

PHENOTYPES AND DIAGNOSIS

Accuracy of the Piko-1 Pocket Spirometer

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Background. Good asthma control is the main goal of long-term asthma treatment. According to the Global Initiative for Asthma (GINA) guidelines (www.ginasthma.com), medical professionals assess asthma control based on specific questions regarding asthma symptoms and by spirometry measuring forced expiratory volume in 1 second (FEV₁). Patients trained in early self-detection of asthma exacerbations use a symptom-based questionnaire, such as the Asthma Control Test (ACT) [Nathan RA, Sorkness CA, Kosinski M, et al. Development of the Asthma Control Test. A survey for assessing asthma control. *J Allergy Clin Immunol* 2004; 113:59–64]. However, some patients may prefer harder indicators, like peak flow values, when considering how to act within their regular asthma self-management plan. **Objectives.** Monitoring of FEV₁ at home could be an even more valuable alternative to recording peak flow values. The inexpensive handheld pocket spirometer “Piko-1®” offers the opportunity to monitor and store consecutive FEV₁ values. This study assesses the accuracy of the Piko-1 device. **Methods.** Twenty volunteers tested 20 Piko-1 devices over five consecutive days. All results were compared to daily FEV₁ values, as measured by a calibrated reference spirometer. **Results.** Overall, the accuracy was acceptable, although Piko-1 tended to underestimate FEV₁ in the lower range. Moreover, there was no evidence of major heterogeneity between Piko-1 devices. **Conclusion.** The Piko-1 FEV₁ measurements are sufficiently accurate to start a clinical trial to compare the detection of asthma exacerbations with this device and based on asthma symptoms alone.

Keywords asthma, asthma monitoring, FEV₁, peak flow, spirometry

INTRODUCTION

In more than one-half of all adult asthma patients in Switzerland the disease is not sufficiently controlled (1). Strengthening asthma self-management seems to be a promising strategy to improve this situation. The Swiss lung league recently started a countrywide campaign for asthma education that includes teaching self-management skills. The aim of the campaign is to empower patients in the same way that modern diabetes therapy has. Written asthma action plans are an integral part of self-management. They are based on monitoring symptoms and/or peak flow values. However, peak flow monitoring in asthma does not appear to be any better than symptom monitoring only (2). FEV₁, measured by spirometry, could be a more sensitive parameter in detecting changes in bronchial obstruction compared with peak flow (3–5).

Due to its high cost, home spirometry has not achieved wide use, apart from detecting early rejection in lung transplant patients (6). Even today, in occupational medicine, peak flow monitoring is the recommended assessment tool for the work place and at home (7). However, the Piko-1 pocket spirometer, being relatively inexpensive, capable of storing data and easy to use, might be a viable candidate to replace peak flow meters.

To date, there is little in the way of published data regarding the accuracy of this pocket spirometer (8–10). Therefore, in this inquiry, the accuracy of the Piko-1 was

studied by comparing it to a calibrated spirometer equipped with a Fleisch pneumotachograph (pneumotach).

The study had been presented to the appropriate local ethical committee. According to the rules of the committee, a waiver was issued declaring that formal approval was unnecessary.

MATERIAL AND METHODS

Instruments

The ZAN 500 bodyplethysmograph (nSpire Germany GmbH, Oberthulba, Germany), based on a pneumotach, was used as a reference spirometer during the trial. Calibration was performed daily with a standardized 3000 mL syringe provided by the producer.

The Piko-1 (Ferraris Respiratory™, a company belonging to nSpire Health™, Louisville, CO, USA) is a small pocket spirometer measuring 75 × 35 × 20 mm and weighting 35 g. A removable mouthpiece is fixed to the top of the device. Just behind it, there is a metal plate that bows with the expired air. The movement is converted into measures of peak expiratory flow and FEV₁, which are then displayed digitally on a liquid crystal screen. Up to 96 measurements can be stored. Additionally, three color zones are visible on the display according to the traffic light system of peak flow interpretation in asthma self-management: green for results of over 80%, yellow for 50–80%, and red for results of less than 50% of an individual's best. The reference values of the Piko-1 can be adjusted for each individual. An infrared port is located at the bottom of the Piko-1, allowing data transfer to a

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serial interface cradle to download data to a computer. The software is easy to use and guarantees storage of data from different patients. Data can be reviewed by date and time in either graphical or tabular format. The accuracy of the Piko-1 device, as given by the producer, is 3.5% or 0.1 L for the FEV₁. The device is powered by batteries, lasting approximately 2 years if used six times a day according to the manufacturer's leaflet (www.nspirehealth.com).

Design

To compare the Piko-1 with a reference spirometer, two different approaches were identified: a longitudinal study, as in asthma monitoring with a peak flow meter, and single spot measurements with many Piko-1 devices to reveal possible differences across different Piko-1 devices. This study uses a combination of both the approaches. The measurements were performed on non-asthmatic volunteers. With asthmatics, consecutive measurements could result in declining values with increasing bronchial obstruction in the course of repetitive forced expiratory maneuvers due to bronchial hyperreactivity.

The study was performed in 2007. Taking into account that measurements from different Piko-1 devices may vary, 20 different Piko-1 devices were tested in 20 healthy adult volunteers, of which 17 were female and 3 male with ages ranging from 21 to 54 years. They all were coworkers of the Luzerner Hoehenklinik at Crans-Montana, which was the cause for the skewed distribution of age and gender of the participants. All denied doctor's diagnosed asthma, and their initial spirometry showed results within normal limits.

The 20 Piko-1 devices were tested on all volunteers. Initially they received thorough verbal instructions according to the ATS/ERS guidelines (11) and a demonstration until they were able to perform two consecutive measurements with a range of FEV₁ < 0.2 L. Thereafter, the subjects came in each day over a period of five consecutive days. During each session, they performed measurements with four Piko-1 devices and with the reference pneumotach within 30 min. For each device, two tests were performed. The order of devices, including the reference spirometer, was randomized according to a Latin square design with rows representing subjects and columns representing the temporal order of the Piko-1 devices, that is, guaranteeing that each device would appear once in each row of the Latin square.

For the Piko-1 device, the measurement was repeated twice. The best FEV₁ was accepted if the two values did not differ by more than 0.2 L. Only the two best results were stored. Tests with the ZAN 500 pneumotach were performed according to International Guidelines and the best daily result was stored.

Sample Size Calculation

Given the study design, $n = 20$ patients was deemed enough to provide sufficiently precise estimates. For instance, with a true correlation of 0.9 between Piko-1 and pneumotach measurements across different healthy persons, the observed correlation among 20 randomly selected persons would be in the interval (0.76, 0.96)

with a probability of 95%. If the true correlation were 0.95, the observed correlation would lie in the interval (0.88, 0.98) with a probability of 95%.

Statistical Analysis

First, the means and standard deviations (SDs) of all Piko-1 and all pneumotach measurements were computed. Moreover, device-specific means and SDs of the differences between Piko-1 measurements and the respective pneumotach measurements, as well as rank correlation coefficients and regression slopes between Piko-1 measurement and pneumotach measurements were computed. These device-specific measures were summarized by range and quartile. Similarly, subject-specific SDs of pneumotach and Piko-1 measurements and of the differences between pneumotach and Piko-1 measurements were computed. These measures were also summarized by range and quartile. To assess the relative importance of subject, device and session factors in explaining the observed differences between Piko-1 and pneumotach measurements, a mixed linear model analysis was performed, with the differences as dependent variables and an intercept parameter with subject, device, and day of measurement nested within subject as random factors. This analysis also served to assess the statistical significance of the average difference between Piko-1 and pneumotach measurements. Piko-1 and pneumotach measurements were visually compared using a scatter plot and a Bland–Altman plot. For this purpose, the four Piko-1 measurements from each session were averaged. To test the hypothesis that the slope between Piko-1 and pneumotach measurements equals 1, the individual daily means of the Piko-1 measurements were regressed on the respective concurrent pneumotach measurements. Since the residuals of this regression model were correlated within and between subjects, the standard error of the regression slope had to be corrected using the random variance estimates for subjects and devices provided by the mixed model analysis. Details of this method are described in the Appendix. To test the assumption of a linear relation between Piko-1 and pneumotach measurements, the square of the pneumotach measurement was included as a covariate.

Since there was significant heterogeneity of differences between Piko-1 and pneumotach measurements across subjects, a second analysis was performed, omitting the worst measurement of each subject. The worst measurement was defined as the one with the largest deviation from the reference value. This might provide a more realistic picture of the performance of Piko-1 devices in a normal clinical setting, where patients could first be tested on two devices and be given the one that performs better.

RESULTS

Overall, 100 measurements were performed with the reference spirometer. The mean value of those 100 measurements was 3.09 L (SD 0.66 L). The mean value of the 400

TABLE 1.—Distribution of Piko-1 and pneumotach measurements.

Type of device	<i>n</i>	Mean	SD	Range
Reference ^a	100	3.07	0.66	2.05–5.07
Piko-1	400	2.99	0.73	1.42–5.23

Note: ^aPneumotach spirometer.

measurements collected with 20 different Piko-1 devices was 2.99 L (SD 0.73 L). Data are shown in Table 1. When taking into account the random effects of the subject, device, and session factors, the difference between the mean of Piko-1 measurements and the mean of pneumotach measurements was -0.077 L, with a 95% confidence interval of $(-0.156$ L, 0.001 L) and $p = .053$. However, when the worst measurement from each subject was omitted, the estimated difference was -0.085 L with a 95% confidence interval of $(-0.156$ L, -0.013 L) and $p = .02$. Thus, on average, Piko-1 measurements were about 3% lower than the corresponding pneumotach measurements. A scatter plot of the 400 Piko-1 measurements against the concurrent reference measurements shows the distribution of all measurements (Figure 1).

Figure 1 shows that the regression line between Piko-1 and pneumotach measurements approaches the identity line from below for increasing values of FEV₁, suggesting that Piko-1 underestimates FEV₁ slightly in the lower range. However, the slope between the session means of the Piko-1 measurements and the respective pneumotach measurements was not significantly larger than 1 (Table 2). Moreover, there was no indication of a nonlinear characteristic between Piko-1 and pneumotach measurements.

Subject (27%), device (5%), and day of measurement (15%) factors explained about half of the variation in the

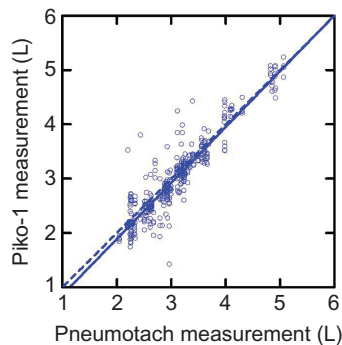


FIGURE 1.—Scatter plot of the 400 Piko-1 measurements against the concurrent reference measurements ($n = 100$), including identity and regression lines.

differences between Piko-1 and pneumotach measurements (i.e., 47%). Obviously, device only accounts for a relatively small fraction of total variability.

Table 3 shows the distribution of device-specific characteristics. Consistent with the preceding result, the median slope was slightly higher than 1. After excluding the worst measurement of each device, the median of device-specific rank correlation coefficients increased from 0.93 to 0.95 and the lowest correlation value changed from 0.67 to 0.84.

Table 4 shows the distribution of subject-specific characteristics of the pneumotach and the Piko-1 measurements. Within-subject SDs of the Piko-1 measurements were clearly higher than those of the pneumotach measurements. However, they also comprise variation across different Piko-1 devices. Moreover, average differences between Piko-1 and pneumotach measurements were negative for about 75% of the subjects. Exclusion of the worst Piko-1 measurement for each subject not only reduced the within-subject variability of Piko-1 measurements considerably but also lowered their individual means slightly.

It is worth exploring whether the variability of differences between Piko-1 and pneumotach measurements depends on the average FEV₁ of a subject. Figure 2 suggests that this might be the case, but rather that differences might vary slightly less at higher levels of FEV₁.

DISCUSSION

Our results suggest that Piko-1 measurements are, on average, slightly lower than the measurements from a calibrated pneumotach. Moreover, the observed slope of 1.04 between Piko-1 and pneumotach measurements means that the underestimation was slightly more pronounced at lower levels of FEV₁ (which can also be seen in the Bland–Altman plot, Figure 2). However, this might just be an incidental finding. In fact, differences between Piko-1 and pneumotach measurements were found to vary markedly across subjects. And, if random subject, device, and session effects were properly taken into account, the difference between the observed slope and slope 1 was far from being statistically significant. Moreover, we did not find any indication of a nonlinear relation between Piko-1 and pneumotach measurements. However, the variability of Piko-1 measurements is larger than that of the pneumotach measurements. As we did not perform repeated measurements with the same device in our subjects, further studies are needed to properly estimate within-subject variability of individual Piko-1 devices.

TABLE 2.—Slope between Piko-1 and pneumotach measurements.

	Estimated slope	95% confidence interval	<i>p</i> -Value
Simple regression model ^a including all Piko-1 measurements	1.029	0.923–1.134 ^b	0.59 ^b
Simple regression model ^a without worst Piko-1 measurement in each subject ^c	1.040	0.988–1.093 ^b	0.51 ^b

Notes: ^aModel derived from session means of Piko measurements and session-specific pneumotach measurements ($n = 100$).

^bConfidence intervals and *p*-values were adjusted for correlations of residuals within subjects and devices. The *p*-value refers to the deviation of the estimated slope from 1.

^cThe worst measurement was defined as the one with the largest deviation from the respective reference value of the pneumotach.

TABLE 3.—Distribution of individual device characteristics.

	Minimum	P25	P50	P75	Maximum
Device-specific rank correlation coefficients ^a	0.67	0.90	0.93	0.95	0.97
Device-specific slopes ^a	0.87	1.0	1.02	1.09	1.13
Device-specific means of differences ^a	−0.237 L	−0.122 L	−0.083 L	−0.008 L	0.084 L
Device-specific SDs of differences ^a	0.147 L	0.174 L	0.217 L	0.312 L	0.468 L
Device-specific rank correlation coefficients ^a , without worst measurement of each device ^b	0.84	0.94	0.95	0.96	0.97
Device-specific slopes ^a , without worst measurement of each device ^b	0.92	1.02	1.04	1.08	1.16
Device-specific means of differences ^a , without worst measurement of each device ^b	−0.212 L	−0.151 L	−0.074 L	−0.048 L	0.065 L
Device-specific SDs of differences ^a , without worst measurement of each device ^b	0.134 L	0.155 L	0.172 L	0.207 L	0.345 L

Notes: ^aBetween Piko-1 and concurrent pneumotach measurements.

^bFor each device, the measurement most strongly deviating from the respective pneumotach measurement was omitted

TABLE 4.—Distribution of subject-specific characteristics of Piko-1 and pneumotach measurements.

	Minimum	P25	P50	P75	Maximum
Subject-specific SDs of pneumotach measurements	0.022	0.051	0.069	0.117	0.235
Subject-specific SDs of Piko measurements	0.094	0.117	0.194	0.276	0.348
Subject-specific means of differences	−0.364	−0.183	−0.060	0.013	0.237
Subject-specific SDs of differences ^a	0.085	0.143	0.198	0.288	0.355
Subject-specific SDs of Piko measurements, without worst measurements of each subject ^b	0.075	0.109	0.123	0.184	0.292
Subject-specific means of differences ^a , without worst measurements of each subject ^b	−0.337	−0.172	−0.099	−0.026	0.226
Subject-specific SDs of differences ^a , without worst measurements of each subject ^b	0.068	0.114	0.145	0.187	0.285

Notes: ^aBetween Piko-1 and concurrent pneumotach measurements.

^bFor each subject, the measurement most strongly deviating from the respective pneumotach measurement was omitted

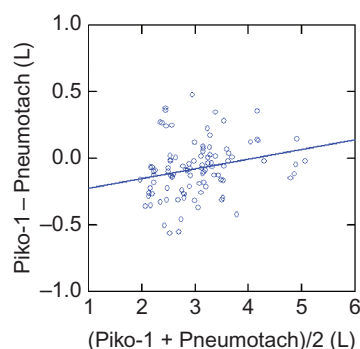


FIGURE 2.—Scatter plot of the individual SDs of differences between Piko-1 and pneumotach measurements and the average individual levels of FEV₁ as measured by the pneumotach spirometer.

Although the accuracy of Piko-1 devices showed considerable variability (Table 3), there is no clear evidence that some of the devices were worse than others. The observed distribution of the frequency of performing worst across devices is consistent with the null hypothesis of no heterogeneity between devices. Likewise, none of the subjects had been the cause of the worst measurement in more than three of the devices, which would have been a relatively unlikely event under the null hypothesis of indistinguishable subjects.

The international Global Initiative for Asthma (GINA) guidelines strongly recommend self-management plans for asthmatic patients including written action plans the size of a credit card (12). The use of action plans enables asthmatics to recognize asthmatic exacerbations early and to treat them in an adequate fashion when away from home or

unable to contact their physician. The lack of an action plan has been found to be a risk factor of near fatal asthma attacks (13).

Action plans are often based on asthmatic symptoms that will be interpreted with the aid of the traffic light system (14). However, patients with severe asthma often have an impaired perception of their bronchial obstruction (15). The routine use of long-acting beta-agonist in moderate and severe asthma may suppress typical asthmatic symptoms, such as nighttime cough or awakening due to acute asthma (16). Both the factors underline the need for additional objective parameters in some patients when assessing asthma control. Regular peak flow measurements, being cheap and simple, have been used to quantify the day-to-day variability of bronchial obstruction. Some studies have confirmed the value of peak flow monitoring in patients with moderate to severe asthma (17, 18). However, in multiple clinical trials, peak flow monitoring did not seem to be more sensitive in detecting an asthmatic deterioration than simple assessment of asthma symptoms alone (19–21). Different reasons may explain this: peak flow compared with FEV₁ is less sensitive in detecting airway obstruction (3). Moreover, many peak flow meters do not measure accurately (22).

For some years now, handheld spirometers for home use have been available and evaluated (23–25). Formerly, they were expensive and not covered by health insurance programs in Switzerland. Now they are cheaper. A digital pocket spirometer has two advantages over a classical peak flow meter: first, it is capable of storing data from hundred consecutive measurements and plotting them graphically with a printer. Second, a pocket spirometer measures not only peak flow, but also FEV₁.

Unfortunately, an initial trial (26) with a small group of children using a somewhat more sophisticated home spirometer, the Koko Peak Pro® from the same manufacturer as the Piko-1, gave disappointing results. The study did not try to compare this device with a reference spirometer but looked at the correlation between spirometric values and clinical parameters. It failed to reveal a correlation of peak flow variation and an older asthma severity index that is not in use anymore in Switzerland since the introduction of the GINA questions to assess asthma control in 2006. Another study evaluating home spirometer use in children using another device was more promising (25). In contrast, our trial did not include children limiting the results with adults.

Piko-1 devices were used in a preliminary trial comparing two pocket spirometers, a Mini Wright peak flow meter and a Vitalograph reference spirometer (9). A good intra-class correlation coefficient was found for FEV₁ (0.98), and to a lesser extent for peak flow (0.90). The Mini Wright peak flow meter was the only device with a non-linear characteristic, relative to the reference device. A second trial comparing Piko-1 to a reference spirometer found that Piko-1 measurements overestimated FEV₁ values by 4%, thus contradicting our results (10). We cannot give a compelling explanation for this discrepancy. Our study differs in design from the trials cited above. We not only compared single sequential spot measurements of a Piko-1 device and a reference spirometer but also tested 20 different Piko-1 devices on all subjects in a longitudinal fashion.

Overall, an acceptable correlation was shown between Piko-1 measurements and measurements of the reference spirometer. However, three potential minor limitations have been identified: first, in the lower range, Piko-1 devices tended to underestimate FEV₁; second, some Piko-1 devices seemed to be slightly less accurate than others; and third, the difference between Piko-1 measurements and reference spirometer values varied between subjects, suggesting that some volunteers performed consecutive tests better than others.

Of the first, the same problem had been identified in peak flow devices. Some of them underestimated peak flow in the lower range too. For the second, this trial showed that 18 out of 20 Piko-1 devices performed well in 75% of the subjects. Up to 10% of the devices might not have been accurate enough. It seems reasonable that in daily practice, when patients are first instructed on taking Piko-1 measurements, two control measurements should be performed with a calibrated spirometer to compare the results and identify lower quality Piko-1 devices. Regarding the third potential limitation, at least 75% of patients will monitor FEV₁ in an accurate fashion. In peak flow monitoring, too, not all patients are capable of generating consistent and valid measurements. Patients unable to comply with FEV₁ home monitoring with a Piko-1 device will be identified within the first weeks of usage. Analogous to inhalation devices, physicians should ask their patients to bring their Piko-1 devices to every appointment to demonstrate the measurement technique

and to compare the values initially and at the end of a trial phase of 4–6 weeks with reference spirometer readings.

Unfortunately, the handling of the Piko-1 spirometer may pose some problems: the air outlet is placed on the opposite site of the mouthpiece. Even a slight coverage of the outlet with the fingers may falsify the data. To avoid this, it is suggested that patients hold the Piko-1 device in the right hand in a flat, vertical position when performing spirometry. This advice is only found in the text of the manufacturer's leaflet: a picture on the package of the device demonstrates an incorrect way of application. Physicians and respiratory nurses have to point out this incongruity when instructing patients on using the device. Regular control of a patient's technique is indicated.

Since the beginning of our study, a newer version of Piko-1 has been released, the Piko-6. This device does not differ from Piko-1 in terms of flow detection but in addition to the features of Piko-1, Piko-6 measures FEV₆, a surrogate marker of FVC (27), and calculates the FEV₁/FEV₆ ratio. This may help to identify measurements where poor effort is responsible for low FEV₁ values and not bronchial obstruction.

CONCLUSION

The data generated by the research justify prospective studies with asthma patients to compare the assessment of asthma control on the basis of defined symptoms, peak flow with conventional devices, and FEV₁ as measured by a Piko device.

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DECLARATION OF INTEREST

All three authors hereby declare that there exists no conflict of interest regarding the content of this paper submitted to the *Journal of Asthma*.

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APPENDIX

Setting:

Analysis of session means (i.e., based on 100 sessions, 5 from each of the 20 subjects).

Definitions:

n = number of subjects.

k = number of sessions per subject.

m = number of measurements per session.

X = design matrix with $n \cdot k$ rows and $p + 1$ columns, whose first column consists of 1's.

I = identity matrix of dimension $n \cdot k$.

$S(i)$ = function returning the subject of the respective session.

$D(i)$ = function returning the set of devices used in the respective session.

A_1 = block diagonal $(n \cdot k, n \cdot k)$ matrix with blocks defined by subjects.

Each block is a (k, k) matrix consisting of 1's.

$$A_1(i, j) = 1 \text{ if } S(i) = S(j) \\ 0, \text{ otherwise}$$

A_2 = $(n \cdot k, n \cdot k)$ matrix taking into account correlations deriving from shared devices, with entries being defined by

$A_2(i, j)$ = number of elements in $D(i) \cap D(j)$;

σ_1^2 = variance of subject effect;

σ_2^2 = variance of device effect;

σ_3^2 = variance of period effect;

σ_4^2 = unexplained variance.

With these constituents, the covariance matrix of residuals can be written as

$$C = (\sigma_3^2 + \frac{\sigma_4^2}{m})I + \sigma_1^2 A_1 + \frac{\sigma_2^2}{m^2 A_2}$$

The covariance matrix of regression estimates is estimated by $(X^T X)^{-1} X^T C X$

In our case, $n = 20$, $k = 5$, $m = 4$, and $p = 1$ or 2.

If $p = 1$, then the only covariate column consists of the session values of the Pneumotach-measurements.

If $p = 2$, then there is a second covariate column defined by the squares of the entries of the second column.

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