

Evaluation of the turbine pocket spirometer

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ABSTRACT: A compact electronic spirometer, the turbine pocket spirometer, which measures the FEV₁, forced vital capacity (FVC), and peak expiratory flow (PEF) in a single expiration, was compared with the Vitalograph and the Wright peak flow meter in 99 subjects (FEV₁ range 0.40–5.50 litres; FVC 0.58–6.48 l; PEF 40–650 l min⁻¹). The mean differences between the machines were small—0.05 l for FEV₁, 0.05 l for FVC, and 11.6 l min⁻¹ for PEF, with the limits of agreement at ±0.25 l, ±0.48 l, and ±52.2 l min⁻¹ respectively. The wide limits of agreement for the PEF comparison were probably because of the difference in the technique of blowing: a fast, long blow was used for the pocket spirometer and a short, sharp one for the Wright peak flow meter. The FEV₁ and FVC showed a proportional bias of around 4–5% in favour of the Vitalograph. The repeatability coefficient for the pocket spirometer FEV₁ was 0.18 l, for FVC 0.22 l, and for PEF 31 l min⁻¹. These compared well with the repeatability coefficients of the Vitalograph and the Wright peak flow meter, which gave values of 0.18 l, 0.28 l, and 27 l min⁻¹ respectively. At flow rates of over 600 l min⁻¹ the resistance of the pocket spirometer marginally exceeded the American Thoracic Society recommendations. The machine is easy to operate and portable, and less expensive than the Vitalograph and Wright peak flow meter combined. It can be recommended for general use.

Simple measurements of pulmonary function, such as FEV₁, forced vital capacity (FVC), and peak expiratory flow (PEF) are now widely used in the monitoring of patients with airflow limitation both in hospital and at home. In occupational medicine and clinical trials repetitive measurements of these indices may be needed in large numbers of subjects. Inexpensive, portable devices for measuring the PEF have been available for clinical use for many years.^{1–3} Instruments for measuring FEV₁ and FVC, however, are often expensive and bulky. In 1982 Chowienczyk and Lawson⁴ described a pocket sized device for measuring the FEV₁, and FVC. This instrument gave measurements that agreed well with those of the Ohio spirometer (Ohio Inc, Houston, Texas) when they were connected in series. The device, which the authors called the turbine spirometer, has now been developed further to measure the PEF. The object of the present study was to evaluate this new device in a clinical setting by comparing its performance with that of the Vitalograph (Vitalograph Ltd, Maids Moreton House, Buckingham) and the Wright peak flow meter

(Airmed, Clement Clarke International Ltd, Harlow, Essex), which are widely used and whose reliability has been established.^{5–9}

Methods

A turbine pocket spirometer loaned by the manufacturers (Micro Medical Instruments, PO Box 6, Rochester, Kent) was compared with a model S Vitalograph and a standard Wright peak flow meter that were in routine use in the lung function laboratory. The turbine pocket spirometer (fig 1) weighs 400 g and is powered by a single 9 v (PP3) battery. The unit consists of a fixed turbine, which generates a rotational flow that drives a low inertia vane. The rotation of the vane is converted into electrical pulses by means of an infrared light emitting diode and a photodiode sensor enclosed in the turbine housing. These electrical pulses are converted into FEV₁, FVC, and PEF measurements by means of a microprocessor in the control unit and are displayed digitally. The pocket spirometer is very easy to operate. When the instrument is switched on no warm up time is necessary, and when the "reset" button is pressed all the readings are converted to zero. The subject is then instructed to perform a forced vital capacity manoeuvre into the mouthpiece. The FVC, FEV₁, and PEF readings can be read directly off the

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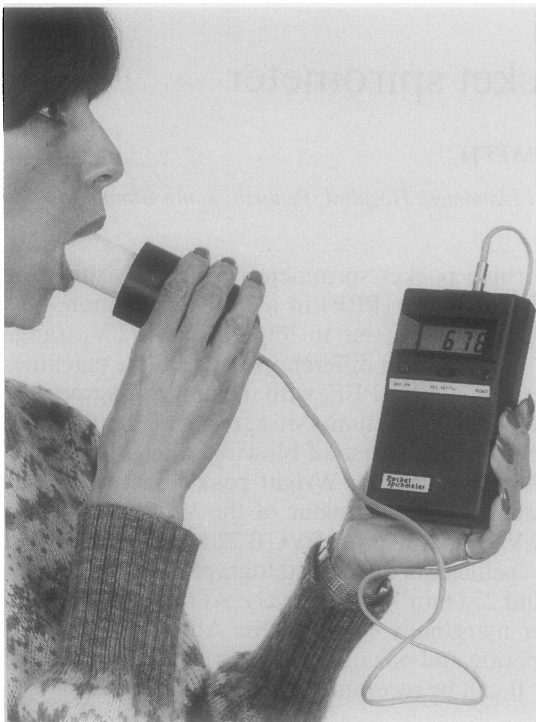


Fig 1 The turbine pocket spirometer in use.

display by means of the selector switch provided. The readings are stored indefinitely until the reset button is pressed again. The unit at present costs £340.

Volume calibration was effected with a 1.0 litre syringe so that the volume displayed on the pocket spirometer agreed with the volume indicated on the ATPS scale of the Vitalograph. The linearity of the Vitalograph was checked further with increments of 1.0 litre up to 6.0 litres. The percentage error was zero for 1.0 l, but increased slightly at higher volumes, the error at 5.0 l being +2.6%. The calibration of the Wright peak flow meter was checked against a Fisher Controls rotameter (Fisher Controls Ltd, Rotameter Works, Croydon, Surrey) as described by Cotes,¹⁰ but with correction of the observed rotameter flow for both the temperature and the back pressure. The observed meter readings were all within 10% of the expected readings, the percentage error being +5.9% at 200 l min⁻¹ and -8.3% at 800 l min⁻¹, indicating a tendency for the Wright peak flow meter to overread at low values and underread at high values.

Ninety nine subjects took part in the main study. They were drawn from the staff and the patients attending the outpatient chest clinics at the Llandough Hospital. Most subjects were regular

attenders at the chest clinics and were familiar with the forced expiratory manoeuvre. The nature and purpose of the study were explained, and after the subject had become familiar with the instruments each provided three technically satisfactory readings with the pocket spirometer, three with the Vitalograph, and three with the Wright peak flow meter. In the case of the pocket spirometer as well as the Wright peak flow meter the assessment of the adequacy of effort could be made only by observing the subject. The instrument to be blown into first was varied systematically, so that the results would not be biased by the effects of training or fatigue. For each comparison the best of the three readings was used. For FEV₁ and FVC the volumes indicated on the BTPS scale of the Vitalograph were compared with the direct digital readout from the pocket spirometer.

Since patients are normally instructed to produce a short, sharp blow into the Wright peak flow meter but a prolonged fast blow for measurement of the FVC and FEV₁, a further study was carried out to compare the PEF readings obtained by a short, sharp blow with the PEF obtained by a prolonged fast blow. Data for short, sharp versus prolonged blows on the Wright peak flow meter were obtained from 44 subjects and similar data for the pocket spirometer were obtained from 41 subjects.

The resistance of the pocket spirometer was measured as described by Cotes.¹⁰

The results were analysed by the statistical methods described by Bland and Altman.^{11 12}

Results

COMPARISON OF THE INSTRUMENTS

In the 99 subjects tested, FEV₁ ranged from 0.40 to 5.50 litres, FVC from 0.58 to 6.48 litres, and PEFR from 40 to 650 l/min. Figure 2 shows the difference between measurements obtained from the two machines plotted against the average of the two readings. The mean difference for the FEV₁ readings was 0.05 l (SD 0.13), for FVC 0.05 l (SD 0.24) and for PEF 11.6 l min⁻¹ (SD 26). Table 1 gives the 95% confidence limits for the estimates of the mean difference, and the "limits of agreement."¹¹

The differences were negatively correlated with the average reading of FEV₁ ($r = -0.39$, $t = 4.18$, $df = 97$; $p < 0.001$), and weakly negatively correlated with average FVC ($r = -0.198$, $t = 1.99$, $df = 97$; $p < 0.05$); but there was no correlation in the case of PEF. The slopes of the regressions for difference versus average were -0.051 for FEV₁ (95% limits -0.075 to -0.027) and -0.041 for FVC (95% limits -0.083 to 0.000). There was thus a significant proportional bias for FEV₁, with the Vitalograph giving the higher readings at higher values of FEV₁.

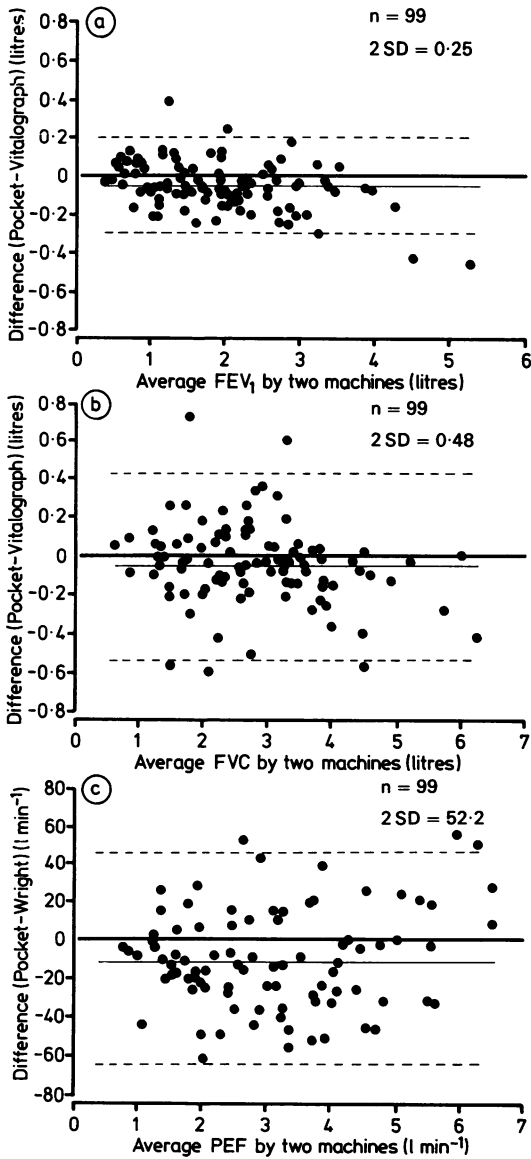


Fig 2 Comparisons of (a) FEV₁, (b) forced vital capacity (FVC), and (c) peak expiratory flow (PEF) readings of the pocket spirometer with those of the Vitalograph and the Wright peak flow meter: difference between the machines plotted against the average. — mean; - - - limits of agreement.

This proportional bias would somewhat overestimate the mean and the SD of the differences for FEV₁ and FVC. Logarithmic transformation of the data to remove this relationship was not helpful, as it tended to disproportionately increase the scatter at low readings.

Table 1 Confidence limits for the estimates of mean difference (pocket spirometer—Vitalograph/Wright peak flow meter) and limits of agreement

		Estimate	95% limits
FEV ₁ (l)	\bar{d}	-0.05	-0.075 to -0.025
	SD	0.13	
	$\bar{d} - 2SD$	-0.30	-0.342 to -0.255
	$\bar{d} + 2SD$	0.20	0.157 to 0.245
FVC (l)	\bar{d}	-0.05	0.00 to -0.10
	SD	0.24	
	$\bar{d} - 2SD$	-0.53	-0.611 to -0.488
	$\bar{d} + 2SD$	0.43	0.347 to 0.513
PEF (l min ⁻¹)	\bar{d}	-11.6	-16.8 to -6.4
	SD	26.1	
	$\bar{d} - 2SD$	-63.6	-68.1 to -59.1
	$\bar{d} + 2SD$	40.4	35.9 to 44.9

FVC—forced vital capacity; PEF—peak expiratory flow; \bar{d} —mean difference; SD—standard deviation; $\bar{d} - 2SD$ = lower limit of agreement; $\bar{d} + 2SD$ —upper limit of agreement.

SHORT VERSUS LONG BLOWS

The results of the comparisons of the short sharp blows versus the prolonged fast blows are shown in figure 3. For the Wright peak flow meter the mean

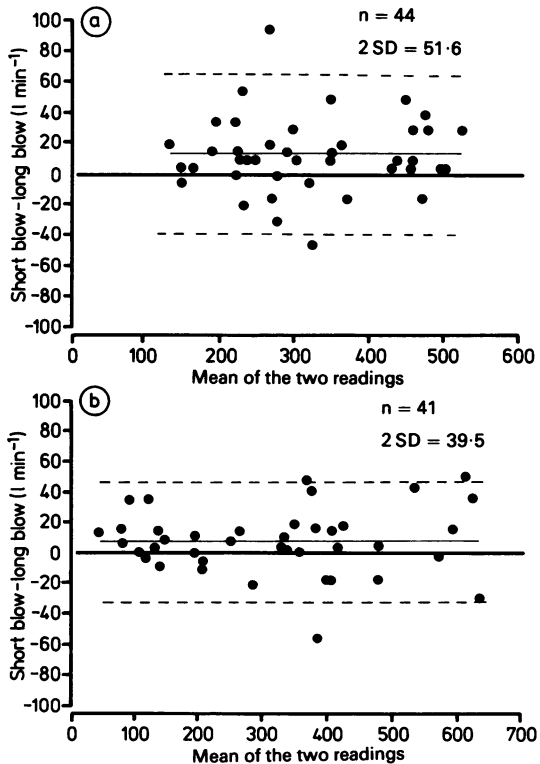


Fig 3 Comparisons of short, sharp blows with prolonged fast blows for the measurement of peak expiratory flow on (a) the Wright peak flow meter and (b) the pocket spirometer. — mean; - - - limits of agreement.

Table 2 Confidence limits for the estimates of the mean differences (short blow—long blow)

		Estimate ($l\ min^{-1}$)	95% limits
Wright peak flow meter	\bar{d}	14.1	6.25 to 21.93
	SD	25.8	
	$\bar{d} \pm 2SD$	-37.5	-51.09 to -23.91
Pocket spirometer	\bar{d}	7.5	1.29 to 13.74
	SD	19.7	
	$\bar{d} \pm 2SD$	-32.0	-42.79 to -21.21
		47.0	36.21 to 57.79

Abbreviations as in table 1.

difference between the short and the long blows was $14.1\ l\ min^{-1}$ (SD 25.8), the short blow producing higher readings than the long one. This difference was significant (paired $t = 4.705$, $df = 43$; $p < 0.001$). For the pocket spirometer the difference was less— $7.5\ l/min$ (SD 19.7)—but still significant (paired $t = 2.44$, $df = 40$; $p < 0.02$). The 95% confidence limits for the estimates of the mean differences and the limits of agreement are given in table 2.

REPEATABILITY

The repeatability for each of the measurements on the series of 99 subjects was assessed by calculating the standard deviation of the difference between the two closest values. The defined repeatability coefficients are twice these standard deviations.¹¹ This would indicate the 95% probability limit within which the best two out of the three readings would lie. For the Vitalograph FEV_1 the repeatability coefficient was 0.18 l, for FVC 0.28 l, and for the Wright machine's PEF 27 $l\ min^{-1}$. The corresponding values for the pocket spirometer were: FEV_1 0.18 l, FVC 0.22 l, and for PEF 31 $l\ min^{-1}$. Thus the repeatability of the readings on the pocket spirometer appeared to be as

Table 3 Resistance of the pocket spirometer at different flow rates (actual flow rates calculated by correcting the observed flow rate for both the temperature and the back pressure)

Observed rotameter flow ($l\ min^{-1}$)	Actual flow ($l\ min^{-1}$)	Back pressure ($mm\ H_2O$)	Resistance ($mm\ H_2O\ l\ s^{-1}$)
100	98	6.2	3.8
150	148	13.0	5.3
200	198	20.2	6.1
250	249	29.0	7.0
300	300	43.2	8.6
350	352	59.4	10.1
400	405	74.0	11.0
450	459	94.4	12.3
500	514	114.4	13.3
550	570	135.1	14.2
600	627	160.2	15.3
650	687	188.9	16.5

good as those for the Vitalograph and the Wright peak flow meter.

The back pressure generated by the pocket spirometer at various flow rates and resistance of the instrument are shown in table 3.

Discussion

Electronic spirometers offer considerable advantages over water filled or bellows spirometers in terms of portability and ease of operation. The direct digital readout offered by most of these instruments is also a major time saving advantage. Previous studies, however, have shown that electronic spirometers could be seriously inaccurate by comparison with the standard volume displacement spirometers.^{7 13-15}

The device tested in this study has been shown to produce results for FEV_1 and FVC that agree closely with those obtained with the Ohio spirometer when the machines are connected in series. We compared it with the Vitalograph and found that the mean differences for both FEV_1 and the FVC were in the region of 0.05 litres. The limits of agreement, however, seemed somewhat wide, being around $\pm 0.25\ l$ for FEV_1 , and around $\pm 0.48\ l$ for FVC. Since we used the machines separately, we could expect the scatter of the differences to be wider than if the machines were connected in series. A proportional bias would also increase the estimated random error of the difference between the two methods.¹⁶ We found that the difference in the readings could be around 5% for the FEV_1 , with the Vitalograph producing higher readings than the pocket spirometer. It is difficult to know which machine actually gives the "true" value. Indeed, the Vitalograph used for the study showed an error of +2.6% at the 5.0 l calibration. It is also possible that the Vitalograph overshoots at high flow rates, as a result of inertia effects—an observation not uncommonly made when one tries to calibrate the Vitalograph with a syringe. Observations reported by Wever *et al*⁶ suggests a proportional bias of 6–8% in favour of the Vitalograph when it was compared with the Stead-Wells spirometer, and the data presented by Gardner *et al*¹⁷ also indicate that the Vitalograph could over-read at high flow rates.

The question of whether the pocket spirometer could be used interchangeably with the Vitalograph and the Wright peak flow meter depends on the relative biases and on the relative values of the repeatability coefficients and the limits of agreement. If the observed bias is not clinically significant, and if the differences between the machines are not too large in relation to the differences between repeated measurements by the same method, then one may use the machines interchangeably. In other words, the

limits of agreement should not be too large in relation to the repeatability coefficient for the established method.

For the FEV₁ comparison (disregarding the proportional bias), the limits of agreement of ± 0.25 l seem quite acceptable, considering that the repeatability coefficient of the FEV₁ for the Vitalograph is of the order of 0.18 l. For the FVC, however, with a repeatability coefficient of 0.28 l, the limits of agreement of ± 0.48 l, even though not excessive, appear less than ideal. The lack of a comparable endpoint to the expiratory manoeuvre may explain part of the variation between the machines. The pocket spirometer does not provide a visual display of the spirographic curve, and therefore the adequacy of effort and the end of expiration are more difficult to judge than with the Vitalograph, especially in patients with severe airflow obstruction. Despite this, the repeatability coefficient of 0.22 l for the FVC on the pocket spirometer was marginally better than with the Vitalograph.

For PEF, the coefficients of repeatability for the Wright peak flow meter and for the pocket spirometer were broadly similar, and the mean difference in the readings negligible. The limits of agreement of ± 52.2 l/min were, however, wide, but were of the order that would be expected from comparison of the readings obtained with a short, sharp blow with the readings obtained with a prolonged blow on the Wright peak flow meter. Perhaps the wide limits of agreement between the two machines could be explained by the fact that we used a prolonged blow for the pocket spirometer and a short, sharp one for the Wright peak flow meter. Possibly better agreement would have been obtained if we had used similar type of blows for the two machines.

The minimal spirometry standards laid down by the American Thoracic Society¹⁸ require the resistance of a spirometer used for measuring the FEV₁ to be less than 1.5 cm of water l⁻¹ s⁻¹ at a flow rate of 12 l s⁻¹. With the pocket spirometer the resistance exceeds 1.5 cm of water l⁻¹ s⁻¹ at a flow rate of around 10 l s⁻¹ (table 3). This, however, should not be a serious drawback to the clinical use of the instrument.

The major disadvantage of the pocket spirometer is the lack of a visual display of the spirographic curve. Despite this, its overall performance was impressive. It is eminently portable and easy to use, and gives accurate and reliable readings if the tests are performed with sufficient care. The tests can be performed rapidly with a lesser number of efforts on the part of the patient to obtain the three most commonly used parameters of ventilatory function. At £340 it is considerably cheaper than the combined cost of a model-S Vitalograph and a standard Wright peak flow meter (about £820 + £180). The pocket spirometer should therefore prove to be a useful tool in a busy respiratory laboratory as well as in the

doctor's surgery or in clinical and epidemiological research.

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References

- 1 Wright WB, McKerrow CB. Maximum forced expiratory flow rate as a measure of ventilatory capacity. *Br Med J* 1959;ii:1041-7.
- 2 Wright BM. A miniature Wright peak flow meter. *Br Med J* 1978;ii:1627-8.
- 3 Perks WH, Cole M, Steventon RD, Tams IP, Prowse K. An evaluation of the Vitalograph pulmonary monitor. *Br J Dis Chest* 1981;75:161-4.
- 4 Chowienzyk PJ, Lawson CP. Pocket-sized device for measuring forced expiratory volume in one second and forced vital capacity. *Br Med J* 1982;285:15-7.
- 5 Drew CDM, Hughes DTD. Characteristics of the Vitalograph spirometer. *Thorax* 1969;24:703-6.
- 6 Wever AMJ, Britton MG, Hughes DTD. Evaluation of two spirometers. A comparative study of the Stead-Wells and the Vitalograph spirometers. *Chest* 1976;70:244-50.
- 7 Wever AMJ, Britton MG, Hughes DTD, Van der Plas KH, Wever-Hess J. Clinical evaluation of five spirometers: Monaghan M403, Pneumoscreen, Spirotron, Vicatest and Vitalograph. *Eur J Respir Dis* 1981;62:127-37.
- 8 Lockhart W, Smith DH, Mair A, Wilson WA. Practical experience with the peak flow meter. *Br Med J* 1960;i:37.
- 9 Shephard RJ. Some observation on peak expiratory flow. *Thorax* 1962;17:39-48.
- 10 Cotes JE. *Lung function: assessment and application in medicine*. 4th ed. Oxford: Blackwell Scientific Publications, 1979:25.
- 11 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;i:307-10.
- 12 Altman DG, Bland JM. Measurement in medicine: the analysis of method comparison studies. *Statistician* 1983;32:307-17.
- 13 Fitzgerald MX, Smith AA, Gaensler EA. Evaluation of "electronic" spirometers. *N Engl J Med* 1973;289:1283-8.
- 14 Shanks DE, Morris JF. Clinical comparison of two electronic spirometers with a water-sealed spirometer. *Chest* 1976;4:461-6.
- 15 Gunawardena KA, Smith AP. An evaluation of the LA3 Mk.2 lung function analyser. *Breath* 1984;21:7-9.
- 16 Westgard JO, Hunt MR. Use and interpretation of common statistical tests in method-comparison studies. *Clin Chem* 1973;19:49-57.
- 17 Gardner RM, Hankinson JL, West BJ. Evaluating commercially available spirometers. *Am Rev Respir Dis* 1980;121:73-82.
- 18 American Thoracic Society. Snowbird workshop on standardization of spirometry. *Am Rev Respir Dis* 1979;119:831-8.