

Comparing MiniWright and Spirometer Measurements of Peak Expiratory Flow*

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The accuracy and instrument variability of the MiniWright (Clement Clarke) peak expiratory flow (PEF) meter was determined with 6 of the 24 American Thoracic Society's (ATS) standard waveforms using a mechanical pump. Both room air and air heated to 37°C and saturated with water vapor were used. In addition, MiniWright-determined PEF measurements were compared with those obtained using a dry rolling-seal spirometer (Ohio No. 822; Ohio Medical Products; Madison, Wis) from 75 subjects on 2 different days. The MiniWright average coefficient of variation within a waveform was found to be 2.8%. Results using heated and humidified air (body temperature, ambient pressure, and saturated with water: body conditions) were 2.5% lower than those obtained using room air. Comparisons with mechanically simulated

PEF and with spirometry-determined peak flow in 75 human subjects showed that MiniWright meters overestimated flows at lower flow rates and slightly underestimated flows at higher flow rates. These results suggest that the new "mechanical PEF" MiniWright scale should be used instead of the "traditional" MiniWright scale. (CHEST 1995; 108:407-10)

ATS=American Thoracic Society; BTPS=body conditions: body temperature, ambient pressure, and saturated with water vapor at these conditions; CV=coefficient of variation; PEF=peak expiratory flow

Key words: peak expiratory flow; peak flow meters; spirometry

The National Asthma Education Program of the National Heart Lung and Blood Institute¹ recommended that peak expiratory flow (PEF) meters be evaluated at several PEFs using waveforms produced by a mechanical syringe. In response to this recommendation and to test results from several studies,²⁻⁸ the manufacturer has recently provided an additional scale based on "a mechanical test rig"⁹ as well as their "traditional" scale based on human population test results, leaving it to the user to decide which scale to use. This study was conducted to evaluate the MiniWright (Clement Clarke) PEF meter using both a "mechanical test rig" and human subjects to resolve the issue of whether the new "mechanical PEF" or "traditional" scale should be used when testing subjects.

METHODS

Forty-five different unused MiniWright PEF meters (Clement Clarke model PF-239) were tested using a mechanical pump lung simulator¹⁰ at a room temperature of 22°C and a relative humidity between 17 and 21%. The PEF meters were purchased in June 1992 from a distributor who was unaware of our intentions to conduct an evaluation of the device. Armstrong Medical Industries, the distributor of the MiniWright PEF meters (T. Lehman, BS; written

communication, 1994), provided us an equation, developed by Dr. M. Miller, used to derive the new "mechanical" PEF scale. The Miller equation was used to convert MiniWright PEF values ("traditional" scale) to values using the new "mechanical" PEF from the 45 meters. In addition, a recently purchased MiniWright PEF meter with the "mechanical" scale was tested, and the results were essentially the same as those obtained with the 45 meters ("traditional" scale) using the Miller equation (within 6%). Therefore, it appears that the mechanical characteristics of the MiniWright PEF meter have not changed significantly since 1992 except for the new "mechanical" scale.

A total of 30 separate injections of room air were made into each of the 45 PEF meters. These consisted of five repeat injections of 6 of the 24 standard waveforms of the American Thoracic Society (ATS)¹¹ (waveforms 15, 18, 20, 21, 23, and 24). These particular waveforms were chosen because of their wide acceptance as testing signals and to provide a range of PEFs from 2.075 L/s (125.7 L/min) to 12.132 L/s (727.9 L/min [Table 1]). All MiniWright PEF measurements were made by the same pulmonary function technician who attempted to read the meter to within 2 L/min using a lighted magnifying glass (one minor division on the MiniWright meter is 10 L/min). While the technician was aware of the general range of PEFs expected to be produced by the mechanical simulator, he was unaware of the exact ATS values in liters per minute.

To examine the effects of humidity and temperature on PEF measurements, 7 of the 45 MiniWright PEF meters were tested using heated (37 ± 1°C) and humidified (saturated with water vapor) air—barometric pressure of 740 mm Hg. A total of 30 injections of heated and humidified air were made into each of the 7 PEF meters, 5 repeat injections of 6 ATS waveforms. These results were compared with the room air results to calculate the percentage of difference between tests using room air from those using body conditions: body temperature, ambient pressure, and saturated with water vapor at these conditions (BTPS). Analogous testing of a dry rolling-seal spirometer using heated and humidified air has been

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Table 1—Mean, Standard Deviation and Coefficient of Variation of Peak Expiratory Flow Measurement*

ATS waveform No.	24	23	20	18	21	15
ATS peak flow, L/min	125.7	172.1	349.3	451.4	563.9	727.9
PEF mean (n=225), L/min	167.2	242.4	442.3	539.9	583.8	740.4
SD	8.81	9.72	8.57	16.8	9.32	7.40
CV, %	5.27	4.01	1.94	3.11	1.60	1.00
Difference from ATS, L/min	41.5	70.3	93.0	88.5	19.9	12.50
Difference from ATS, %	33.0	40.8	26.6	19.6	3.53	1.72

*Measurements made on 45 different MiniWright PEF meters (“traditional” scale) using the mechanical simulator filled with room air—5 replicates for each meter for 6 different ATS standard wave forms.

previously reported¹² and provided the equation used to calculate a dynamic BTPS correction factor for spirometric PEFs.

In addition to testing using the mechanical simulator, comparisons were made between PEFs measured on the MiniWright PEF meter and on the dry rolling-seal spirometer (Ohio No. 822; Ohio Medical Products; Madison, Wis) for 75 aluminum processing plant workers (barometric pressure, 694 to 710 mm Hg; temperature, 18 to 25°C). These data were collected as part of a 10-day study of these workers which included spirometry before and after a work shift at the beginning and end of their work week. After receiving standardized instruction, the workers were given MiniWright PEF meters and asked to record PEFs from three blows within 2 h before and after the spirometry examination. Only the largest of the three PEFs was used in our analysis.

Spirometry was performed in accordance with the ATS recommendations for spirometry¹¹ and using a dynamic BTPS correction factor. The BTPS correction factor for PEF measured with a dry rolling-seal spirometer has previously been described as being about 30% of the full BTPS correction factor,¹² *eg*, BTPS factor of 1.027 instead of 1.09. The largest spirometric peak flow was compared with the average of the two MiniWright PEF measurements, *ie*, PEF tests before and after spirometry. No additional adjustments for altitude or BTPS conditions were made for the human MiniWright PEF measurements. Adjustments for altitude (barometric pressure) were not believed to be necessary since less than a 2 to 3% difference was expected¹³ between MiniWright PEFs measured in the laboratory (barometric pressure, 740 mm Hg) and field (694 to 710 mm Hg).

The dry rolling-seal spirometer had been modified by the addi-

tion of a digital shaft encoder interfaced to a digital computer. The shaft encoder is capable of resolving a volume of about 2.8 mL and used a sampling rate of 100 samples per second. To eliminate sampling aliasing, the raw spirometry volume-time signal was filtered by a low pass digital filter (11.5 Hz cutoff frequency). To derive flow, a quadratic least squares fit was made to a 80-ms segment of the volume-time curve, using the equations described in the ATS spirometry recommendations.¹¹ The accuracy of spirometry-determined peak flow also was estimated for each of the four spirometers used in the human studies by using the 24 ATS waveforms and the mechanical pump filled with room air. Statistical analyses (Statistical Analysis System, SAS; Cary, NC) and regression analyses (MATLAB, The Math Works; South Natick, Mass) were conducted.

RESULTS

Table 1 shows the means, SDs, and coefficients of variation (CV) of observed PEFs for the 45 different meters using the mechanical simulator, 5 replicates for each meter. Also shown in Table 1 are the ATS standard peak flow target values and the differences between the observed PEF means and the ATS standard values for each of the 6 different ATS standard waveforms produced by the mechanical simulator. The variability within a waveform was small, with an overall waveform CV average of 2.82%. The CV also tended to decrease with increasing PEF. The mean within-instrument CVs (averaged over 5 replicates and 6 waveforms) were even smaller, ranging from 0.13 to 1.11% for each instrument with an overall mean CV of 0.43%.

Figure 1 shows the means and SDs of the PEFs observed on the MiniWright PEF meters for each of the 6 waveforms. As can be seen in Figure 1 and in Table 1, the PEF meters tend to overread consistently, more so at lower PEFs. The within-waveform variability was small, indicating a relatively higher instrument precision than accuracy. A least squares quadratic function was fit to these data (solid line) for use in later comparisons. The equation for the quadratic function shown in Figure 1 follows:

$$(1) \text{ FMW} = 12.94 + 1.3877 * \text{FS} - 0.0006 * \text{FS}^2$$

where flow MiniWright (FMW) equals estimated flow for MiniWright PEF meter based on simulator or spirometry-determined peak flow. Flow-simulator (FS) equals simulator flow or spirometric peak flow.

The corresponding equation, based on the simula-

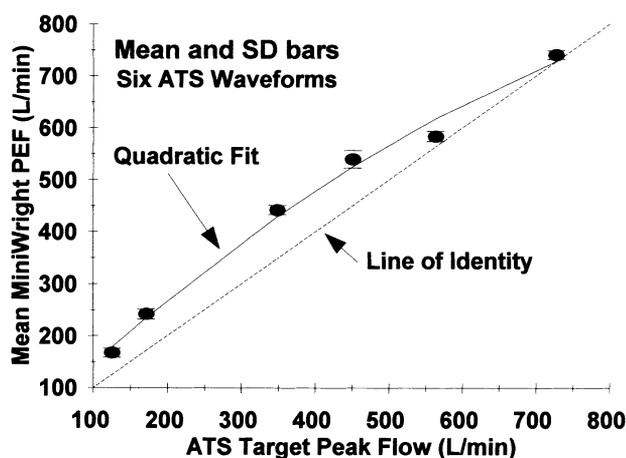


FIGURE 1. Means and SDs (SD bars) for MiniWright PEF values (“traditional” scale) vs target ATS standard waveform values. Data from 6 ATS standard waveforms generated by mechanical simulator using room air, each measured 5 times on each of 45 MiniWright PEF meters. Because of the relatively small variance within an instrument, SD bars rather than the SEM are shown.

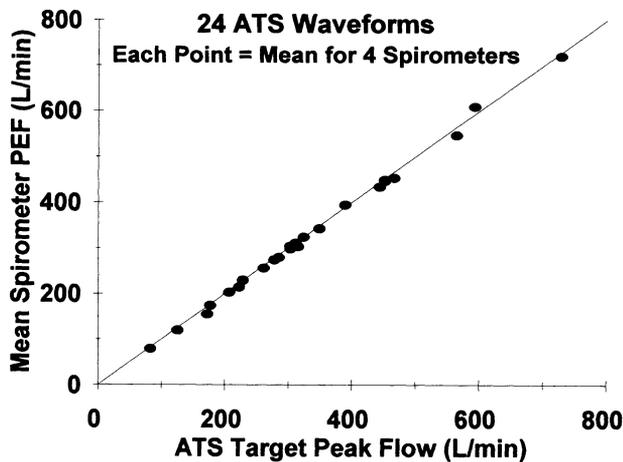


FIGURE 2. Means for spirometer-determined peak flow values vs target ATS standard waveform values. Data from 24 ATS standard waveforms generated by mechanical simulator using room air; each point represents the average value for the four spirometers used in the human studies. Because of the small between-spirometer variability, SEM or SD bars are not shown. However, one spirometer read approximately 8% lower than the other three spirometers at the highest flow rate (727.9 L/min).

tor results, for converting MiniWright PEFs to ATS values follows:

$$(2) \text{ FATS} = 23.74 + 0.4643 * \text{FMW} + 0.0007 * \text{FMW}^2$$

where FATS (flow-ATS) equals flow corresponding to ATS target values as produced by the simulator.

Figure 2 shows the mean flows for the four spirometers used in the human studies using the 24 ATS waveforms and the mechanical pump filled with room air. Since the spirometric peak flows were found to be very similar to peak flows produced by the simulator, spirometric peak flows can be substituted in equation 1 to estimate corresponding MiniWright PEFs.

Figure 3 shows the mechanical simulator test results using room air expressed as a percentage of the results using heated (37°C) and humidified air. The results for the MiniWright PEF meter at a room temperature of 22°C appear to be larger than those using heated and humidified air by an average of approximately 2.5%. For the two waveforms with lower flows, the percentage differences are lower and more variable. If the PEF readings are proportional to the gas density raised to the 0.33 power,¹⁴ then the expected percentage change (room air 22°C and 20% relative humidity to heated air 37°C and saturated with water vapor) would be about 2.4% as a result of the lower density of heated and humidified air.

Figure 4 shows results for the tests conducted on 75 aluminum plant workers measured on two separate days. Similar to the results shown in Figure 1, at lower flow rates the PEFs from MiniWright meters tend to be higher than those from the dry rolling-seal spirometer. The relationship between the MiniWright- and

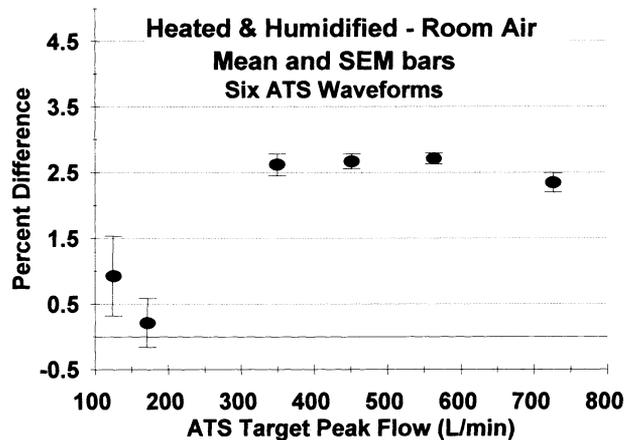


FIGURE 3. Room air PEF values minus PEF values obtained using heated and humidified air expressed as a percentage of room air results. Data is from 6 ATS standard waveforms generated by mechanical simulator using heated (37°C) and humidified (saturated with water vapor) air, each measured 5 times on each of 7 MiniWright PEF meters and from analogous data using room air (22°C, 17 to 21% relative humidity).

spirometer-determined values closely approximates the results from the similar fit to the simulator data (solid line) shown in Figure 1. In addition, these results are similar to those that would have been obtained using the new MiniWright “mechanical” PEF scale (second solid line based on Miller’s equation).

DISCUSSION

Our results indicate that the MiniWright PEF meter, using the “traditional” scale, consistently overreads values at lower PEFs when evaluated with either a mechanical simulator using standard waveforms or with values obtained on human subjects using a dry rolling-seal spirometer. When equation 2 or Miller’s equation available from the manufacturer (T. Lehman,

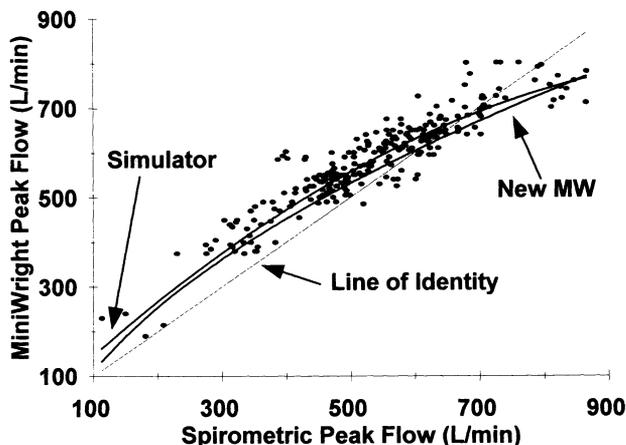


FIGURE 4. Spirometry-determined peak flow vs MiniWright-determined PEF values in 75 workers tested on 2 different work days. Solid lines represent predicted results based on either the mechanical simulator results (Fig 1) or the “mechanical PEF” equation provided by the manufacturer (“mechanical” scale).

BS; written communication, 1994) implementing the new “mechanical PEF” scale is used, the differences between the MiniWright-PEFs and spirometer-determined peak flows are reduced and are no longer related to the PEF. These results indicate that the new “mechanical” PEF scale should be used instead of the “traditional” scale. If comparisons with previously determined values are necessary, either the equation in this study or the conversion method available from the manufacturer could be used.

Using the simulator, we observed differences between MiniWright PEFs when room air is injected vs heated and humidified air. These differences are small (less than 2.5%) in comparison with other differences observed using the 6 ATS waveforms.

The room air vs heated and humidified air differences can be explained by differences in gas density resulting from differences in water vapor pressure and temperature. These results are consistent with the results of Miller et al¹⁵ who found, using a pump system, no significant difference in portable PEFs for a change in gas meter temperature from 6 to 25°C. Because these differences are small, testing of PEF instruments whose flows are dependent on gas density should be possible using room air without significant differences between those conducted at BTPS conditions. In addition, human expiratory air temperatures¹⁶ may be closer to 34°C—lower than the 37°C at which our tests were conducted. Therefore, testing the MiniWright, or similar PEF meters, under BTPS is not necessary except for new designs.

Other studies⁶⁻⁸ have shown similar results to ours using mechanical simulators, but these studies did not compare MiniWright PEF measurements from human subjects with those obtained using a dry rolling-seal spirometer. Milledge¹⁷ has advocated the continued use of the “less elegant but clinically more useful method of Wright and McKerrow,”² who conducted comparisons using human subjects, relegating use of mechanical pumps to a secondary level of importance. Our results comparing human MiniWright PEFs to those measured with a dry rolling-seal spirometer were consistent with what would be predicted based on our mechanical simulator results. Therefore, our findings suggest that the mechanical simulator can be used to estimate the results that could be expected when testing human subjects—eliminating the need for more variable and expensive testing using human subjects.

In summary, these results suggest the new Mini-

Wright “mechanical” PEF scale, rather than the “traditional” scale, should be used when testing subjects. It appears feasible to compare accurately PEF values obtained using a MiniWright meter with those obtained using a dry rolling-seal spirometer when a dynamic BTPS correction factor is used. In addition, our results suggest that a mechanical simulator can be a useful, and possibly a preferred, tool in predicting the behavior of portable PEF meters.

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REFERENCES

- 1 National Asthma Education Program. Statement on technical standards for peak flow meters. Washington, DC: US Dept of Health and Human Services, National Institutes of Health publication No. 92-2113A, October, 1992; 1-3
- 2 Wright BM, McKerrow CB. Maximum forced expiratory flow rate as a measure of ventilating capacity with a description of a new portable instrument for measuring it. *BMJ* 1959; 2:1041-47
- 3 Perks WH, Tams IP, Thompson DA, et al. An evaluation of the mini-Wright peak flowmeter. *Thorax* 1973; 34:79-81
- 4 Eichenhorn MS, Beauchamp RK, Harper PA, et al. An assessment of three portable peak flowmeters. *Chest* 1982; 82:302-09
- 5 Shapiro SM, Hendler JM, Ogirala RG, et al. An evaluation of the accuracy of Assess and miniWright peak flowmeters. *Chest* 1991; 99:358-62
- 6 Jensen RL, Crapo RO, Jackson RL, et al. Evaluation of peak flow meter precision using a computerized pump [abstract]. *Am Rev Respir Dis* 1991; 143:A347
- 7 Miller MR, Dickenson SA, Hitchings DR. The accuracy of peak flow measurements using different peak flow meters [abstract]. *Am Rev Respir Dis* 1991; 143:A29
- 8 Gardner RM, Crapo RO, Jackson BR, et al. Evaluation of accuracy and reproducibility of peak flow meters at 1,400 m. *Chest* 1992; 101:948-52
- 9 Clement Clarke. Package insert for new MiniWright peak flow meters. Columbus, Ohio, 1994; 1
- 10 Gardner RM, Hankinson JL, West BJ. Evaluating commercially available spirometers. *Am Rev Respir Dis* 1980; 121:73-82
- 11 American Thoracic Society statement: standardization of Spirometry—1987 Update. *Am Rev Respir Dis* 1987; 136:1285-98
- 12 Hankinson JL, Viola JO. Dynamic BTPS correction factors for spirometric data. *J Appl Physiol* 1983; 123:659-64
- 13 Thomas PS, Harding RM, Milledge JS. Peak expiratory flow at altitude. *Thorax* 1990; 45:620-22
- 14 Forster P, Parker RW. Peak expiratory flow rate at high altitude [letter]. *Lancet* 1983; 2:100
- 15 Miller MR, Dickinson SA, Hitchings DJ. The accuracy of portable peak flow meters. *Thorax* 1992; 47:904-09
- 16 Cole P. Recordings of respiratory air temperature. *J Laryngol* 1954; 68:295-307
- 17 Milledge JS. Calibration of peak expiratory flow (PEF) measuring devices [letter]. *Eur Respir J* 1991; 4:1152