely, that backpressure should not exceed 5 cm. H_2O for longer than 30 milliseconds and after that should not be more than 1·5 cm. H_2O.

ACCURACY OF RECORDING SPEED Comparison of the time measured on the Vitalograph trace with that recorded on the stop-watch showed no significant difference. The mean difference of 30 readings was −0·017 second. The range of times was between 1 and 5·50 seconds, with a mean of 3·66 seconds as measured by a stop-watch. Thus the Vitalograph gives an infinitesimally lower reading of 0·017/3·66=0·0046%.

ACTIVATION VOLUME OF INSTRUMENT The minimum volume of room air required to activate the timing device with the release button depressed was repeatedly found to be 60 ml. This compared with 46 ml. allowed for on the volume scale, *viz.*, the thickness of the tracing. In a forced expiratory manœuvre the time interval required for displacing this activation volume is almost unmeasurable and therefore has no effect on the accuracy of the recorder speed.

LEAKAGE RATE During this particularly stringent test the leakage rate never exceeded 2 ml. over a one-second period from a 4-litre volume level.

BIOLOGICAL CALIBRATION No significant differences were obtained when 15 normal subjects and 15 patients with obstructive airways disease compared their FEV_1 and FVC on both spirometers (Figs 3 and 4). The values obtained with both instruments correlated well.

Biological calibration for the physiological indices an instrument measures is essential to ensure that the results obtained with it are comparable with those of other workers using different types of equipment. Whilst one would normally assess the biological calibration on a much larger population sample in relation to sex, age, and height, smoking habits, and exclusion of subjects with chest disease, our smaller sample confirmed the multiple regressions reported by Lowe *et al.* (1968) and can therefore be regarded as adequate for the purpose of this investigation.

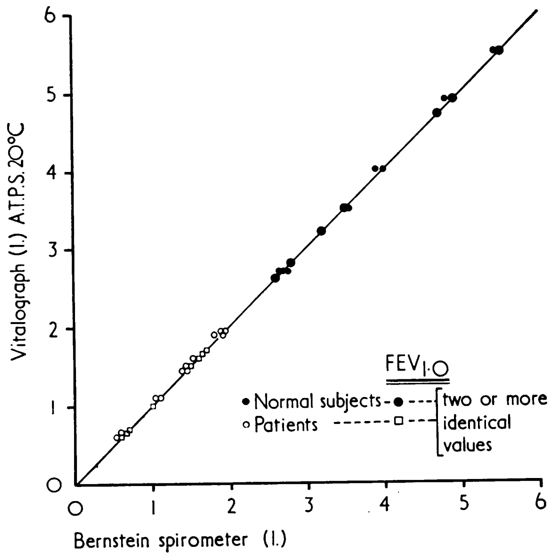

FIG. 3. *Comparison of FEV_1 measured by the Bernstein and Vitalograph spirometers.*

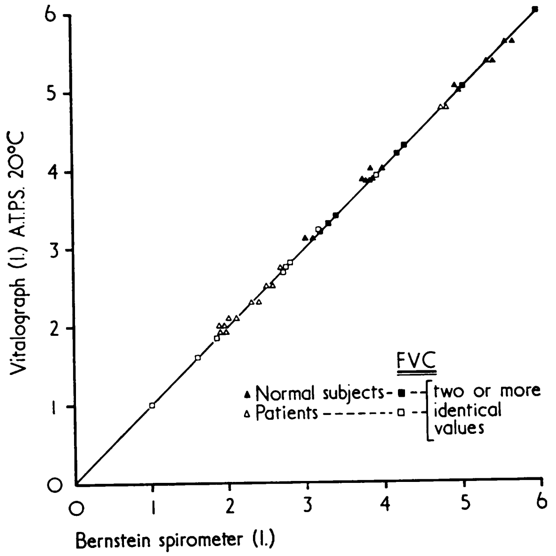

FIG. 4. *Comparison of the forced vital capacity measured by the Bernstein and Vitalograph spirometers.*

ACCURACY OF VOLUME CALIBRATION AND LINEARITY The Vitalograph was found to record displacement of air volumes in a linear manner over the entire measuring range tested and well within the limits of volumetric accuracy certified by the manufacturers (Fig. 5). Each Vitalograph spirometer is individually calibrated under standard conditions (ATPS at 20° C.) on to a precision-printed volume-time grid of a chart paper which in itself remains dimensionally stable, even with changing humidity. Since most conventional spirometers, even if of the same make, require different correction factors for expressing values measured by them at standard conditions, this practical feature of nil variability between Vitalograph instruments is a time and cost saving one when comparing data reported by other workers or when evaluating massive data collected during epidemiological, industrial, or other large surveys.

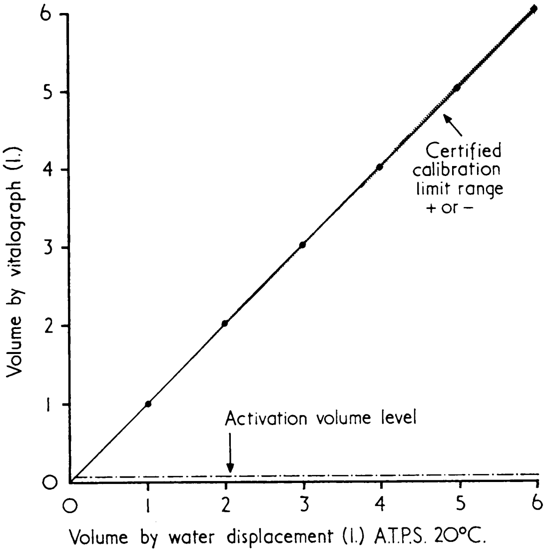

FIG. 5. *Volumetric calibration of the Vitalograph spirometer.*

DISCUSSION

These studies with the Vitalograph show that the recorder speed, activation volume, and accuracy of volume calibration and linearity comply with most of the suggestions for these made in the I.L.O. Report. The standard calibration with nil variability between instruments is an added advantage. The leakage rate under static conditions, even under heavy loading, was only 2 ml. over a one-second period, and so its effect on FEV_1 is likely to be negligible. Its combined resistance and inertia are greater than those recommended by Cotes (1966) and that reported for other portable spirometers by McKerrow, McDermott, and Gilson (1960) and Collins, McDermott, and McDermott (1964). They are also greater than those of the Bernstein spirometer. Nevertheless, the Vitalograph calibrates well against the Bernstein for vital capacity and FEV_1 measurements. This is not altogether surprising considering its compensating design, and, as Fry and Hyatt (1960) have shown, the FEV_1 is relatively insensitive to external resistance. The higher instrumental resistance and inertia of the Vitalograph probably make it unsuitable for measurement of expiratory peak flow, or even forced expiratory flow ($FEF_{200-1200}$) in spite of the manufacturer's recommendations. This higher resistance was not harmful to patients, for Vitalographs have been used to test over 2,000 patients in this laboratory without any barotrauma, as shown by pain or damage to eardrums, throat, or sinuses. Two possible sources of error have been encountered in practice: first, it is essential to ensure that the tubing fits snugly into the orifice receiving it in the instrument itself. Secondly, there may be creases between folds in the bellows which need to be blown out before use.

Thus the Vitalograph appears to be sufficiently accurate for the assessment of ventilatory capacity in patients, normal subjects, or in population survey work. In this connexion it is only fair to point out that its maximum excursion is about 6·6 litres (BTPS). This is adequate for all work on patients with chest disease and many normal subjects, but will not be large enough to include some fit young male subjects. It has several advantages over other spirometers in that it is robust, lightweight, and portable. It does not require water or ink but gives a permanent record should this be desired. In particular, it may be taken to the patient's bedside or carried around for survey work as well as being used in the laboratory.

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