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Eleven peak flow meters: a clinical evaluation

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Eleven peak flow meters: a clinical evaluation. H. Folgering, W.v.d. Brink, O.v. Heeswijk, C.v. Herwaarden. ©ERS Journals Ltd 1998.
ABSTRACT: Peak flow meters are essential tools in the management of asthma. Many types are on the market. A computer-driven piston pump is normally not available for evaluation of the various meters. Comparison with values from a pneumotachograph is an accepted way of testing peak flow meters. This study aims at comparing 11 peak flow meters, for accuracy and linearity.

Seven adult peak flow meters were tested: Miniwright with an equidistant scale (Clement Clarke); Personal Best (Healthscan); Wright Pocket fdE (Ferraris); Vitalograph (Vitalograph); Assess (Healthscan); Pocket Peak flow meter (Micro Medical); and Truzone (Monaghan). Furthermore, four low-range (LR) peak flow meters were tested: LR Miniwright with equidistant scale (Clement Clarke); LR Personal Best (Healthscan); LR Wright Pocket (LR Ferraris); and LR Pocket peak flow meter (LR Micro Medical).

Two test series were performed: in the first one, a peak flow meter was connected downstream in series with a Fleisch #4 pneumotachograph. One subject performed 50 partial forced expiratory manoeuvres through this ensemble. In the second series, 50 adult patients and 25 healthy children performed sequential maximal forced expiratory manoeuvres on each peak flow meter, and on the pneumotachograph. A ranking system was devised for the various parameters of agreement of the meters with the pneumotachograph.

Substantial differences in the quality of the adult meters were found. The adult peak flow meters with the closest agreement to the pneumotachograph were Personal Best and Micro Medical. In the low-range peak flow meters, the lowest differences were seen in the LR Personal Best and LR Micro Medical.
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"When treating asthmatic patients, it is often desirable to make frequent objective assessments of peak expiratory flow (PEF), usually more than once a day. Daily, or circadian, variations in PEF reflect the severity of asthma." [1]. This statement from the International Consensus Report on Diagnosis and Treatment of Asthma has made peak flow measurement one of the mainstays of asthma management. Peak flow measurement is a tool for treatment by the physician, and especially a tool of self-management by the patient. Peak flow meters generally are inexpensive devices, that can be provided for personal use, for every individual patient. As many types and brands are on the market, it is relevant to evaluate the merits of the various meters, such as within-instrument variability, patient variability, accuracy and linearity. Laboratory evaluation, according to American Thoracic Society (ATS) standards, requires expensive and sophisticated equipment: computer-controlled and servo-driven piston pump. Such a calibrating instrument is usually not available in most lung function laboratories. The purpose of this study was to compare seven adult peak flow meters, and four low-range peak flow meters for paediatric use.

The evaluation was performed, using a Fleisch pneumotachograph as a reference instrument, either in series with the peak flow meter, or used sequentially before or after the peak flow meter. Some authors even propose such a clinical calibration procedure, in favour of the computerized piston pump [2].

A ranking system was developed for determining which peak flow meter had the closest agreement with the pneumotachograph readings.

Materials and methods

The following peak flow meters were tested: Miniwright with equidistant scale (Clement Clarke, Harlow, UK); Personal Best (Healthscan, Cedar Grove, NJ, USA); Wright Pocket fdE (Ferraris, Medical, London, UK); Vitalograph (Vitalograph, Buckingham, UK); Assess (Healthscan, Cedar Grove, NJ, USA); Pocket Peak flow meter (Micro Medical, Chester, UK); and Truzone (Monaghan, Plattsburgh, NY, USA). Furthermore, four low-range peak flow meters were tested: LR Miniwright with equidistant scale (Clement Clarke, Harlow, UK) (this was the LR Miniwright that has the same size as the adult meter), LR Personal Best (Healthscan, Cedar Grove, NJ, USA), LR

Wright Pocket (LR Ferraris, Medical, London, UK), and LR Pocket peak flow meter (LR Micro Medical). All low-range instruments were separate instruments, except for the LR Micro Medical. The latter is converted from the adult Micro Medical peak flow meters by plugging a hole in the instrument, as prescribed by the manufacturer. All peak flow meters were new, and had not been used previous to this investigation.

One series of tests was done, in which the peak flowmeter was connected downstream in series to a Fleisch #4 pneumotachograph (Discom, Chest corporation, Tokyo, Japan). The heated pneumotachograph had a cone-shaped connector at both sides, and an upstream wirescreen. Such a pneumotachograph setup has an "excellent linearity" [3]. The diameters of the base and top of the cones were 60 and 30 mm respectively, the height of the cone was 100 mm. One side of the pneumotachograph was connected to a mouthpiece, the other side to the various peak flow meters. The time constant of the differential pressure transducer is 0.01 s. The flow signal was sampled with a frequency of 100 Hz. The integrated signal of the pneumotachograph was calibrated with a 3 L syringe, at three flow-levels (approximately 1 $L \cdot s^{-1}$, 6–8 $L \cdot s^{-1}$, and 10 $L \cdot s^{-1}$). The common mode rejection of the pneumotachograph could not be provided by the dealer. Therefore the calibration procedure was repeated with the peak flow meter in series. The integrated flow was 1.03 % higher than without the peak flow meter in series.

One subject performed 50 partial forced expiratory flow-volume manoeuvres through each combination of pneumotachograph and peak flow meter. These manoeuvres were evenly distributed over the whole range of peak flows, for every peak flow meter.

In the second series of tests, 50 adult patients were asked to perform a maximal forced expiratory manoeuvre from total lung capacity (TLC), through each peak flow meter and through the pneumotachograph in a randomized sequence. Three manoeuvres were performed on every instrument; the highest of these three values was kept for later evaluation. The low-range peak flowmeters were tested in the same way, by 25 healthy children, aged 6–12 yrs.

The agreement between the peak flowmeter reading and the pneumotachograph reading was assessed by a BLAND and ALTMAN [4] analysis of all data-pairs, plotting the difference between both readings *versus* the mean of the readings of the pneumotachograph and the respective peak flow meter. The mean difference, and the standard deviation of this difference, was calculated. Furthermore, assuming that the reading of the pneumotachograph could be considered as a reference instrument, we tested for the criterium whether the readings of the peakflow meters were within 10% of the pneumotachograph values [5]. This was done only in the in-series experiments, in order to eliminate deviations due to possible differences in effort by the subjects.

In order to combine the parameters of mean difference, standard deviations of these differences, and the occurrence of readings deviating >10%, a ranking system was used. The peak flow meter with the lowest value for mean difference was assigned rank number 1. The same was done for the standard deviation of the differences, and for the number of deviations of 10% or more. The peak flow meter with the highest difference, standard deviation, and deviating readings, was assigned rank number 7 for the adult meters (seven instruments evaluated) and rank number 4 for the low-range peak flow meter (four instruments evaluated). The rank numbers of the three parameters were added, both for the in-series experiments, and for the sequential experiments. The lowest possible cumulative rank score, indicating the closest association between peak flow meters and pneumotachograph, was 5 for both the adult and the low-range meters (2+3). The highest possible cumulative rank score was 35 for the adult meters ((2×7) + (3×7)), and 20 for the low-range meters ((2×4) + (3×4)).

Results

The values of all parameters for all peak flow meters are shown in table 1. The BLAND and ALTMAN [4] plots for the adult and low-range peak flow meters are shown in figures 1 and 2, respectively.

The values of the cumulative ranking for both groups of peak flow meters is shown in table 2. In the group of adult peak flow meters, the Personal Best appears to show the best agreement with the pneumotachograph readings. In the paediatric group, the LR Personal Best and the LR Micro Medical both have the lowest cumulative ranking and therefore have the best agreement with the pneumotachograph.

Table 1. – Comparison of peak flow meter readings with pneumotachograph

Peak flow meter	PEFR difference+ L·min-1	Difference >10 %# n
Adult peak flow meters		
In series		
Assess	-16.3±45.1	15
Ferraris	37.2±45.4	7
Micro Medical	6.7±28.8	6
Miniwright	-20.3±42.6	10
Personal Best	-0.6±44.9	5
Truzone	0.2±57.42	5
Vitalograph	26.4±31.8	9
Sequential		
Assess	-6.2±57.9	
Ferraris	9.7±99.2	
Micro Medical	19.9±46.7	
Miniwright	-2.9±102.4	
Personal Best	1.9±51.3	
Truzone	-1.47±60.0	
Vitalograph	6.1±48.2	
Low-range peak flow meters		
In series		
LR Ferraris	58.3±21.4	25
LR Micro Medical	4.3±26.9	5
LR Miniwright	33.4±14.1	20
LR Personal Best	17.5±19.4	8
Sequential		
LR Ferraris	48.4±37.7	
LR Micro Medical	0.7±25.9	
LR Miniwright	13.9±29.9	
LR Personal Best	-11.1±20.2	

+: mean±SD difference between peak flow meter and pneumotachograph. #: number of readings of the peak flow meter, deviating more than 10% from the pneumotachograph reading, in the in-series experiment. PEFR: peak expiratory flow rate.

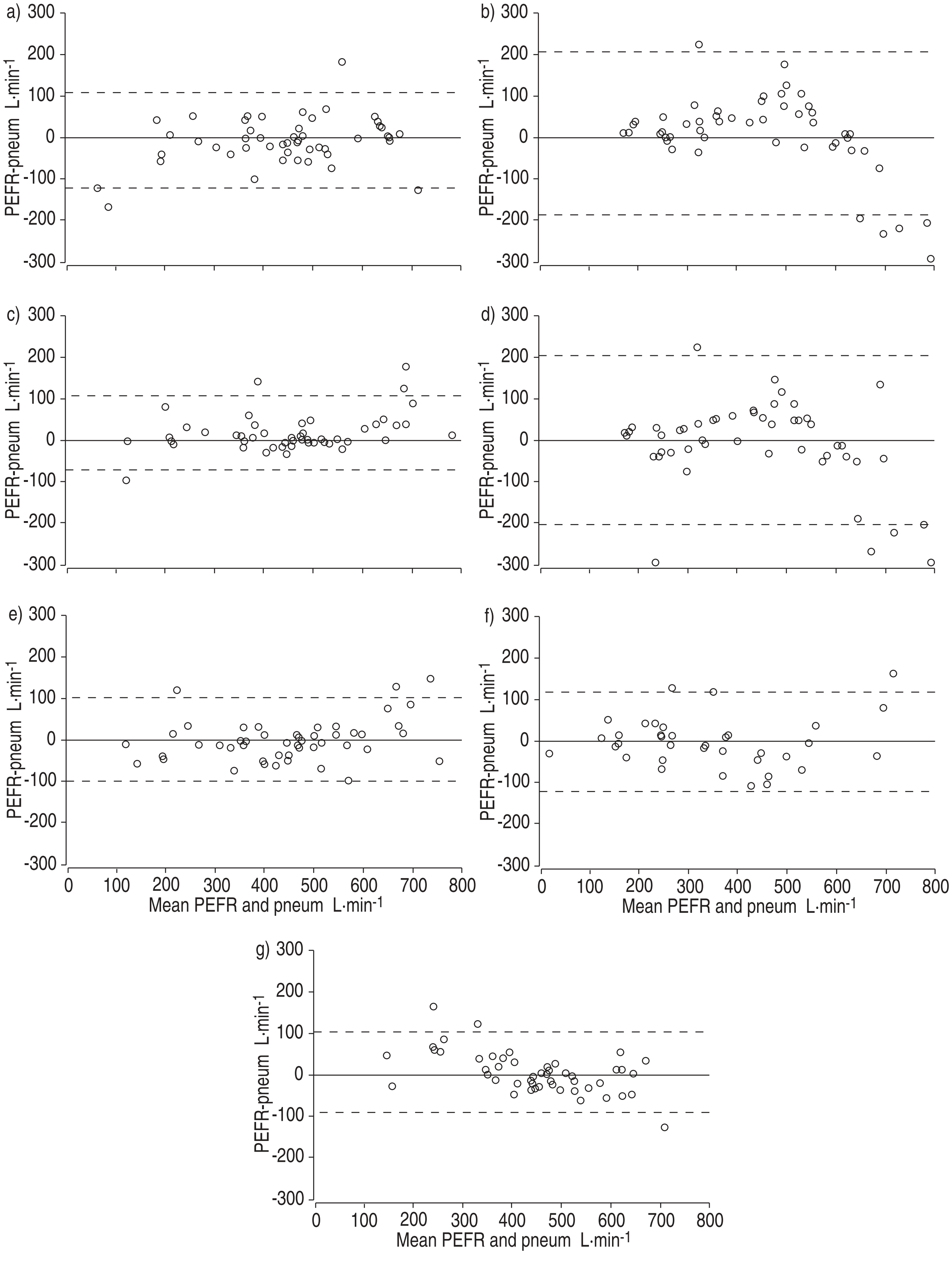

Fig. 1. – Bland and Altman plots of the adult peak flow meters measured sequentially with the pneumotachograph. a) Assess; b) Ferraris; c) Micro Medical; d) Miniwright; e) Personal Best; f) Truzone; g) Vitalograph. ——— : zero difference; – – – : mean±2SD. PEFR: peak expiratory flow rate from peak flow meter; pneum: pneumotachograph reading.

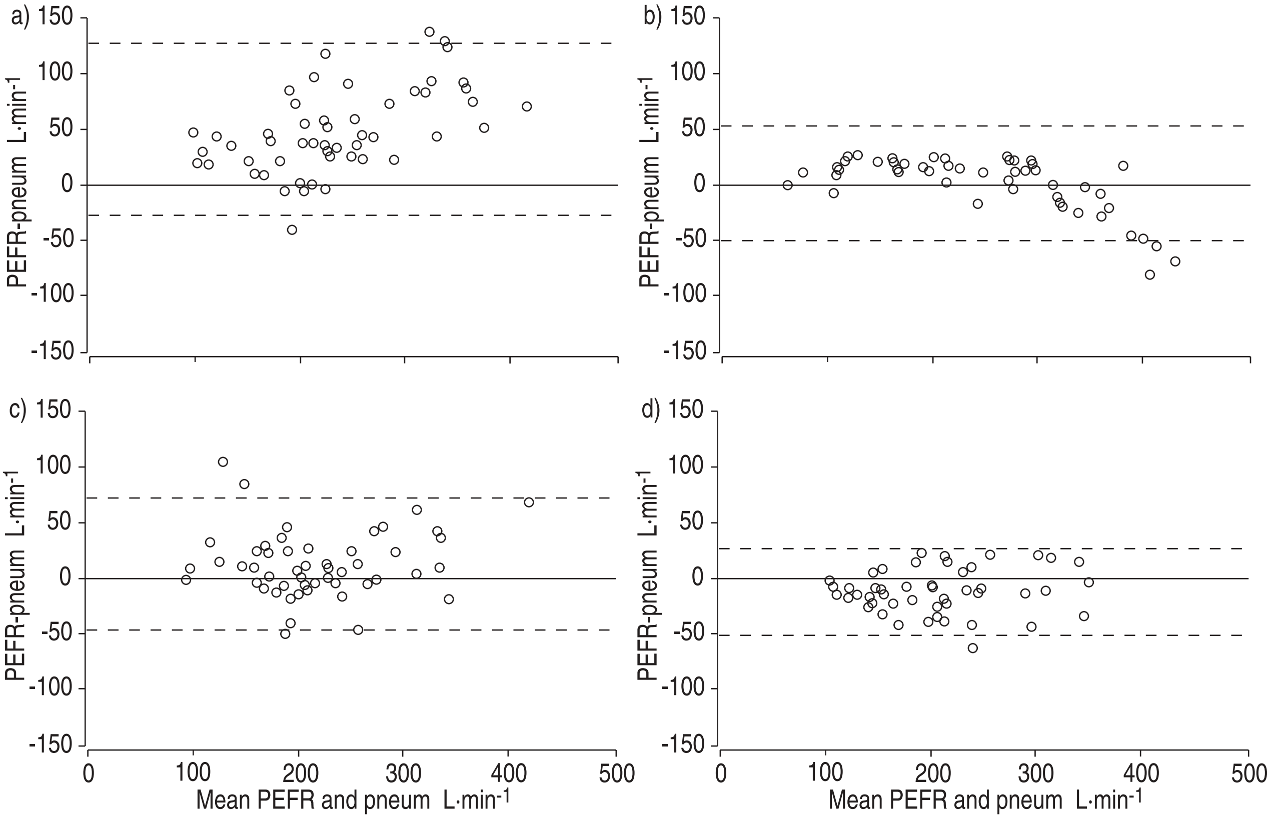

Fig. 2. – Bland and Altman plot of the low-range (LR) peak flow meters measured sequentially with the pneumotachograph. a) LR Ferraris; b) LR Micro Medical; c) LR Miniwright; d) LR Personal Best. ——— : zero difference; – – – : mean±2SD. PEFR: peak expiratory flow rate from peak flow meter; pneum: pneumotachograph reading.

Table 2. – Comparison of peak flow meter readings with pneumotachograph

Peak flow meter	Cumulative score
Adult peak flow meters	
Assess	24
Ferraris	28
Micro Medical	14
Miniwright	23
Personal Best	13
Vitalograph	18
Truzone	15
Low-range peak flow meters	
LR Ferraris	17
LR Micro Medical	9
LR Miniwright	13
LR Personal Best	9

The lower the score, the better the peak flow meter.

Discussion

The two series of tests on both groups of peak flow meters evaluate different aspects of accuracy of the instruments. The variability of the measurements with two instruments in series reflects more the instrument variability; the sequential measurements reflect both instrument variability and patient variability. The latter can be brought about by reproducibility problems of the peak flow manoeuvre, or if the patient inadvertently blocks part of the outflow from the instrument by the way he or she holds the instrument. Squeezing the body of the peak flow meter might impede the movement of the piston in the Miniwright, the Vitalograph, and the Truzone; this is not possible in the Assess, the Personal Best, Ferraris, and Micro Medical. In this perspective, one would expect the sequential measurements to have larger mean deviations from the standard instrument than the measurements with both instruments in series. However, this mean deviation is rather heavily weighted by the readings in the high flow ranges. Furthermore, some peak flow meters overread in the middle range, and underread the higher levels of flow. As a result, in the calculation of the mean difference over the total range, this mean difference may become rather small. This may explain the similar ranges in mean deviations of peak flow in both series of measurements.

The ranking of the various instruments is performed according to several aspects of accuracy of the instruments. The precision of the instruments could not be tested, since we had no access to a generator of a reproducible input signal, such as a computer-driven piston. Multiple forced expiratory manoeuvres in the same peak flow meter would always comprise instrument variability as well as subject variability. The latter has a coefficient of variation of approximately 6%. For sequential peak flow measurements within one subject, the precision may be as important as the accuracy. According to DEKKER *et al.* [6], a change of 60 L·min^{-1} is adequate to detect a change in peak flow due to a bronchodilator test. Consequently, the precision of the peak flow meter should be better than this value.

Placing two instruments in series may cause deviations in flow patterns and may affect the reading of one of the instruments. The pneumotachograph, however, has a cone at both sides, to avoid turbulence at the inflow and outflow. Thus the interference between the two instruments was kept at a minimum level.

PEDERSEN *et al.* [7] performed experiments with the Miniwright, with and without a pneumotachograph in ser-ies. In their experiments the peak flow meter was upstream of the pneumotachograph. The peak flow measured with the pneumotachograph in series was hardly different (<1%) at flow levels below 600 L·min^{-1}. At 720 L·min^{-1}, the flow measured by the pneumotachograph was 3% less when the peak flow meter was in series. This was ascribed mainly to the change in frequency response of the system, and was hardly due to the higher resistance of the two meters in series.

Some peak flow meters such as Ferraris and Miniwright underestimate in the high ranges, and overestimate in the middle range. This deviation of the instrument may be potentially detrimental for the management of obstructive disease in patients, since slight to moderate decreases in true peak flow are not reflected, or strongly attenuated, in the readings of the peak flow meter. Patients and their doctors assume that the peak flow value remains at the same level, even when the true peak flow has dropped considerably. This problem has been recognized by the manufacturers of the Miniwright, who also provide instruments with a nonequidistant scale. This makes the data of home measurements with the peak flow meter, more comparable to peak flow measurements performed in the lung function laboratory with a flow-volume curve. Furthermore, they provide conversion charts for both scales. However, this may lead to confusion if one does not adhere to a very strict regimen of documenting whether the value in the patient record is a converted one or not.

The guidelines of the National Heart, Lung and Blood Institute (NHLBI) [8] recommend that:

1) The meter have a range of 100–400 L·min^{-1} for children and a 100–700 L·min^{-1} range for adults. All peak flow meters tested here, fulfilled that criterion.

2) The meter be accurate over the full range to ±10%. The adult Miniwright (equidistant scale) and Ferraris peak flow meters did not meet this criterion.

3) The reproducibility of the meter be 10 L·min^{-1} or ±5% of the reading, whichever is larger. This aspect of the NHLBI criteria could not be tested in this experiment, since we had no computer-driven piston pump, providing reproducible flow rates.

4) The interdevice variability be ±5%. We did not test this aspect. IMBRUCE [9] has tested four adult peak flow meters: Assess, Miniwright, Vitalograph, and Ferraris. Only in the very low ranges of the reading (100–125 L·min^{-1}), none of these meters met this criterion.

5) The product labelling contain a statement on the useful life of the peak flow measurement. None of the meters contained such a label. In a previous study we tested the reproducibility of the Miniwright peakflow meter after 4.5 yrs of daily use by 50 patients. There was a small overreading of 10.2±3.77 L·min^{-1} (p=0.009) on the used meters as compared with new, unused meters [10]. The useful life of the Miniwright therefore seemed to be at least 4.5 yrs.

SHAPIRO *et al.* [11] also tested the effect of wear in the Miniwright and the Assess peak flow meters. They also found that the peak flow meters showed overreading of approximately 100 L·min^{-1}, over the whole range, after 2 yrs. SIMMONS *et al.* [12] showed that after 200 uses, the comparison between the Miniwright and the Ferraris *versus* a calibrated pneumotachograph did not result in any bias, whereas the Assess did develop a bias.

The findings of our study are in agreement with our previous findings with the Assess peak flow meter [13]. In that study we also found a systematic underreading of 19–34%, by this peak flow meter, as compared to the same pneumotachograph.

EICHENHORN *et al.* [14] tested the Miniwright and the Vitalograph peak flow meters in a comparable way: in series with a Fleisch pneumotachograph. They found an overreading of the Miniwright of 15.3%, and a small underreading of the Vitalograph (-2.7%). This shows tendencies in the opposite direction to those found in our study. One of the explanations for this discrepancy might be that they used a hand-driven calibrating syringe for generating flows, and they measured at very low flows (150 L·min^{-1}) in adult peak flow meters. Especially in the Vitalograph, there were very high deviations at this low flow range. We did not use these low flows. PEDERSEN *et al.* [15] also found an overreading up to 80 L·min^{-1} in the middle range of flow for the Miniwright and the Ferraris. The Assess peak flow meter showed only minor deviations of <10 L·min^{-1} over the whole range of peak flows. After mathematical correction for gas density, altitude, temperature, and humidity, the reading of all these meters was within 10% of the standard, except for flow ranges below 150 L·min^{-1}.

MILLER *et al.* [16] tested the Miniwright, Vitalograph, Ferraris, and Assess adult peak flow meters, and the low-range meters of Miniwright, Assess, and Vitalograph, using two different computer-driven piston pumps. They also tested the Fleisch pneumotachograph with this system, and showed that it had no appreciable deviations in flow values. Thus the pneumotachograph indeed seems to be a valid instrument for calibrating peak flow meters. The low-range peak flow meters performed better than the adult ones, in the study of MILLER *et al.* [16]. This is in agreement with our findings. IMBRUCE [9] tested 10 adult Miniwright, Assess, Vitalograph, and Ferraris peak flow meters, with a computer-driven piston pump. He concluded that the Assess meters were the only ones that met all criteria of the NHLBI.

SLY *et al.* [17] tested in 12 boys (11–17 yrs) with asthma, a series of low-range peak flow meters, LR Miniwright, LR Ferraris, LR Vitalograph, and Breathtaker. The boys also performed, almost simultaneously, peak flow manoeuvres on a Welch-Allyn spirometer. In general, the relation between changes in lung function shown by the spirometer and by the miniflow meters was poor. The Miniwright detected six out of 19 clinically important deteriorations in lung function; the Ferraris six out of 15; Vitalograph six out of 18; and Breathtaker three out of 21. The authors conclude that, "miniflow meters for measuring peak expiratory flow may produce clinically misleading results when used by children in the community".

In conclusion, various brands of peak flow meters differ substantially in the level of agreement with pneumotachograph readings. Some peak flow meters substantially attenuate falls in true peak flow values. In the adult meters, the Personal Best and the Micro Medical seem to have the closest agreement with the pneumotachograph. The low-range meters showing the best agreements with the pneumotachograph were the LR Personal Best and LR Micro Medical.

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