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Home spirometry and asthma severity in children

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ABSTRACT: The usefulness of peak expiratory flow monitoring is disputed because of the unreliability of written peak flow diaries. The aim of the present study was to examine the relationship of peak flow and forced expiratory volume in one second (FEV_1) variation to other estimates of asthma severity in children, using an electronic home spirometer with automatic data storage.

Over a 3-month period, 36 children with mild-to-moderate persistent asthma recorded peak flow and FEV_1 electronically twice daily and noted an asthma severity score in a written diary. Bronchial responsiveness was assessed at the beginning and bronchodilator response and asthma-specific quality of life at the end of the study.

Variations in peak flow correlated significantly but weakly to bronchial responsiveness and bronchodilator response, but not to the asthma severity score or quality-of-life scores. Within-individual correlations between asthma severity scores and home spirometry indices and between peak flow and FEV_1 were highly variable.

In conclusion, variations in peak flow and forced expiratory volume in one second, obtained by home spirometry, show poor concordance with other indices of disease activity and with each other. This limits the usefulness of home spirometry in childhood asthma.

KEYWORDS: Asthma severity, childhood asthma, home monitoring, peak expiratory flow, self-management

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International guidelines on the management of asthma stress the importance of pulmonary function tests to monitor the clinical course of asthma and to achieve optimal control [1–3]. Measurements of bronchial responsiveness (BR) provide an estimate of asthmatic airway inflammatory activity and can be used in monitoring childhood asthma [1, 3, 4]. A study in adults has shown that adjusting maintenance therapy based on BR measurements improves asthma control and reduces asthmatic airway inflammation [4]. However, the downside of BR measurements, and of pulmonary function tests in general, is that they have to be performed in hospital and only provide a snapshot impression of asthma status, rather than reflecting the inherent variability of the disease [1–3, 5]. This variation of pulmonary function is considered to be one of the key characteristics of asthma [1, 2]. Day-to-day home monitoring of peak expiratory flow (PEF) is thought to reflect this variability and is, therefore, recommended in guidelines as a monitoring tool [6]. Early studies have found a strong correlation between PEF variation and BR in adult asthmatics [7, 8]. However, more recent studies have found a weaker relationship between PEF variation and BR in patients treated with inhaled corticosteroids [9–12]. In all previous studies on the relationship between PEF variation and other indices of asthma severity [13–15], mechanical PEF meters and written PEF diaries have been used. Several studies have shown that written PEF diaries are unreliable [16, 17] and it has been suggested that using electronic home spirometers could overcome this drawback [18]. Before being able to use electronic home spirometers in a asthma self-management, the usefulness of these instruments in accurately reflecting asthma severity should be investigated. Therefore, the present study was designed to examine the relationship of home measured PEF and forced expiratory volume in one second (FEV_1) and their variation, using an electronic home spirometer, to other parameters of asthma severity in children with chronic persistent asthma.

PATIENTS AND METHODS

Patients aged 6–16 yrs with mild-to-moderate persistent asthma were recruited at the current authors' outpatient clinic (Princess Amalia Children's Clinic, Isala klinieken, Zwolle, The

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Netherlands). All had been using maintenance therapy with inhaled corticosteroids in daily dosages $\leqslant$400 μg·day^{-1} (budesonide, beclomethasone) or $\leqslant$200 μg·day^{-1} (fluticasone) for $\geqslant$6 months and were able to perform pulmonary-function measurements reproducibly [3, 5]. Children who had used systemic corticosteroids <4 weeks before the start of the study were excluded. Written informed consent was obtained from all participants and their parents. The study was approved by the hospital ethics review board.

For characterisation purposes, different lung-function measurements were completed by these patients. Flow–volume loops were performed on a Jaeger Masterlab pneumotachograph (Erich Jaeger, Würzburg, Germany), following American Thoracic Society/European Respiratory Society guidelines [3, 5]. Short-acting and long-acting bronchodilators were withdrawn for 8 h and 24 h, respectively, prior to each session. At the start of the 3-month study period, the degree of BR was assessed using a methacholine provocation test with the dosimeter method and results were expressed as the provocative dose of methacholine causing a 20% fall in FEV_1 [3, 19]. At the end of the 3-month period, the patients performed flow–volume loops before and after inhalation of 800 μg salbutamol to assess bronchodilator response [5]. Children aged $\geqslant$7 yrs, and one parent of each patient, completed the validated Dutch versions of the disease-specific paediatric Asthma (Caregiver's) Quality-of-Life Questionnaire. Responses to these quality-of-life questionnaires were expressed on a seven-point Likert scale; higher scores reflected better quality of life [20, 21].

At the first visit, patients were instructed how to use the electronic portable spirometer (Koko Peak Pro; Ferraris, Louisville, CO, USA) [5, 6, 22]. This home spirometer has been validated using a precision waveform generator (Pulmonary Waveform System; MH Custom Design and Mfg, Midvale, UT, USA) demonstrating its agreement with performance standards as recommended by international guidelines [5].

Patients were instructed to perform three forced expiratory flow manoeuvres twice daily between 06:00–10:00 h and between 18:00–22:00 h throughout the study period. All instructions were given by the same skilled assistant, encouraging the children to obtain optimal lung-function values. Patients were instructed to expire for $\geqslant$2 s and measurements were only accepted if forced vital capacity was more than FEV_1. The device automatically stored the highest of the three correctly performed PEFs on a microchip, along with the accompanying FEV_1.

Throughout the 3-month period, patients also recorded a validated asthma severity score on a continuous visual analogue scale twice daily in a written diary [23]. Score 0 represented the ''worst possible state of their asthma'' and score 10 the ''sensation of having no asthma at all''. Children were instructed to first score their perception of asthma severity, then to perform the forced expiratory flow manoeuvres on their home spirometer and finally to take their medication. Patients also recorded use of rescue bronchodilators in the diary, both as a measure of asthma stability at home and to identify and exclude lung-function values influenced by bronchodilator medication. In order to identify exacerbations of asthma, patients were instructed to return to the clinic if they felt their asthma symptoms could not be controlled with rescue bronchodilators. Such exacerbations and use of systemic corticosteroids were recorded in the diary. Once a month, data from the home spirometer were downloaded to a computer. After careful inspection following a pre-defined algorithm [24], recordings due to technical errors and unexplained outliers were excluded [22]. Adherence to the home recording regime was calculated by comparing the number of recordings expected over ~13 weeks (180 recordings, minus the technical

TABLE 1 Characteristics of 36 asthmatic children completing the study with $\geqslant$80% adherence with home spirometry

Male/female n	25/11
Age yrs	10.4±2.5
Age of onset of asthma yrs	2.8±2.1
Maintenance medication:	
Inhaled corticosteroids %	100
Short-acting bronchodilators on demand %	100
Long-acting bronchodilators %	44
LTRA %	0
Exacerbations requiring systemic corticosteroids %	0
Smoking parent(s) %	31
Positive skin prick test or specific IgE to common inhalant allergens %	89
History of asthma in parent(s) or sibling(s) %	78
Log PD_{20}-methacholine μg	1.98 (1.28–2.91)
FEV_1 % pred	99.1±12.6
QOL children 0–7[#]	6.0±0.81
QOL caregiver 0–7[¶]	6.4±0.48

Data are presented as mean±SD or as median (interquartile range) unless otherwise stated. LTRA: leukotriene receptor antagonists; Ig: immunoglobulin; PD_{20}-methacholine: provocative dose of methacholine causing a 20% fall in forced expiratory volume in one second (FEV_1); % pred: % predicted; QOL: quality of life. [#]: disease-specific QOL of children $\geqslant$7 yrs old (n=34); [¶]: disease-specific QOL of caregivers.

TABLE 2 Results of home spirometry and severity score measurements

Home spirometry	
PEF %PB	81.4±6.3
FEV_1 % pred	85.5±15.5
vPEF ampl/mean	7.9±3.4
$vFEV_1$ ampl/mean	9.5±4.3
Symptom diary	
Use of rescue Salbutamol#	0.5±0.7
Asthma severity score %PB	83.4±12.9

Values are presented as mean±SD. PEF: peak expiratory flow; %PB: percentage of personal best value; FEV_1: forced expiratory volume in one second; % pred: % predicted; vPEF: variation in PEF; ampl/mean: size of day's range as a percentage of the day's mean; $vFEV_1$: variation in FEV_1. #: 100 μg puffs·day^{-1}.

errors) with the number of recordings actually obtained. The PEF and the asthma severity score were expressed as a percentage of the personal best value and the FEV_1 as a percentage of the predicted value [25]. Variation in PEF (and FEV_1) was expressed in terms of the size of the day's range (amplitude) as a percentage of the day's mean [13]. These calculations of diurnal variation were only performed in children with an overall adherence to the home spirometry regime of ⩾80%, in order to obtain reliable variation calculations. The Spearman rank correlation coefficient was applied as appropriate during data analysis [26].

RESULTS

In total, 42 children completed the study. The median overall adherence to the home spirometry and symptom diary keeping regimes was 91.5 and 98.7%, respectively. Six children were excluded because of an adherence with the home spirometry regime of <80%. Technical errors accounted for <10% of the missing data. The clinical characteristics of the remaining 36 children are presented in table 1 and results of home spirometry and asthma severity scores in table 2.

The mean PEF variation (expressed as amplitude/mean) over the 3-month period correlated significantly to BR (Spearman's rank correlation coefficient (r_s)=-0.43; p=0.009) and to bronchodilator response (expressed as a percentage of pre-bronchodilator FEV_1; r_s=0.34; p=0.04), but the scatter was wide (fig. 1). Mean PEF and FEV_1 variation did not show significant

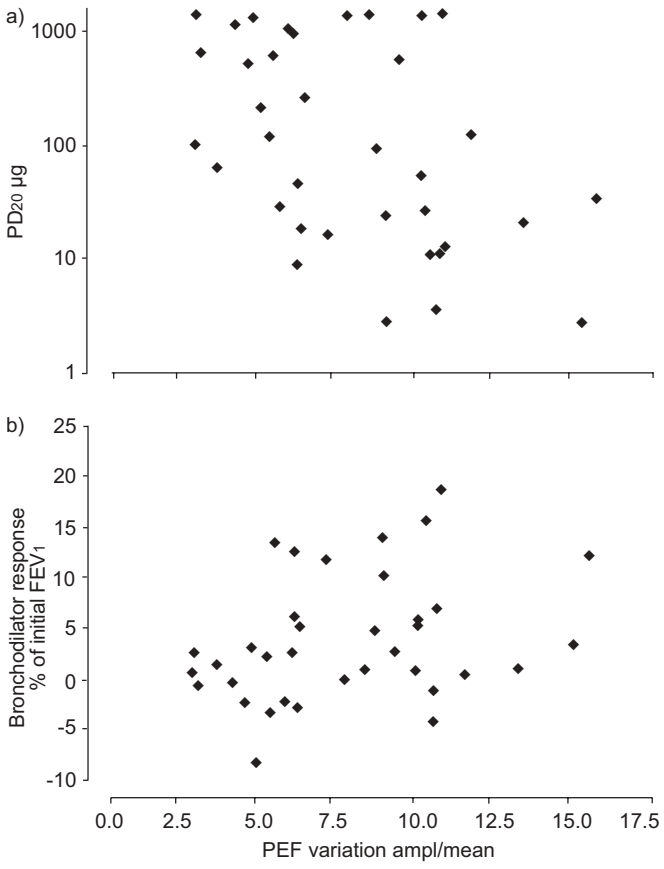

FIGURE 1. Correlation of peak expiratory flow (PEF) variation expressed as size of day's range as a percentage of the day's mean (ampl/mean) to a) dose of methacholine causing a 20% fall in forced expiratory volume in one second (FEV_1; PD_{20}); and b) bronchodilator response. Although the correlation is significant (Spearman's rank correlation coefficient (r_s)= -0.43; p=0.009, and r_s=0.34; p=0.04, a and b, respectively), the scatter is wide.

TABLE 3 Correlations between home spirometry results and asthma severity measures

	PD_{20} μg	Bronchodilator response#	Paediatric asthma quality-of-life score	Asthma severity score¶
PEF % PB	0.35; 0.04 (0.01–0.61)	-0.38; 0.02 (-0.64– -0.06)	-0.10; 0.58 (-0.43–0.26)	0.08; 0.64 (-0.26–0.41)
FEV_1 % pred	0.36; 0.03 (0.02–0.61)	-0.42; 0.01 (-0.66– -0.09)	0.15; 0.39 (-0.20–0.47)	0.06; 0.76 (-0.28–0.39)
vPEF ampl/mean	-0.43; 0.009 (-0.67– -0.11)	0.34; 0.04 (0.00–0.61)	-0.05; 0.79 (-0.39–0.31)	-0.15; 0.39 (-0.46–0.20)
$vFEV_1$ ampl/mean	-0.43; 0.008 (-0.67– -0.11)	0.14; 0.41 (-0.20–0.46)	-0.15; 0.41 (-0.47–0.21)	-0.32; 0.06 (-0.59–0.02)

Data are presented as Spearman's rank correlation coefficient; p-value (95% confidence interval). PD_{20}: dose of methacholine causing a 20% fall in forced expiratory volume in one second (FEV_1); %PB: percentage of personal best value; PEF: peak expiratory flow; % pred: % predicted; vPEF: variation in PEF; ampl/mean: size of day's range as a percentage of the day's mean; $vFEV_1$: variation in FEV_1. #: percentage of initial FEV_1; ¶: %PB.

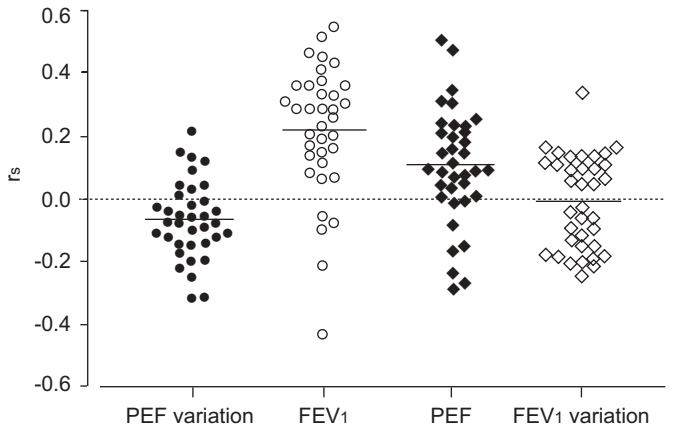

FIGURE 2. Distribution plots of individual Spearman's rank correlation coefficients (r_s; one point per patient) of asthma severity score to peak expiratory flow (PEF) variation (expressed as size of day's range as a percentage of the day's mean (ampl/mean); ●), forced expiratory volume in one second (FEV_1; expressed as percentage of predicted value; ○), PEF (expressed as percentage of personal best; ♦) and FEV_1 variation (ampl/mean; ◇). ——: median values.

correlations to asthma severity score or to the patient's quality of life (table 3).

The correlations between asthma severity score and home spirometry indices were highly variable in individual patients (fig. 2). For example, the individual correlation coefficients between asthma severity scores and corresponding FEV_1 values in individual patients ranged from -0.28–0.51, with a mean of 0.10.

Several examples of individual recordings of home spirometer indices and the asthma severity score are presented in figure 3. The most striking finding was the large variation between and within subjects in the relationships between PEF, FEV_1 and asthma severity scores. Increases in asthma severity scores were accompanied by decreases in PEF and FEV_1 values in some patients, but by increases in others. Based on the association patterns between home spirometry results and asthma severity scores, the study group could be divided into four distinguishable patterns; reasonable concordance (n=7; 19.5%), dissociation or chaos (n=9; 25%), poor perceivers (n=13; 36%) and excessive symptoms (n=7; 19.5%; fig. 3). To the current authors' surprise, the concordance of PEF and FEV_1

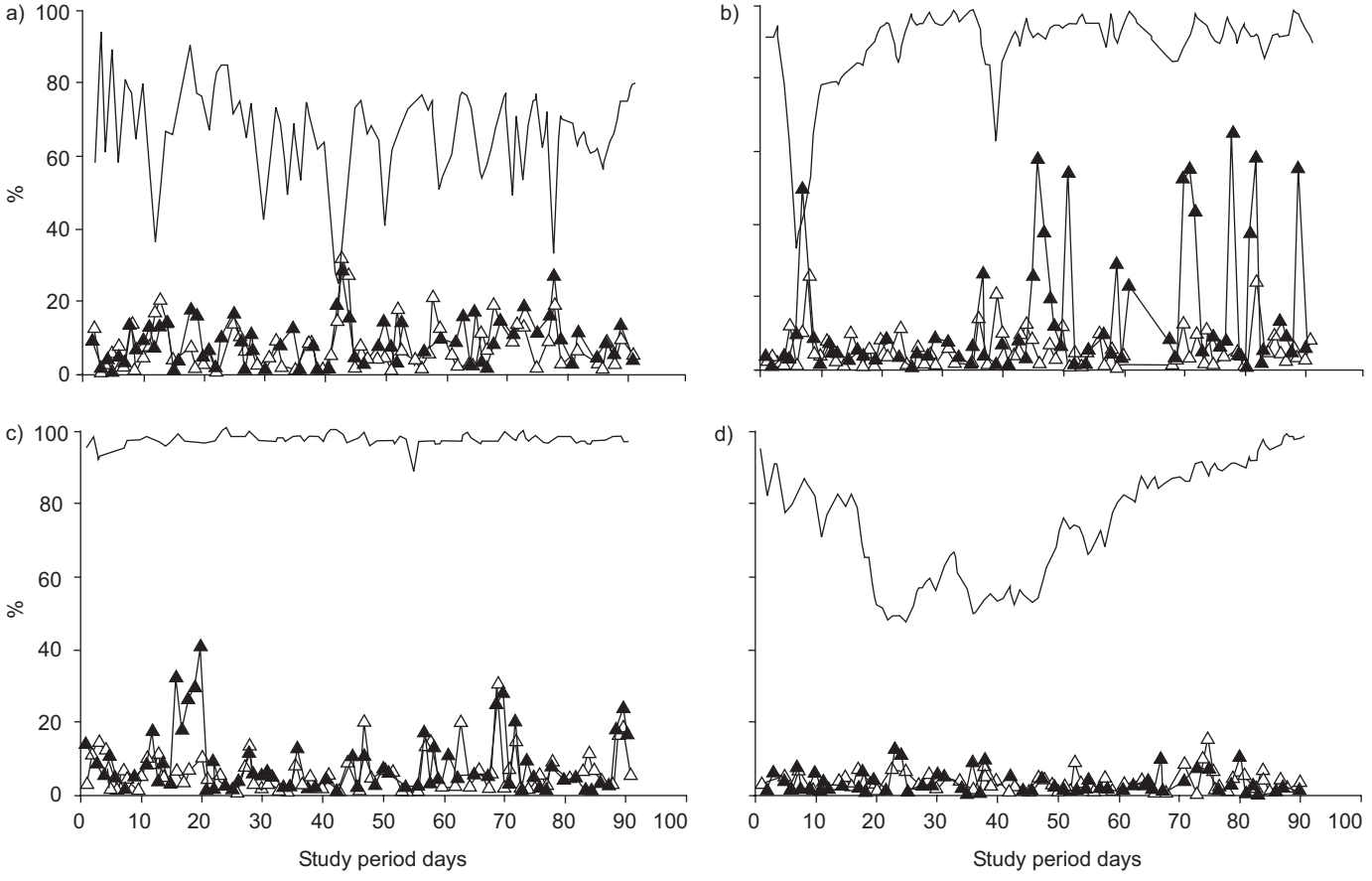

FIGURE 3. Samples of individual monitoring data showing four different patterns of relationships between asthma severity score, forced expiratory volume in one second (FEV_1) and peak expiratory flow (PEF) variation. a) concordance of patients; b) dissociation or chaos; c) poor perceiver; and d) excessive symptoms categories. ——: asthma severity score (percentage of personal best); △: PEF variation (expressed as size of day's range as a percentage of the day's mean (ampl/mean)); ▲: FEV_1 variation (ampl/mean).

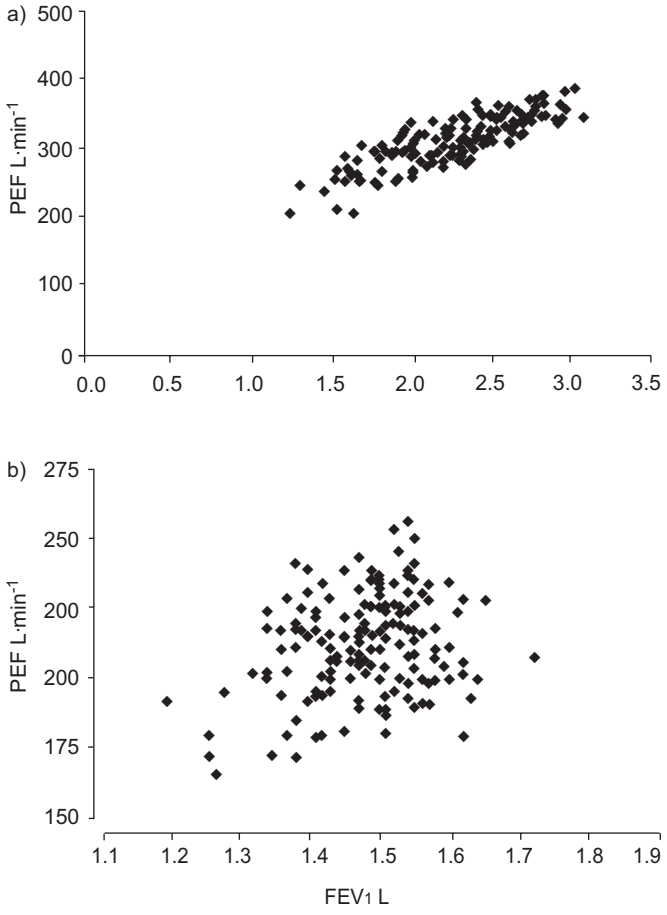

FIGURE 4. a) Concordance and b) discordance between measured peak expiratory flow (PEF) and accompanying forced expiratory volume in one second (FEV_1) in two individual patients.

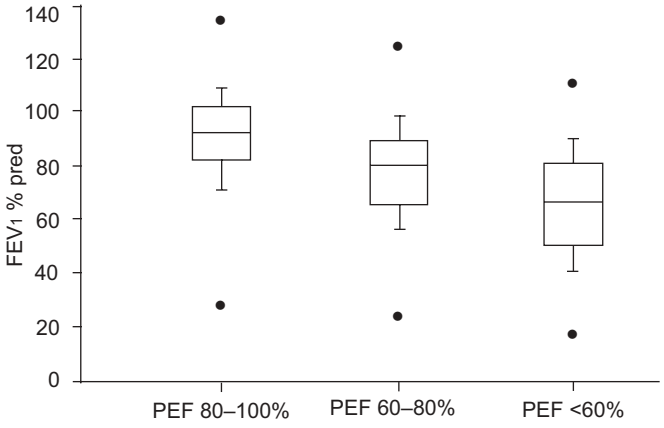

FIGURE 5. Box-and-whisker plots representing distributions of forced expiratory volume in one second (FEV_1) accompanying peak expiratory flow (PEF) values at 80–100% (n=4,060), 60–80% (n=2,162), and <60% (n=371) of personal best. Data are presented as medians, interquartile ranges and 90% ranges. ●: minimal and maximal outliers.

values was highly variable between patients, with only 67% showing an acceptable concordance (r_s>0.5; fig. 4).

Falls of PEF below 80% or below 60% of personal best values were accompanied by highly variable FEV_1 values (fig. 5). For example, although the mean FEV_1 associated with a PEF falling below 60% of the personal best value was 65.8% pred (95% confidence interval 63.9–67.8), the spread of FEV_1 values associated with this drop in PEF ranged from 18–120% pred.

DISCUSSION

The current study shows that in asthmatic children, the correlation of electronically recorded PEF variation to other asthma parameters is too inconsistent to be clinically useful. This is not only true for PEF variation expressed as the amplitude as a percentage of the day's mean, but also for PEF expressed as a percentage of the personal best value and for the variation of FEV_1 (table 3). Although the unreliability of written PEF diaries is overcome by using an electronic home spirometer, this does not improve the poor concordance of PEF variation to other parameters of asthma severity [11, 12, 27]. The present authors propose that this poor concordance, both between and within patients, limits the usefulness of home spirometers in the monitoring and management of childhood asthma.

It is commonly stated that variation in pulmonary function is one of the key characteristics of asthma [1, 2], and that PEF variation reflects this variability [6]. In the present study, the variability of the subjective severity of disease was recorded daily using an asthma severity score that has been validated as accurate and reproducible [23]. Although PEF variation mirrored the variability of the asthma severity score in some patients, in most cases there appeared to be no relationship at all. In fact, 80% of subjects displayed a (complete) dissociation between indices of home spirometry and asthma severity score (fig. 3). These findings concur with earlier studies using mechanical PEF meters [27]. Some of these patients may be regarded as ''poor perceivers'', with few symptoms despite considerable variation in PEF and FEV_1 and others as patients with excessive symptoms without any variation in PEF and FEV_1 [28]. It would be interesting to see whether poor perceivers, identified by home recordings, could benefit from stepping up therapy, but this study was not designed to answer that question.

Another striking finding of the present study was the poor concordance of changes in PEF with changes in FEV_1, the gold standard of peripheral airways obstruction. Although overall correlation between PEF and FEV_1 is present and can be expected with properly performed manoeuvres, some individual patients show complete dissociation between PEF and FEV_1 (fig. 4). Given the low use of rescue bronchodilators in the current study, it is highly unlikely that these findings were influenced by bronchodilators used during the day and before measurements [29].

Similarly, falls of PEF below 80% or even below 60% of personal best values, which are commonly used as cut-off values for stepping up asthma therapy in self-management plans [13], were accompanied by a wide range of drops in FEV_1 (fig. 5). This illustrates that PEF and FEV_1 are not interchangeable parameters of assessing airway obstruction [6]. FEV_1 is less dependent than PEF on the patient's effort and, consequently, is a better estimate of smaller airway obstruction [5]. Theoretically, therefore, monitoring FEV_1 could provide a

more reliable assessment of airway obstruction than PEF. Possibly, the discordance between PEF and FEV_1 could, to some extent, be explained by FEV_1 being a better measure of smaller airway obstruction than PEF. In the current study, however, the relationship of FEV_1 variation to other parameters of disease activity was as variable as that of PEF variation (table 3).

The present findings can probably not be explained by the poor accuracy or measurement characteristics of the home spirometers, which meet the performance standards recommended by international guidelines, both for PEF and for FEV_1 [5]. Although it can be argued that measurements at home are not performed under supervision of a skilled assistant, who can encourage the children to obtain optimal recordings and who can provide visual feedback of correct performance by examining flow–volume loops or by using computer incentives or animations, it has been shown that the technical quality of home spirometry recordings in children is usually acceptable [30]. It is therefore, even more striking that very low FEV_1 levels may be encountered occasionally in children with chronic persistent, but clinically stable, asthma (fig. 5). It can not be ruled out that some of these very low PEF and FEV_1 values were caused by poor lung-function performance and lack of quality control at home. Lung function was, on average, normal in patients taking part in the current study (table 1). Even though there were no exacerbations requiring oral corticosteroids in this study group throughout the 3-month period, PEF and FEV_1 values were highly variable in a number of patients (fig. 3). In such patients, FEV_1 values can drop as low as 18% pred, without being considered as technical errors or unexpected outliers according to predefined criteria [24]. As, in the context of the present study, data recorded on the home spirometer were not used in a self-management setting as a basis for adjustment of therapy and were only analysed after completion of the 3-month study period, these low FEV_1 values did not prompt changes in asthma management immediately. If they had been used in such a setting, the poor concordance of FEV_1 and PEF (fig. 5) would have complicated self-management considerably. If a drop of PEF below 60% of personal best can be accompanied by FEV_1 levels ranging 18–120% pred, it is quite unclear what the best approach to asthma management should be. At such a point in time, current self-management strategies suggest commencing oral steroids. Although this is logical with accompanying low FEV_1 levels, giving oral prednisolone to children with an accompanying FEV_1 of 120% pred is clearly inappropriate. Thus, monitoring both FEV_1 and PEF can be confusing when the changes in these two parameters are discordant. Similar findings have previously been described in adults with intermittent or mild persistent asthma [31], but not in children. The current study shows that such discordance occurs in as many as 33% of children with mild-to-moderate persistent asthma.

Asthma is a variable disease and although home spirometry appears to be a reliable and intuitively appealing way to monitor pulmonary function in children daily, the current study demonstrates that home spirometry in children with asthma shows highly variable relationships with several distinct measures of asthma severity, namely bronchial responsiveness, bronchodilator response, asthma severity scores and quality of life. In addition, peak expiratory flow values, obtained by home spirometry, show highly variable concordance to accompanying measurements of forced expiratory volume in one second. The results of the present study may help to explain why using an electronic home spirometer in self-management of childhood asthma does not appear to be useful in improving asthma control [32]. It is unlikely, therefore, that home spirometry is going to be useful in the long-term monitoring and management of childhood asthma.

REFERENCES

1 International consensus report on diagnosis and treatment of asthma. National Heart Lung and Blood Institute, National Institutes of Health. Bethesda, Maryland 20892. Publication No. 92-3091, March 1992. *Eur Respir J* 1992; 5: 601–641.

2 NAEPP Expert Panel. Guidelines for the diagnosis and management of asthma - update on selected topics 2002. National Institutes of Health. Publication No. 02-5075. Bethesda, National Institutes of Health, 2002.

3 Crapo RO, Casaburi R, Coates AL, *et al*. Guidelines for methacholine and exercise challenge testing-1999. *Am J Resp Crit Care Med* 2001; 163: 309–329.

4 Sont JK, Willems LN, Bel EH, van Krieken JH, Vandenbroucke JP, Sterk PJ. Clinical control and histopathological outcome of asthma when using airway hyperresponsiveness as an additional guide to long-term treatment. The AMPUL Study Group. *Am J Respir Crit Care Med* 1999; 159: 1043–1051.

5 American Thoracic Society, Standardization of Spirometry, 1994 Update. *Am J Respir Crit Care Med* 1995; 152: 1107–1136.

6 Quanjer PH, Lebowitz MD, Gregg I, Miller MR, Pederson OF. Peak expiratory flow: conclusions and recommendations of a working party of the European Respiratory Society. *Eur Respir J* 1997; 10: Suppl. 24, 2s–8s.

7 Ryan G, Latimer KM, Dolovich J, Hargreave FE. Bronchial responsiveness to histamine: relationship to diurnal variation of peak flow rate, improvement after bronchodilator, and airway calibre. *Thorax* 1982; 37: 423–429.

8 Higgins BG, Britton JR, Chinn S, Cooper S, Burney PG, Tattersfield AE. Comparison of bronchial reactivity and peak expiratory flow variability for epidemiologic studies. *Am Rev Respir Dis* 1992; 145: 588–593.

9 Verberne AA, Frost C, Roorda RJ, van der Laag H, Kerrebijn KF. One year treatment with salmeterol compared with beclomethasone in children with asthma. The Dutch Paediatric Asthma Study Group. *Am J Respir Crit Care Med* 1997; 156: 688–695.

10 Simons FE. A comparison of beclomethasone, salmeterol, and placebo in children with asthma. The Canadian Beclomethasone Dipropionate-Salmeterol Xinafoate Study Group. *N Engl J Med* 1997; 337: 1659–1665.

11 Brand PLP, Duiverman EJ, Waalkens HJ, Essen-Zandvliet EE, Kerrebijn KF. Peak flow variation in childhood asthma: correlation with symptoms, airways obstruction, and hyperresponsiveness during long-term treatment with inhaled corticosteroids. Dutch CNSLD Study Group. *Thorax* 1999; 54: 103–107.

12 Brand PLP, Duiverman EJ, Postma DS, Waalkens HJ, Kerrebijn KF, Essen-Zandvliet EE. Peak flow variation in

childhood asthma: relationship to symptoms, atopy, airways obstruction and hyperresponsiveness. Dutch CNSLD Study Group. *Eur Respir J* 1997; 10: 1242–1247.
13 Jain P, Kavuru MS, Emerman CL, Ahmad M. Utility of peak expiratory flow monitoring. *Chest* 1998; 114: 861–876.
14 Turner MO, Taylor D, Bennett R, Fitzgerald JM. A randomized trial comparing peak expiratory flow and symptom self-management plans for patients with asthma attending a primary care clinic. *Am J Respir Crit Care Med* 1998; 157: 540–546.
15 Grampian Asthma Study of Integrated Care (GRASSIC) Effectiveness of routine self monitoring of peak flow in patients with asthma, *BMJ* 1994; 308: 564–567.
16 Redline S, Wright EC, Kattan M, Kercsmar C, Weiss K. Short-term compliance with peak flow monitoring: results from a study of inner city children with asthma. *Pediatr Pulmonol* 1996; 21: 203–210.
17 Kamps AW, Roorda RJ, Brand PLP. Peak flow diaries in childhood asthma are unreliable. *Thorax* 2001; 56: 180–182.
18 Sly PD, Flack F. Is home monitoring of lung function worthwhile for children with asthma? *Thorax* 2001; 56: 164–165.
19 Birnie D, thoe Schwartzenberg GW, Hop WC, Essen-Zandvliet EE, Kerrebijn KF. Does the outcome of the tidal breathing and dosimeter methods of assessing bronchial responsiveness in children with asthma depend on age? *Thorax* 1990; 45: 199–202.
20 Juniper EF, Guyatt GH, Feeny DH, Ferrie PJ, Griffith LE, Townsend M. Measuring quality of life in children with asthma. *Qual Life Res* 1996; 5: 35–46.
21 Juniper EF, Guyatt GH, Feeny DH, Ferrie PJ, Griffith LE, Townsend M. Measuring quality of life in the parents of children with asthma. *Qual Life Res* 1996; 5: 27–34.
22 Brouwer AFJ, Roorda RJ, Brand PLP. Compliance, accuracy and reliability of home spirometry in children with asthma. *Eur Respir J* 2004; 24: Suppl. 48, 272s.
23 Kucera CM, Greenberger PA, Yarnold PR, Choy AC, Levenson T. An attempted prospective testing of an asthma severity index and a quality of life survey for 1 year in ambulatory patients with asthma. *Allergy Asthma Proc* 1999; 20: 29–38.
24 Chatburn RL. Evaluation of instrument error and method agreement. *AANA J* 1996; 64: 261–268.
25 Zapletal A, Paul T, Samanek M. Normal values of static pulmonary volumes and ventilation in children and adolescents. *Cesk Pediatr* 1976; 31: 532–539.
26 Altman DG, Machin D, Bryant T, Gardner MJ. Statistics with confidence. 2nd Edn. London, BMJ Books, 2002.
27 Uwyyed K, Springer C, Avital A, Bar-Yishay E, Godfrey S. Home recordings of PEF in young asthmatics: does it contribute to management? *Eur Respir J* 1996; 9: 872–879.
28 Horak E, Grassl G, Skladal D, Ulmer H. Lung function, symptom perception in children with asthma and their parents, *Pediatr Pulmonol* 2003; 35: 23–28.
29 Reddel HK, Ware SI, Salome CM, Marks GB, Jenkins CR, Woolcock AJ. Standardization of ambulatory peak flow monitoring: the importance of recent β-agonist inhalation. *Eur Respir J* 1998; 12: 309–314.
30 Wensley D, Silverman M. The quality of home spirometry in schoolchildren with asthma. *Thorax* 2001; 56: 183–185.
31 Palma-Carlos AG, Palma-Carlos ML. Correlation between clinical classification, PEF, FEV1: guidelines and reality. *Allerg Immunol (Paris)* 2002; 34: 274–276.
32 Wensley D, Silverman M. Peak flow monitoring for guided self-management in childhood asthma: a randomized controlled trial. *Am J Respir Crit Care Med* 2004; 170: 606–612.