Clinical Evaluation of a New Electronic Spirometer*

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An electronic spirometer which utilizes a thermistor and an linearizing circuit, was evaluated. When compared to a Collins 13.5 liter water seal spirometer, 60 test results from 30 patients revealed no clinically significant difference in forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), or maximum voluntary ventilation (MVV). The device was found durable and highly useful in the hospital or clinic.

Simple spirometric measurements should be available in the physician's office. The ideal instrument would give rapid results not only in screening patients with minimal abnormalities but also in following serial determinations in patients with ventilatory abnormalities. The 9.0 or 13.5 liter water filled instrument of the Benedict-Roth type has become the standard clinical spirometer. It is quite satisfactory when adequate laboratory space and personnel are available but is not ideal for office use. Several bellows-type spirometers which are smaller and more convenient to use are available for office practice, but have limitations. We recently have had the opportunity to evaluate a new type of electronic spirometer which employs a thermistor to sense flow-induced heat loss. A device apparently similar in theoretic principle has recently been described for use as a ventilator monitor.

We evaluated this instrument in comparison with the standard 13.5 L water seal spirometer while testing 30 unselected patients in our clinical pulmonary function laboratory.

MATERIALS AND METHODS

Instrument: The model of the electronic spirometer used is pictured in Figure 1. Its largest dimensions are 31 cm x 31 cm x 18 cm and it weighs 3.4 kilograms. Its operation requires a single standard grounded 120 volt electrical outlet and it requires approximately 25 watts of power.

The mouthpiece contains a thermistor wire which is maintained at constant temperature by the electronic circuitry in the analyzer. Airflow across the thermistor reduces the temperature. This temperature reduction is sensed by the circuitry and sufficient voltage is fed back to the thermistor to keep it at a constant temperature (200°-220°C). The relationship of voltage to flow is nonlinear; this is compensated for by a linearizing circuit which calculates flow. The flow is then integrated over time to give volume. The forced vital capacity (FVC) or forced expiratory volume in one second (FEV₁) in liters (at BTPS) is indicated by a needle on the dial when the appropriate button is depressed.

If a maximum voluntary ventilation (MVV) measurement is desired the timing circuit changes and the integrator operates for 12 seconds. An indicator light comes on at the beginning of the test and goes off after 12 seconds have elapsed. Circuitry similar to that described above makes appropriate calculations and the results are given on the same

FIGURE 1. Electronic spirometer - readout meter left and mouthpiece right. Test controls on lower part of instrument.
needle-dial display in liters per minute (LPM).

An airflow threshold of 20 LPM is necessary to activate the circuitry, which then remains active until flow falls below 4 LPM. Since it was found that some severely obstructed patients did not reach flow rates of 20 LPM, a threshold override button was placed on this machine; this is used whenever the initial determination shows a measured FEV₁ less than 2 liters.

The electronic spirometer as received from the factory was calibrated against a 13.5 L water respirometer using the FVC of two normal individuals (FVC 3.5 L and 5.0 L). It did not require recalibration during the evaluation period.

The patients tested were selected from people sent to our clinical pulmonary function laboratory for routine pulmonary function tests. They ranged from essentially normal persons sent from clinics for routine screening to very severely incapacitated patients recently admitted to the hospital in respiratory failure.

It was found that the mouthpiece of the electronic spirometer fits snugly into the mouthpiece holder of the water spirometer. Thus, patients were able to breathe simultaneously through the electronic spirometer into the water spirometer and the results obtained from both machines on the same breath. Each patient performed six forced vital capacity maneuvers (two on the electronic spirometer alone, two on the water spirometer alone, and two with the two devices "in line") and three maximum breathing capacity maneuver (MVV) (one each on the electronic spirometer, the water spirometer, and with the two "in line"). Each patient was allowed to rest after each maneuver as needed. In more severely ill patients as much as 15 minutes rest was allowed after an MVV maneuver. The order in which the patient performed the maneuvers was randomized in an attempt to balance the effects of learning or fatigue or both. In fact, an apparent effect of learning was seen in only one patient and of fatigue in one patient.

Results

Our study found no significant difference between the results of the FVC, FEV₁, and MVV as obtained by the water spirometer "in line" vs the water spirometer alone or for the same measurements as obtained by the electronic spirometer "in line" vs the electronic spirometer alone (through the use of Scheffé's multiple comparison test). With this indication that placing the two instruments together does not significantly alter the performance characteristics of either, we concentrated our analysis on the results from the two different machines "in line" thus eliminating breath to breath variations in the same patient.

Figure 2 is the plot of the FVC results obtained by the electronic spirometer vs the results on the same breath obtained from the water spirometer for two breaths from each of 30 patients (60 observations). These points fall very close to the line of identity. The least mean squares regression of our data give a slope (β) of 1.019 and an intercept (a) of +0.023. The probability that the slope of the calculated line from our data differs by chance alone from one with β = 1.00 (the ideal case) is \( P > 0.3 \), but the probability that the observed intercept varies from \( a = 0.0 \) (the ideal case) using the paired t-test is <0.01. Thus there is a small systematic difference between the electronic and the water spirometer, the electronic spirometer tending to overestimate the FVC. However, this error in any given patient never exceeded 10 percent and was always less than the breath to breath variation seen among the four maneuvers done on the water spirometer.

Figure 3 is a similar plot for results of the FEV₁.
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Easily carried under one convenient instrument suitable for office or field use. In comparing it to the standard 13.5 L water spirometer, the two obviously spurious points are due to "sampling error" induced when a patient inhales through the electronic spirometer at the end of the FVC maneuver. This error can be easily recognized because in this situation the FEV₁ reading is identical to the FVC reading.

A similar plot of one value for MVV performed simultaneously on the two machines by each of 29 patients is presented in Figure 4. The scatter for MVV is somewhat greater than for FEV₁ or FVC with a calculated β of 1.057, α = -3.8, 0.02 < P < 0.025. The greatest discrepancy between the two spirometers was 13 liters per minute (in a patient with an MVV of 110).

DISCUSSION

We found the electronic spirometer an accurate and convenient instrument suitable for office or field use. In comparing it to the standard 13.5 L water spirometer we found no significant difference in the values for FVC, FEV₁ and MVV. There is a statistically significant deviation from the ideal for the regression equation of the FVC, FEV₁ and MVV. However, considering the usual test variation of the parameters, these deviations do not appear clinically significant.

The instrument is compact, light weight and easily carried under one arm. It is surprisingly durable—we accidentally dropped the entire device from bench top to concrete floor on two occasions and the mouthpiece on several more without visible damage or change in its performance. The initial cost is comparable to a water seal spirometer; however, it does not require a trained technician for its use.

An additional advantage over bellows-type portable spirometers is that MVV is directly measurable. Also, FVC and FEV₁ are measurable and accurate at both upper and lower extremes.

A theoretical disadvantage of the electronic spirometer is that the patient has to inspire to TLC before inserting the mouthpiece and has to avoid inhaling through the mouthpiece at the end of expiration. We did not find this a frequent problem even in our least cooperative patients. When these errors occur it is readily recognized by the technician and the test can be easily repeated.

The equipment does not provide the spiographic record so that additional analyses such as FEV₂₀, MEFR (maximum expiratory flow rate), MMEF (maximum mid-expiratory flow), MET (mid-expiratory time), etc, cannot be performed. Also, the spirograms cannot be inspected for sources of error as a slow start or cough, or for subtle signs of disease such as evidence of air trapping, e.g., significant end expiratory flow.

We found the dial face somewhat difficult to read accurately, particularly the MVV portion of the dial whose smallest divisions were in "units" of 12.5 liters. Present models of the device have a digital readout meter obviating the dial reading problem entirely.

The commercial models are all calibrated for atmospheric pressure at sea level. When the machine is used above sea level (such as in our study at 5,200 feet) the device must be recalibrated for effects of altitude by a simple rear panel adjustment.

Changes in ambient temperature do not affect the performance of the instrument. According to the manufacturer a change in the patient's temperature will cause an error of 1 percent per 3°C of temperature change.

REFERENCES


CHEST, VOL. 63, NO. 4, APRIL, 1973

Figure 4. Comparison of 29 test results for MVV from 29 patients (electronic vs water spirometer).