



Contents lists available at ScienceDirect



Electronic monitoring of symptoms and lung function to assess asthma control in children

Dillys van Vliet, MD^{*}; Marieke van Horck, MD^{*}; Kim van de Kant, PhD^{*}; Sanne Vaassen, MD^{*}; Sjoerd Gulikers, MD^{*}; Bjorn Winkens, PhD[†]; Philippe Rosias, MD, PhD[‡]; Jan Heynens, MD[‡]; Jean Muris, MD, PhD[§]; Brigitte Essers, PhD[¶]; Quirijn Jöbsis, MD, PhD^{*}; and Edward Dompeling, MD, PhD^{*}

^{*} Department of Pediatric Pulmonology, School for Public Health and Primary Care, Maastricht University Medical Center, Maastricht, the Netherlands

[†] Department of Methodology and Statistics, School for Public Health and Primary Care, Maastricht University Medical Center, Maastricht, the Netherlands

[‡] Department of Pediatrics, Orbis Medical Center, Sittard, the Netherlands

[§] Department of Family Medicine, School for Public Health and Primary Care, Maastricht University Medical Center, Maastricht, the Netherlands

[¶] Department of Clinical Epidemiology and Medical Technology Assessment, Maastricht University Medical Center, Maastricht, the Netherlands

ARTICLE INFO

Article history:

Received for publication February 27, 2014.

Received in revised form April 22, 2014.

Accepted for publication May 19, 2014.

ABSTRACT

Background: Asthma remains poorly controlled in children. Home monitoring of asthma control may help to improve the level of asthma control.

Objectives: To compare 2 methods to assess asthma control: (1) prospective home monitoring, based on daily assessment of forced expiratory volume in 1 second (FEV₁) and electronic symptom score, and (2) Asthma Control Questionnaire (ACQ) with retrospective assessment of symptoms and FEV₁.

Methods: Ninety-six children with asthma were prospectively followed up during 1 year. Asthma control was assessed by home monitoring, including an electronic symptom score based on Global Initiative for Asthma (GINA) criteria and FEV₁ measurements. In the hospital, the ACQ was completed and FEV₁ was measured. Kappa analysis was performed to assess levels of agreement between the 2 methods.

Results: Agreement between the 2 methods was low (κ coefficient of 0.393). In 29 children (37%), prospective home monitoring was less optimistic than the retrospective assessment of asthma control by the ACQ.

Conclusion: This study found low agreement between asthma control based on GINA criteria by means of prospective home monitoring and the hospital ACQ. The prospective home monitor detected more cases of less well-controlled asthma than the ACQ. However, optimization of adherence to home monitor use is necessary.

Trial Registration: clinicaltrials.gov Identifier: NCT01239238.

© 2014 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

Introduction

Asthma control in children is a central goal in evidence-based guidelines concerning the management of asthma. In clinical practice, there is room for improvement in the control of asthma in children.^{1–4} Therapy is often titrated based on the Global Initiative for Asthma (GINA) criteria, which are described in the Global Strategy for Asthma Management and Prevention guidelines.³ According to these criteria, asthma control is based on symptoms and spirometry. Currently, asthma control is mostly evaluated during consultations with an interval of at least 2 to 3 months between visits. However, evaluating asthma control during clinical

visits is vulnerable for recall bias as a result of retrospective assessment of symptoms. It is possible that prospective monitoring of symptoms and lung function, for instance by means of a home monitor, provides a more realistic picture of asthma control levels.

Home monitoring can be advocated as a useful tool in the monitoring of asthma control because it can prospectively collect symptoms and/or lung function. Consequently, home monitoring may give more insight into the day-to-day level of asthma control than regular physician visits because symptoms and multiple lung function measurements are assessed more frequently and prospectively. However, some studies reported that home monitoring did not improve asthma control.^{5–8} The limitations of these studies were that symptom scores were not collected electronically, and peak expiratory flow (PEF) rate instead of forced expiratory volume in 1 second (FEV₁) was recorded. A possible pitfall for the efficacy of a home monitor is adherence to home monitor use.

Therefore, the aim of this study was to compare 2 methods of assessing asthma control in children, namely, (1) prospective home monitoring, based on daily FEV₁ measurements and a daily

Reprints: Dillys van Vliet, MD, Department of Pediatric Pulmonology, School for Public Health and Primary Care, Maastricht University Medical Center, PO Box 5800, NL-6202 AZ Maastricht, the Netherlands; E-mail: dillys.van.vliet@mumc.nl.

Disclosures: Authors have nothing to disclose.

Funding: This study was funded by The Netherlands Organization for Health Research and Development (project number 171001009) and the board of the Maastricht University Medical Center.

<http://dx.doi.org/10.1016/j.anai.2014.05.015>

1081-1206/© 2014 American College of Allergy, Asthma & Immunology. Published by Elsevier Inc. All rights reserved.

electronic symptom score, and (2) retrospective assessment of symptoms during a clinical visit by means of the Asthma Control Questionnaire (ACQ) and FEV₁ measurements. Finally, adherence to the home monitor use was assessed.

Methods

Study Design

Children aged 6 to 18 years with a diagnosis of asthma were included in a 1-year, multicenter, observational study (NCT01239238). This study was performed in 2 hospitals in the Netherlands (Sittard and Maastricht). All children were treated at the outpatient clinic of these 2 specialized pediatric pulmonology centers for their physician-diagnosed asthma for at least 6 months and received inhaled corticosteroids (ICSs) during the year preceding the study. All children fulfilled the criteria for an asthma diagnosis of GINA and the Dutch Pediatric Pulmonology Society: (1) recurrent episodes of wheezing, coughing, breathlessness, or chest tightness^{3,9}; (2) reversibility to a bronchodilator defined as an increase in FEV₁ of 9% or more of predicted value^{9,10}; and/or (3) histamine bronchial hyper-responsiveness defined as a 20% decrease in FEV₁ caused by histamine inhalation of 8 mg/mL or less.⁹ Exclusion criteria included cardiac abnormalities, intellectual disability, congenital abnormalities, existence of a syndrome, active smoking, immunotherapy, or no technical satisfactory performance of lung function and exhaled nitric oxide measurements.

Ethical approval was obtained from the Medical Ethical Committee of the Maastricht University Medical Center. All parents and children 12 years and older signed informed consent forms at the start of the study.

Study Parameters

Regular clinical visits took place every 2 months. During every clinical visit, the ACQ was filled out, FEV₁ was measured, and other measurements were performed as described below. In addition, daily home monitor data were collected.

Home Monitoring

Daily monitoring was performed using a Jaeger Asthma Monitor (AM2+; ERT, Hoechberg, Germany). The AM2+ home monitor is a handheld spirometer that was used to measure FEV₁. In addition, an asthma symptom score was recorded electronically, which was based on the GINA criteria for asthma control (eTable 1).³ All lung function values and symptom scores were stored in the device. At the first clinical visit, children and parents were carefully instructed how to use the home monitor, answer and interpret the symptom score, and perform a correct FEV₁ maneuver. Children were asked to perform 3 FEV₁ maneuvers with maximal effort. The highest FEV₁ value of each day was selected. Participants were instructed to use the home monitor daily at the same time and to transfer data into a secured web-based portal twice a week (Aventana GmbH, Hoechberg, Germany). Data were checked every week by a thoroughly instructed medical intern. Patients who did not send their data received a reminder to increase adherence. Adherence to home monitor use during the study was defined as no missing data for more than 5 of the 7 days on average.

For assessment of asthma control by home monitoring 1 week before the clinical visit, the exclusion criterion of missing home monitor data for more than 2 of the 7 days before the clinical visit was applied. To compare asthma control based on ACQ with home measured asthma control, the home monitoring asthma control for 1 week before the clinical visit was calculated on basis of the GINA criteria for asthma control.³

Measures During Clinical Visits

Children were evaluated at the hospital by a trained research nurse or physician every 2 months. During each clinical visit, the following parameters were assessed: (1) asthma control level (assessed with the ACQ),^{11,12} (2) disease-specific quality of life (Pediatric Asthma Quality of Life Questionnaire [PAQLQ]),^{13,14} (3) fractional exhaled nitric oxide (FeNO), and (4) spirometry before and after bronchodilatation.

Patients completed the Dutch version of the ACQ, which assesses the asthma control level during the past 7 days.¹² The following cutoff points for level of control were used: controlled asthma, ACQ score of 0.75 or less; partly controlled asthma, ACQ score of greater than 0.75 to 1.5; and uncontrolled asthma, ACQ score greater than 1.5. The PAQLQ was used to assess the asthma-specific quality of life. The questions represent 3 domains concerning symptoms, activity limitations, and emotional function. The range in scores is from 1 to 7, which represents poor to good quality of life.^{13,14} All children older than 10 years filled out the questionnaires without help from their parents. When needed, children younger than 10 years were assisted by their parents.

FeNO was measured online by a NIOX analyzer (NIOX MINO; Aerocrine, Solna, Sweden). The measurements were performed according to the American Thoracic Society/European Respiratory Society criteria for children.¹⁵

Dynamic spirometry was performed with the ZAN 100 spirometer, according to American Thoracic Society/European Respiratory Society standards (nSpiro Health GmbH, Oberthulba, Germany).¹⁶ The highest value of 3 technically correct maximal expiratory flow volume curves was used for analysis. Recorded parameters included FEV₁, forced vital capacity (FVC), and maximum expiratory flow at 50% of FVC (MEF₅₀). All parameters were expressed as a percentage of the predicted value. Subsequently, the patient inhaled 400 µg of salbutamol. After 15 minutes, a second lung function was performed to test for reversibility. Patients were instructed to stop use of short-acting bronchodilators at least 8 hours and long-acting bronchodilators at least 48 hours before testing. Reversibility was defined as an increase in FEV₁ of at least 9% of the predicted value.

Bronchial hyperresponsiveness was evaluated by bronchial histamine challenge testing.¹⁷ This test was performed at the start of the study. At first, an aerosol of buffered saline was inhaled, followed by aerosols of histamine solutions with doubling concentrations of 0.03 to 16 mg/mL, at intervals of 5 minutes. Spirometry maneuvers were performed 0.5, 1.5, and 2 minutes after inhalation of each solution. The required concentration of histamine to produce a 20% decrease of FEV₁ (PC₂₀) was calculated. After reaching the threshold, children inhaled 800 µg of salbutamol, followed by 3 maximal expiratory flow volume curves. A total of 16% of the PC₂₀ histamine tests were missing because of recurrent active airway infections, inability to stop use of antihistamines or bronchodilators, and calibration errors of the histamine nebulizer.

Atopy was objectified by Phadiatop Infant (Phadia, Uppsala, Sweden), radioallergosorbent assay (Pharmacia, Uppsala, Sweden), or allergen skin test, which were performed in the past or during the study for clinical purposes.

Patients were treated according to the Pediatric Pulmonology Section of the Dutch Society of Pediatrics.⁹ Medication was strictly titrated based on level of asthma control according to the GINA guidelines during the regular clinical visits. Physicians did not use the home monitor data to titrate therapy. Moreover, patients were asked not to modify their treatment on the basis of home monitoring data. Treatment adherence was measured by using the Medication Adherence Report Scale.¹⁸ This questionnaire consists of 9 questions with an answer scale of 1 to 5. The sum of all answers

is reported with a range of 9 to 45, which represents poor to good adherence to medication use.

Statistical Analysis

Numerical variables are expressed as mean (SD) or as median (IQR). Categorical variables are expressed as number (percentage). Comparison of characteristics among the groups was performed with independent-sample *t* tests for parametric data and the Mann-Whitney test for nonparametric data. Categorical variables were compared using the χ^2 test. $P < .05$ was considered statistically significant. Data were analyzed with SPSS statistical software, version 20 (SPSS Inc, Chicago, Illinois).

One set of asthma control levels at home and in the hospital for each patient was used to compare asthma control outcome of the 2 methods. Home monitor measurements during the run-in phase, which included clinical visits 1 and 2, were not used for analysis because the home monitor was not regularly used. Therefore, from clinical visits 3 to 7, the first complete set of level of asthma control assessed by home monitor and hospital ACQ was selected for each patient. Agreement between home measurements and hospital measurements for assessment of asthma control was analyzed by the linear weighted Cohen κ coefficient.¹⁹

Results

Patient Characteristics

Ninety-six children with asthma participated. Most children were atopic, had well-controlled asthma at baseline, and experienced a good disease-specific quality of life (Table 1). There was no clinically important difference in baseline characteristics among the centers, but there was a small difference in age (difference of 1 year).

Seven patients were excluded from the analysis (Fig 1). Six of these patients dropped out before the third clinical visit and did not have all the technical properties to perform home assessments in the run-in phase. One patient did not use the home monitor because of personal constraints. In addition, 11 patients were excluded from the comparative analysis of asthma control between both methods because of missing home monitor data of more than 2 of the 7 days (Fig 1).

Comparison of Asthma Control Level According to Home Monitor Assessments and Hospital ACQ Scores

For 78 children, a comparison could be made between the classification of asthma control by the home monitor assessments and the ACQ scores (Table 2). There was low agreement between the 2 instruments to distinguish the 3 levels of asthma control (linear weighted $\kappa = 0.393$; 95% CI, 0.244–0.543). In 54% of the

children, there was agreement between the 2 methods with respect to level of asthma control. However, by means of the home monitor, more than twice as many cases of partly controlled asthma were found compared with the ACQ (33 of 78 patients with the home monitor vs 16 of 78 patients with the ACQ). Moreover, in 29 of 78 children, the home monitor evaluated asthma control 1 or 2 classes lower than the ACQ (Table 2). These 29 children with a lower home monitor asthma control level than the ACQ result were compared with the 36 children in whom there was agreement between the home monitor and the ACQ result 7 days before the clinical visit (Table 2). It appeared that the FEV₁ percent predicted value, FEV₁/FVC ratio, and MEF₅₀ percent predicted value were significantly lower (Table 3), which indicated that the home monitor better reflected asthma control than the ACQ.

Adherence to Home Monitor Use

Median completed data of all children was 69% (IQR, 53%–89%). A total of 47% of the study population was adherent to the home monitor use. Comparing the adherent and the nonadherent groups, a significantly higher FeNO was found at baseline in the non-adherent group. Children who were less adherent to home monitor use had higher baseline ACQ scores and higher FeNO levels (eTable 2). This finding indicated that children with partly controlled and uncontrolled asthma and patients with higher FeNO values were less willing to use the monitor.

Discussion

This study found low agreement between the asthma control levels based on the prospective home monitor data compared with the retrospective hospital ACQ score. By means of the home monitor, twice as many cases of partly controlled asthma were found than with the hospital ACQ. Moreover, in 37% of the children with lower asthma control according to the home monitor compared with the ACQ, lung function levels (FEV₁, FEV₁/FVC ratio, and MEF₅₀) were significantly lower, a finding that further supports the reliability and validity of the home monitor data. These findings confirm our hypothesis that prospective monitoring of symptoms and lung function by means of a home monitor provides a more realistic picture of asthma control levels than retrospective assessment of asthma control during consultations in the hospital with 2- to 3-months intervals between visits. However, the adherence to the home monitor was low and should be optimized.

Assessment of Asthma Control: Home Monitoring vs ACQ

To our knowledge, no other studies have investigated the use of a home monitor in pediatric asthma in which electronic symptom scores and FEV₁ were combined. However, the low agreement between home measured asthma control based on GINA criteria

Table 1
Patient baseline characteristics of total population and each center

Characteristic	Total (N = 96)	Maastricht center (n = 51)	Sittard center (n = 45)
Male sex, No. (%)	50 (52)	27 (53)	23 (51)
Age, mean (range), y	10 (6–17)	9 (6–17)	10 (7–15)
FEV ₁ , mean (SD), % predicted	96.8 (14.2)	95.4 (15.5)	98.4 (12.7)
Bronchodilator response, Δ FEV ₁ , mean (SD), % predicted	6.6 (8.5)	6.7 (9.8)	6.5 (7.0)
ICS use, %	94	90	98
Fluticasone daily dosage or equivalent, mean (SD)	269 (175)	295 (202)	240 (134)
ACQ, median (IQR)	0.6 (0.3–1.0)	0.5 (0.3–1.0)	0.6 (0.1–1.1)
PAQLQ total score, median (IQR)	6.4 (5.9–6.7)	6.3 (5.8–6.7)	6.6 (6.0–6.8)
FeNO, median (IQR), ppb	12.5 (8.0–31.0)	13.0 (8.0–35.0)	12.0 (8.0–27.0)
PC ₂₀ histamine test, median (IQR), mg/mL	1.2 (0.3–2.9)	1.0 (0.3–2.3)	1.4 (0.4–3.2)
Atopic, % ^a	76	77	76
Completed home monitor data, median (IQR), %	70.6 (51.4–87.8)	69.6 (52.5–88.4)	70.9 (78.0–87.2)

Abbreviations: ACQ, Asthma Control Questionnaire; FeNO, fractional exhaled nitric oxide; FEV₁, forced expiratory volume in 1 second; ICS, inhaled corticosteroids; IQR, interquartile range; PAQLQ, Pediatric Asthma Control Quality of Life Questionnaire; PC₂₀, concentration of histamine inducing a 20% decrease in FEV₁.

^aAtopy is defined as a positive Phadiatop or allergen skin test result.

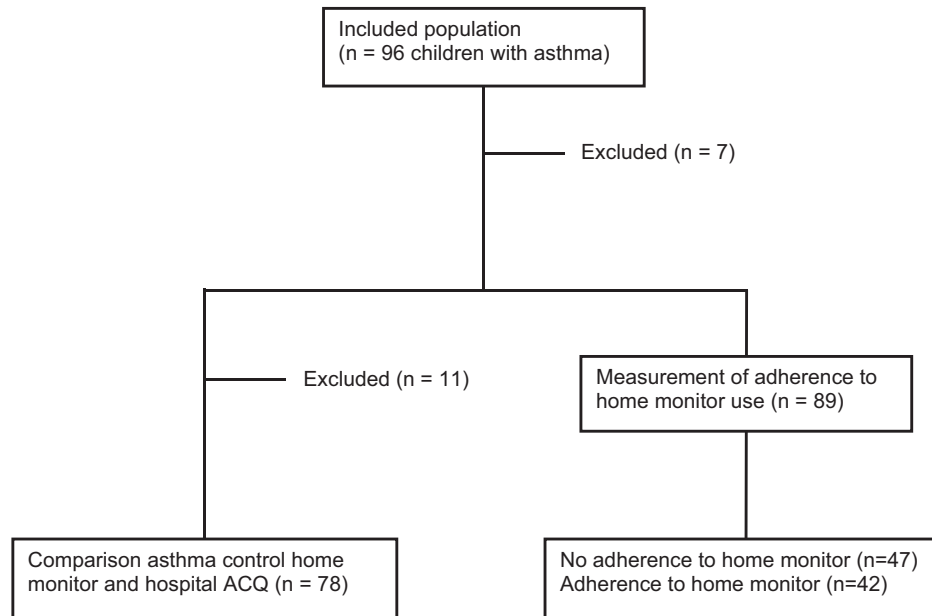


Figure 1. Overview of patients included in the study and number of patients for analysis.

and ACQ found in the present study is in concordance with earlier studies that retrospectively evaluated the assessment of level of asthma control on basis of GINA criteria and ACQ (κ index of 0.44 and 0.27 in the studies by Korn and colleagues²⁰ and Olaguibel and colleagues²¹). In these studies, asthma control was based on GINA criteria measured using a retrospective questionnaire. Prospective assessment of GINA-based asthma control at home in the current study is preferable because recall bias is ruled out.²² This recall bias may also have affected the study by Brouwer and colleagues,²³ which examined the association between home measured PEF and FEV₁ to asthma severity. In this study, electronic home spirometry parameters were related to asthma severity assessed by written home diaries. Home PEF values showed poor agreement with asthma severity.²³

Effect of Home Monitoring on Asthma Control

We searched for studies that evaluated the influence of daily electronic monitoring of FEV₁ and symptoms on asthma control levels in children. However, such a study that includes both electronic FEV₁ and symptoms in children has not been performed so far. The study by Jan et al²⁴ reported that home monitoring of PEF

and internet symptoms was effective in a randomized controlled trial (RCT) that included 164 asthmatic children with asthma. This study compared self-management based on daily PEF and internet symptom scores with written diaries. Internet-based tele-monitoring of PEF and symptoms resulted in improvement of asthma control.²⁴ Furthermore, Rasmussen and colleagues²⁵ conducted an RCT in 300 adults with asthma. This RCT compared internet-based management to monitor asthma control (ie, PEF and electronic symptom score with evaluation by general practitioner or specialist).²⁵ Significant improvement of asthma symptoms, quality of life, lung function, and airway responsiveness was found in the intervention group compared with those evaluated by the specialist.²⁵ There are also studies in which home monitoring was reported not to be effective. These studies were limited by small study populations or by the fact that the home monitoring did not include electronic symptom scores or FEV₁.^{5–7}

Strengths of this study are the substantial number of included children, the 1-year prospective character, the electronic home monitor with recording of symptoms and FEV₁ at home, and the simultaneous assessment of the ACQ and the FEV₁ during each clinical visit. Poor perception of symptoms may cause underestimation of asthma control by both methods. Besides, in some

Table 2

Classification of asthma control on the basis of GINA Guidelines and ACQ Scores

Asthma type	ACQ controlled asthma ^a	ACQ partly controlled asthma ^a	ACQ uncontrolled asthma ^a	Total
Home monitor controlled asthma (GINA)	29	3	0	32
Home monitor partly controlled asthma (GINA)	22	7	4	33
Home monitor uncontrolled asthma (GINA)	1	6	6	13
Total	52	16	10	78

Abbreviations: ACQ, Asthma Control Questionnaire; GINA, Global Initiative for Asthma.

^aThe following cutoff points for level of control were used: controlled asthma, ACQ score of 0.75 or less; partly controlled asthma, ACQ score of greater than 0.75 to 1.5; and uncontrolled asthma, ACQ score greater than 1.5.

Table 3
Comparison of asthma features between children with lower asthma control according to the home monitor and children with agreement between both methods (concerning controlled and partly controlled asthma)

	Children with agreement between methods concerning controlled and partly controlled asthma ^a	Children with lower asthma control according to home monitor ^b	P value
FEV ₁ , mean (SD), % predicted	102.1 (13.2)	94.2 (12.9)	.02
FVC, mean (SD), % predicted	101.1 (11.7)	99.1 (10.4)	.47
FEV ₁ /FVC, mean (SD)	85.5 (7.5)	80.9 (10.2)	.04
MEF ₅₀ , mean (SD), % predicted	85.5 (24.5)	71.4 (19.8)	.01
FEV ₁ , median (IQR), % predicted	103.5 (98.3–113.3)	102.0 (92.5–108.0)	.23
FEV ₁ /FVC after bronchodilator, median (IQR)	90.0 (82.3–92.8)	87.0 (78.5–90.5)	.12
FeNO, median (IQR), ppb	12.5 (9.0–30.8)	13.0 (8.0–28.5)	.76
PAQLQ total score, median (IQR)	7.0 (6.0–7.0)	7.0 (6.0–7.0)	.64

Abbreviations: FeNO, fractional exhaled nitric oxide; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; IQR, interquartile range; MEF₅₀, mean expiratory flow at 50%; PAQLQ, Pediatric Asthma Control Quality of Life Questionnaire.

^aCells A and E from Table 2 (n = 36).

^bCells D, G, and H from Table 2 (n = 29).

children younger than 10 years, completion of the ACQ was complicated by lack of understanding of included words or timeline. However, this effect was reduced in young children by completion of questionnaires with an interviewer. Moreover, we have added FEV₁ to symptoms, which reduces underestimation of asthma control levels because of poor perceivers.

How can these findings be explained? The most likely explanation for the difference in asthma control between the 2 methods is the exclusion of recall bias by means of electronic home assessment of asthma control. Another important finding of this study is the relative low adherence to home monitor use and higher FeNO levels and higher ACQ scores in the nonadherent children compared with the adherent children. During the recruitment of patients, we observed that patients refused to attend this study because they were busy with life and school activities. This was also often a reason that patients reported no adherence to home monitor use. Moreover, technical problems can arise with the software or hardware communication, stressing the importance of a robust and patient-friendly device. Technical problems can arise during installation of software on computers and transmission of data to the portal. The combination of lack of time and previous technical problems resulted in reluctance to use the home monitor in this study. The technology of electronic home monitors and communication with databases needs to be improved.

The clinical implication of this study is that home monitoring could be an additional tool to assist health care professionals in improving management of asthma in children. In this study, we found that children with worse adherence had higher FeNO levels and that this group consisted of slightly more children with partly or uncontrolled asthma. This finding needs attention because this group in particular will benefit from better adherence to the use of the monitor. One question is how the adherence rate can be increased in this group. In our study daily, home monitoring of symptoms and lung function was applied. First, it is likely that the adherence to monitor use will increase when a lower frequency of measurements is asked from parents and children. In case of no symptoms and good asthma control, one can imagine that 1 or 2 assessments per week may be sufficient, whereas daily monitoring may be necessary in case of more symptoms or increased use of β_2 -agonists. The adherence to the home monitor may increase when parents and children can directly contact the medical team and/or have an extra clinical evaluation in case asthma control deteriorates. Second, it is essential to have a monitor that is easy to use. The monitor should have an application that makes it easy and effortless to send data to the hospital. The monitor used in this study has room for improvement in this regard. Third, constant communication with children and parents about the purpose and advantages of proper use of the home monitor may help to increase the motivation of children and parents to adhere to the home

monitor. The effect of these suggestions to increase adherence to home monitor use should be the subject of future studies.

In our study, we aimed to apply a strict cutoff point to assess asthma level of control with the home monitor. Future studies should investigate which adherence rate is sufficient to reliably assess the level of asthma control. Potentially, with less frequent use of the home monitor, the level of asthma control could be reliably assessed. Less frequent use of the home monitor could increase the adherence rate to home monitor use. Furthermore, in an RCT the effectiveness of titration of medication in asthmatic children based on home monitored electronic symptoms and FEV₁ needs to be proven. Outcome variables of this RCT should include asthma control, moderate or severe asthma exacerbation rate, health care costs (eg, emergency department visits due to asthma exacerbations), and quality of life. Management based on home monitoring probably improves asthma control and may result in a decrease of regular clinical visits and reduction in costs of health care.

In conclusion, we found low agreement between the asthma control levels based on the prospective home monitor data and the retrospective hospital ACQ score. By means of the home monitor, twice as many cases of partly controlled asthma were found than with the hospital ACQ. Adherence to home monitor use needs to be further optimized to increase the clinical usefulness of measuring disease control in children with asthma.

Acknowledgments

We thank all children and parents for taking part in this study. This study could not have been performed without efforts of Tiny Dauven, Irene van der Sterren-Breugelmans, Rianne Römers, and Sylvia Esten, who were responsible for the performance of the clinical visits. We also thank the medical students Myrthe Kersemaekers, Myrthe Berkhof, and Elles Broen for their outstanding assistance during this study.

Supplementary Data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jana.2014.05.015>.

References

- [1] Rabe KF, Adachi M, Lai CK, et al. Worldwide severity and control of asthma in children and adults: the global asthma insights and reality surveys. *J Allergy Clin Immunol*. 2004;114:40–47.
- [2] Gustafsson PM, Watson L, Davis KJ, Rabe KF. Poor asthma control in children: evidence from epidemiological surveys and implications for clinical practice. *Int J Clin Pract*. 2006;60:321–334.
- [3] Global Initiative for Asthma (GINA). Global strategy for asthma management and prevention. 2012. ginasthma.org/local/uploads/files/GINA_Report_March13.pdf. Accessed January 31, 2014.

- [4] British Thoracic Society Scottish Intercollegiate Guidelines Network. British Guideline on the Management of Asthma. <https://www.brit-thoracic.org.uk/document-library/clinical-information/asthma/btssign-guideline-on-the-management-of-asthma>. Accessed January 31, 2014
- [5] Deschildre A, Beghin L, Salleron J, et al. Home telemonitoring (forced expiratory volume in 1 s) in children with severe asthma does not reduce exacerbations. *Eur Respir J*. 2012;39:290–296.
- [6] 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(6):606–612.
- [7] Willems DC, Joore MA, Hendriks JJ, Nieman FH, Severens JL, Wouters EF. The effectiveness of nurse-led telemonitoring of asthma: results of a randomized controlled trial. *J Eval Clin Pract*. 2008;14(4):600–609.
- [8] Thompson AK, Juniper E, Meltzer EO. Quality of life in patients with allergic rhinitis. *Ann Allergy Asthma Immunol*. 2000;85:338–347.
- [9] Jongste JC, Vrijlandt ELJE. *Astma bij Kinderen: Herziene Richtlijnen van de Sectie Kinderlongziekten van de NVK [Asthma in Children: Revised Guidelines of the Paediatric Department of the Dutch Paediatric Society]*. Amsterdam, the Netherlands: Dutch Paediatric Society; 2007.
- [10] Dales RE, Spitzer WO, Tousignant P, Schechter M, Suissa S. Clinical interpretation of airway response to a bronchodilator. Epidemiologic considerations. *Am Rev Respir Dis*. 1988;138(2):317–320.
- [11] Juniper EF. Assessing asthma control. *Curr Allergy Asthma Rep*. 2007;7:390–394.
- [12] Juniper EF, Gruffydd-Jones K, Ward S, Svensson K. Asthma Control Questionnaire in children: validation, measurement properties, interpretation. *Eur Respir J*. 2010;36:1410–1416.
- [13] 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.
- [14] Juniper EF, Svensson K, Mork AC, Stahl E. Modification of the asthma quality of life questionnaire (standardised) for patients 12 years and older. *Health Qual Life Outcomes*. 2005;3:58.
- [15] Dweik RA, Boggs PB, Erzurum SC, et al. American Thoracic Society Committee on Interpretation of Exhaled Nitric Oxide Levels for Clinical A. An official ats clinical practice guideline: Interpretation of exhaled nitric oxide levels (feno) for clinical applications. *Am J Respir Crit Care Med*. 2011;184:602–615.
- [16] Wanger J, Clausen JL, Coates A, et al. Standardisation of the measurement of lung volumes. *Eur Respir J*. 2005;26:511–522.
- [17] Sterk PJ, Fabbri LM, Quanjer PH, et al. Airway responsiveness. Standardized challenge testing with pharmacological, physical and sensitizing stimuli in adults. Report working party standardization of lung function tests, european community for steel and coal. Official statement of the european respiratory society. *The Eur Respir J Supplement*. 1993;16:53–83.
- [18] Horne R, Weinman J. Self-regulation and self-management in asthma: exploring the role of illness perceptions and treatment beliefs in explaining non-adherence to preventer medication. *Psychol Health*. 2002;17:17–32.
- [19] Fleiss JL. *Statistical Methods for Rates and Proportions*. 2nd ed. New York, NY: Wiley; 1981.
- [20] Korn S, Both J, Jung M, Hubner M, Taube C, Buhl R. Prospective evaluation of current asthma control using ACQ and ACT compared with GINA criteria. *Ann Allergy Asthma Immunol*. 2011;107:474–479.
- [21] Olaguibel JM, Quirce S, Julia B, et al. Measurement of asthma control according to Global Initiative for Asthma guidelines: a comparison with the Asthma Control Questionnaire. *Respir Res*. 2012;13:50.
- [22] Okupa AY, Sorkness CA, Mauger DT, Jackson DJ, Lemanske RF Jr. Daily diaries vs retrospective questionnaires to assess asthma control and therapeutic responses in asthma clinical trials: is participant burden worth the effort? *Chest*. 2013;143:993–999.
- [23] Brouwer AF, Roorda RJ, Brand PL. Home spirometry and asthma severity in children. *Eur Respir J*. 2006;28:1131–1137.
- [24] Jan RL, Wang JY, Huang MC, Tseng SM, Su HJ, Liu LF. An internet-based interactive telemonitoring system for improving childhood asthma outcomes in Taiwan. *Telemed J E Health*. 2007;13:257–268.
- [25] Rasmussen LM, Phanareth K, Nolte H, Backer V. Internet-based monitoring of asthma: a long-term, randomized clinical study of 300 asthmatic subjects. *J Allergy Clin Immunol*. 2005;115:1137–1142.

eTable 1

Home monitor symptom questionnaire

Question	Answers options (score per answer)
Did you have any complaints of your asthma (cough, wheeze, dyspnea) last night?	(0) No complaints (1) One time awake (2) Two times awake (3) Three or more times awake
Did you have any complaints of your asthma (cough, wheeze, dyspnea) during the day?	(0) No complaints (1) One short period (2) Two short periods (3) Three or more periods
Did you have limitations of activity due to asthma symptoms during the day?	(0) Not limited (1) Slightly limited (2) Fairly limited (3) Extremely limited
Number of times in need of rescue medication	Number
Did you take your asthma medication today?	(1) Yes (0) No

eTable 2

Comparison of patient baseline characteristics of the nonadherent and adherent group with respect to the home monitor use

Characteristic	Nonadherent (n = 47)	Adherent (n = 42)	P value
Maastricht center, %	53	52	.97
Male sex, No. (%)	27 (57)	22 (52)	.10
Age, mean (range), y	9 (6–16)	10 (6–17)	.22
FEV ₁ , mean (SD), % predicted	96.9 (10.7)	98.5 (14.2)	.55
Bronchodilator response, Δ FEV ₁ , mean (SD), % predicted	6.4 (8.8)	5.4 (8.4)	.61
Fluticasone daily dosage or equivalent, mean (SD)	257 (157)	257 (165)	.88
ACQ score, median (IQR)	0.6 (0.3–1.4)	0.4 (0.1–0.9)	.05
PAQLQ total score, median (IQR)	6.4 (5.7–6.7)	6.6 (6.0–6.7)	.36
FeNO, median (IQR), ppb	16.0 (9.0–35.0)	9.5 (5.8–20.0)	.03
PC ₂₀ histamine test, median (IQR), mg/mL	1.2 (0.3–2.3)	1.9 (0.7–3.6)	.09
Atopy, % ^a	57	50	.79
MARS-9 score, mean (SD)	37.0 (3.9)	38.3 (2.8)	.09

Abbreviations: ACQ, Asthma Control Questionnaire; FEV₁, forced expiratory volume in 1 second; FeNO, fractional exhaled nitric oxide; IQR, interquartile range; MARS, Medication Adherence Report Scale; PAQLQ, Pediatric Asthma Control Quality of Life Questionnaire; PC₂₀, concentration of histamine inducing a 20% decrease in FEV₁.

^aAtopy is defined as a positive Phadiatop or allergen skin test result.