Original Research

An Internet-Based Interactive Telemonitoring System for Improving Childhood Asthma Outcomes in Taiwan

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ABSTRACT

A randomized, controlled trial was conducted to assess the effectiveness of Blue Angel for Asthma Kids, an Internet-based interactive asthma educational and monitoring program, used in the management of asthmatic children. One hundred sixty-four ($n = 164$) pediatric patients with persistent asthma were enrolled and randomized into two study groups for a 12-week controlled trial. The intervention group had 88 participants who were taught to monitor their peak expiratory flows (PEF) and asthma symptoms daily on the Internet. The also received an interactive response consisting of a self-management plan from the Blue Angel monitoring program. The control group had 76 participants who received a traditional asthma care plan consisting of a written asthma diary supplemented with instructions for self-management. Disease control was assessed by weekly averaged PEF values, symptom scores, and asthma control tests. Adherence measures were assessed by therapeutic and diagnostic monitoring. Outcome was assessed by examining quality of life and retention of asthma knowledge. The data were analyzed by comparing results before and after the trial. At the end of trial, the intervention group decreased nighttime (-0.08 ± 0.33 vs. 0.00 ± 0.20 , $p = 0.028$) and daytime symptoms (-0.08 ± 0.33 vs. 0.01 ± 0.18 , $p = 0.009$); improved morning (241.9 ± 81.4 vs. 223.1 ± 55.5 , $p = 0.017$) and night PEF (255.6 ± 86.7 vs. 232.5 ± 55.3 , $p = 0.010$); increased adherence rates ($p < 0.05$); improved well-controlled rates (70.4% vs. 55.3%, $p < 0.05$); improved knowledge regarding self-management (93.2% vs. 70.3%, $p < 0.05$); and improved quality of life (6.5 ± 0.5 vs. 4.3 ± 1.2 on a 7-point scale, $p < 0.05$) when compared with conventional management. The Internet-based asthma telemonitoring program increases self-management skills, improves asthma outcomes, and appears to be an effective and well-accepted technology for the care of children with asthma and their caregivers.

INTRODUCTION

ASTHMA is the most common chronic disease affecting children, and is a growing prob-

lem in Taiwan.¹⁻³ Statistical data indicate that the prevalence of asthmatic children residing in Taipei who, between 7 and 15 years of age, increased from 1.3% in 1974 to 17.8% in 2004.²

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Studies show that asthma is the leading cause of childhood hospitalizations and school absences.^{3,4} Although the management of asthmatic children involves multiple challenges, it has been shown that physical symptoms can be controlled effectively by monitoring peak expiratory flows (PEF), administering various medications and treatment modalities, and limiting exposure to asthma triggers by modifying the environments to which they are exposed. Therefore, international guidelines recommend the increased use of controller therapy to improve overall asthma management⁵ and participation in comprehensive patient educational programs.^{6,7}

Improved education and monitoring of children with asthma has been shown to be highly effective for controlling symptoms and preventing failure of outpatient therapy.⁷⁻¹⁰ Although appropriate ambulatory care is more cost effective than episodic unscheduled care and hospitalization, frequent follow-up for education reinforcement and monitoring is costly and inconvenient.¹⁰ In recent years, investigators have described the use of real-time telemedicine tools to supplement outpatient monitoring.¹¹⁻²² This technology has been effective for and accepted by children even in low socioeconomic groups.^{15-17,21}

Recent surveys indicate that 73% of adults have personal computers and 54% of families have Internet access in Taiwan.²³ As more families gain Internet access, telemedicine may become a cost-effective way to monitor children with asthma, and may help avoid unscheduled clinic visits, emergency department visits, and hospitalizations for asthma. Moreover, because this method allows for daily monitoring, it may help increase patients' adherence to treatment regimens.

We have developed Blue Angel for Asthma Kids, an Internet-based pediatric asthma monitoring program, for asthmatic children and/or their parents. This system has multiple functionality using Internet-based diary cards (intelligent cards) for symptom recording, an Internet-based diary record for peak expiratory flow rate (PEFR), symptomatic support information, and an action plan suggestion, which were based on the Global Initiative for Asthma (GINA) program guidelines,⁵ and telecommu-

nication technologies for uploading and retrieving the storage data for personal and physicians use.

Its purpose is to monitor daily allergic and asthmatic symptoms by asthmatic children and their caregivers, provide information for an action plan, and enhance compliance of daily allergy and asthma control. Moreover, it can assist medical doctors in establishing a diagnosis and in monitoring of treatment plans for children with bronchial asthma and their caregivers.

We sought to investigate the outcome of monitoring and treatment using a physician-managed on-line interactive asthma monitoring tool and to assess whether the outcome differs from that of nonmonitoring and traditional treatment, in an outpatient allergy and asthma clinic. The purpose of this study was to determine whether the addition of an interactive, Internet-based multimedia asthma educational and monitoring program to a traditional clinic-based patient educational program would improve childrens' and caregivers' knowledge and health status, and decrease the use of healthcare resources.

MATERIALS AND METHODS

A randomized, controlled trial of Blue Angel for Asthma Kids was conducted in the a pediatric allergy and asthma clinic at National Cheng Kung University Medical Center, Tainan, Taiwan, between January and December 2004. Children were eligible for inclusion in the study if they were between the ages of 6 and 12 years, had access to the Internet by their caregivers, and were diagnosed as having persistent asthma following the GINA clinical practice guidelines. Children with a diagnosis of bronchopulmonary dysplasia, or other chronic comorbid conditions that could affect their quality of life were not eligible.

Randomization

Families were told that the purpose of the study was to find out if keeping track of asthma symptoms daily during a 12-week study period would help them and their physicians manage the child's asthma better; and that two meth-

ods of keeping track were being evaluated. All eligible pediatric patients and their caregivers were given the opportunity to participate in the study. All enrolled in the study signed an informed consent form.

Before randomization, the nurse coordinator administered the baseline questionnaire to the child and the accompanying family member. The nurse then conducted a standardized 10-minute education session using a video and a booklet in which each participating child, who was given an electronic peak flow measuring device, was instructed on proper techniques and how to establish his or her personal best. Following the session, the nurse opened a sealed envelope containing the treatment assignment, and the children were randomized to either traditional asthma education and treatment (control group) or interactive Web-based education and asthma monitoring (intervention group). A sample size calculation determined that 100 children in each of the two groups would have a power of 94% for detecting an effect size of 0.5 (the difference in the group means divided by the common standard deviation) for any of the variables studied.

Control group—Verbal information and booklet for asthma education with written asthma diary

All control group participants received asthma education as part of usual care, including verbal and printed information on the disease and concepts related to its control. A series of instructional sheets in the Caring for Child with Asthma program were available to the clinical team to help families understand asthma, selected devices, medications, and environmental factors. These illustrated information sheets were written at a second-grade reading level. An electronic peak flow meter and a hard copy of an asthma symptom diary were given to the patients, and they were asked to use these regularly, preferably daily. All families received an individualized asthma action plan with detailed instructions for daily self-management, as well as guidelines for handling exacerbations and emergencies. The action plan comprised a three-color warning system based on the symptoms score and PEF

values. Patients were treated according to their current severity level, and they were taught how to adjust their medication.

Intervention group—Internet-based multimedia asthma education with interactive asthma monitoring system

Blue Angel for Asthma Kids, which was comprised of (1) basic information regarding the care of the asthmatic child, (2) an electronic diary, (3) an action plan for the patients, and (4) a retrieval analysis system to review the accumulated data on symptoms score and PEF variability, was used. Families whose children were assigned to the Intervention group were given a demonstration on how to log on to the Internet Web site (<http://140.116.58.191/asthma/first.php>) and complete the daily inquiry about asthma symptoms and medications and upload the information to the central server at the data information center of National Cheng Kung University. In addition to the instructions on the use of the Web-based diary, patients were given an electronic peak flow meter (microlife PF 100 Electronic Asthma Monitor®; Microlife Ltd., Taipei, Taiwan), which measures daily PEF and forced expiratory volume in 1 second (FEV₁) and stores the date and time of performance in memory. The monitor can be connected via a USB connection port with a computer, and all memory data can be analyzed by the Microlife Asthma Monitor software program. In this setting, patients were able to complete the electronic asthma diary and record symptoms, need for rescue medication, and PEF values. The Internet tool's action plan comprised a three-color warning system accompanied by a written treatment plan. Patients were encouraged to fill out the electronic diary daily and to follow the instructions given by the computer and the physician; thereafter, the decision support system was used to check whether asthma had been brought under control. Physicians then instructed the patients by e-mail or telephone to increase, decrease, or continue the usual treatment. Additional details on the Internet tool and treatment protocol are provided at <http://140.116.58.191/asthma/index.php> (in Chinese).

Data collection

Patients in both groups were asked to complete the PEF records and asthma symptom diary daily, and to perform pulmonary spirometric tests at 4-week follow-up visits. The Pediatric Asthma Quality of Life²⁴ and Childhood Asthma Control Test²⁵ for the patients and caregivers were completed by the patients and caregivers at enrollment and at 12 weeks after the start of the trial (used with permission from the original author). The survey of asthma knowledge for caregivers, which consisted of five questions on basic asthma concepts and five questions on dilemmas dealing with real-life asthma scenarios, was conducted before and after the trial. The effectiveness, or the outcome assessment, of asthma control includes measurement of patients' adherence to treatment and disease control. Treatment adherence was assessed by examining selected aspects of therapeutic and diagnostic monitoring.

We defined therapeutic monitoring as outcomes that directly reflect adherence to therapeutic regimens, including controller medication use and test score for dry powder inhaler (DPI) or metered dose inhaler (MDI) with the spacer technique. Diagnostic monitoring included reviewing the asthma symptom diary and records of electronic peak flow meter use. Adherence to the Web-based asthma diaries or traditional diary records was also measured. A survey on satisfaction with the Internet-based interactive and telemonitoring system (i.e., Blue Angel for Asthma Kids) was completed at the end of the study.

Statistical analyses

Chi-square (χ^2) tests, Fisher exact tests, and two-sample *t*-tests were used to compare the two study groups with regard to demographic characteristics (at baseline). Comparison of scores at baseline and at the end of the 12-week trial was made by using the difference in the individual scores. The significance of differences in continuous outcomes (e.g., satisfaction survey scores and participant time) between patients in the intervention and office groups was calculated by using unpaired *t*-tests or, if the normality of data distribution was questionable, with the nonparametric Wilcoxon

rank test. Differences between the intervention and control groups for other outcomes with integer scores were analyzed with the Mantel-Haenszel test for ordinal data, which tests for differences in mean scores. The study was approved by the institutional review board's clinical trial and ethics committees.

RESULTS

Baseline characteristics of children enrolled in the study

The original study sample consisted of 196 children and their caregivers, who were randomized to the control group ($n = 97$) and the intervention group ($n = 99$). Of 184 eligible families with access to the Internet who were invited to participate in the study, five families declined to participate, giving "too busy," "not interested," and "too complex to perform the diary card" as the reasons for their nonparticipation. Fifteen subjects, six from the control group and nine from the intervention group, were excluded either at the request of the participants themselves or for lack of data due to Internet failure. The demographic data for the children are summarized in Table 1. The intervention ($n = 88$) and control ($n = 76$) groups had similar demographic characteristics, illness history, home environment, and use of health services at baseline as expected from the random assignment. Follow-up of participants occurred similarly across the whole study period in the two groups. Ninety-three percent of the participants (82 in the intervention group and 71 in the control group) returned for the follow-up visit at 12 weeks. Seven families who dropped out were unavailable for contact. Baseline characteristics of children who did not complete the trial did not differ from those who did.

Asthma symptoms scores

The scoring method of asthma symptom in the study subjects is divided as daytime symptom (0: no asthma symptoms; 1: symptoms occur several times, but do not interfere with daily activities; 2: symptoms interfere with daily activities; 3: symptoms stop all activity) and night-

TABLE 1. BASELINE CHARACTERISTICS OF CHILDREN ENROLLED IN THE STUDY

Characteristics	Intervention group (n = 88) ^a	Control group (n = 76) ^a	P Value
Children			
Age, years ^b	10.9 ± 2.5	9.9 ± 3.2	0.99 ^c
Male sex	35 (39.7)	28 (36.8)	0.47 ^c
History of asthma, years ^b	2.4 ± 1.9	2.1 ± 1.2	0.65 ^c
Asthma severity (persistent)			
Mild	33 (37.5)	33 (43.4)	0.76 ^d
Moderate	43 (48.9)	35 (46.1)	
Severe	12 (13.6)	8 (10.5)	
Uses of quick relief medication per month ^b	2.4 ± 0.9	2.1 ± 0.3	0.50 ^c
Emergency department visits per year ^b	3.1 ± 1.3	2.8 ± 1.2	0.42 ^c
Caregiver			
Parent is the primary asthma caregiver	63 (71.6)	55 (72.4)	0.87 ^c
Education of the primary asthma caregiver			
High school diploma or below	58 (66.0)	43 (56.6)	0.76 ^d
College or above	30 (34.0)	33 (43.4)	
Passive smoking in the household	21 (23.9)	18 (23.7)	0.55 ^c

^aData are given as number (percentage) of children. Percentages are based on totals within each category and may not total 100 because of rounding.

^bData are given as mean ± SD.

^cBased on the paired *t*-test.

^dBased on the χ^2 -test.

time symptoms (0: no asthma symptoms; 1: wake up once because of asthma symptoms; 2: wake up several times due to asthma symptoms; 3: symptoms stop sleeping and cause the patient to stay awake during the night). At the end of the 12-week trial period, patients in the intervention group showed improvements in nighttime (-0.08 ± 0.33 , $p = 0.108$), and daytime (-0.07 ± 0.33 , $p = 0.122$) asthma symptoms, although the changes were not statistically significant, whereas the patients in the control group remained stable compared with baseline (Table 2). In contrast, when the two groups were compared with regard to change from baseline, the children in the intervention group had a significant decrease of nighttime ($p = 0.028$) and daytime symptoms ($p = 0.009$) compared with the children in the control group.

Peak expiratory flow (PEF) reading and weekly PEF variability

Each subject recorded PEF in the patient diary every morning and night using the Micro-

lite[®]—electronic peak flow meter. There were no statistically significant differences in baseline values between morning and night PEF and daily PEF variability between the intervention and control groups (Table 3). Subjects in both groups had improved morning and night PEF after 12 weeks of the study. Compared to baseline, children in the control group had increased PEF, both morning and night, by 10.9 ± 40.0 and 11.1 ± 41.6 L/min, respectively, after 12 weeks although the increases were not statistically significant ($p = 0.072$ for morning PEF and $p = 0.070$ for night PEF). In contrast, the intervention group showed statistically significant improvement in both morning ($p = 0.017$) and night PEF ($p = 0.010$) at the end of trial. However, there was no significant difference between the groups in the change of morning and night PEF from baseline at week 12. No such within-group or between-group differences were observed with regard to daily PEF variability, which was calculated by multiplying by 100 after dividing the difference of highest and lowest daily PEF reading by the mean daily PEF.

TABLE 2. TRIAL PERIOD COMPARISONS OF SYMPTOM SCORES FOR ASTHMA BETWEEN INTERVENTION AND CONTROL GROUPS

Scores	Statistical parameters	Intervention group (n = 82)			Control group (n = 71)			Group difference	
		Baseline	Week 12	Change from baseline	Baseline	Week 12	Change from baseline	Baseline	Change from baseline
Nighttime	Mean ± SD	0.11 ± 0.28	0.04 ± 0.17	−0.08 ± 0.33	0.05 ± 0.13	0.05 ± 0.19	0.00 ± 0.20		
	Median	0.00	0.00	0.00	0.00	0.00	0.00		
	Range	0.00–1.25	0.00–1.08	−1.25–1.08	0.00–0.58	0.00–1.27	−0.58–1.00		
	95% CI	0.03–0.19	0.01–0.08	−0.17–0.02	0.01–0.09	−0.01–0.11	−0.06–0.06		
	p-value			0.108 ^c			0.998 ^c	0.357 ^a	0.500 ^a
Daytime	p-value (T-C)								0.028 ^b
	Mean ± SD	0.14 ± 0.32	0.07 ± 0.24	−0.07 ± 0.33	0.03 ± 0.11	0.05 0.17	0.01 ± 0.18		
	Median	0.00	0.00	0.00	0.00	0.00	0.00		
	Range	0.00–1.17	0.00–1.25	−1.17–1.07	0.00–0.58	0.00–0.91	−0.58–0.75		
	95% CI	0.05–0.23	0.00–0.14	−0.17–0.02	0.00–0.07	−0.00–0.10	−0.04–0.07	0.138 ^a	0.296 ^a
	p-value				0.122 ^c		0.588 ^c		0.009 ^b
	p-value (T-C)								

^aTreatment effect by two-way ANOVA with treatment, center, and treatment-by-center interaction.
^bTreatment-by-center interaction by two-way ANOVA with treatment, center, and treatment-by-center interaction.
^cBased on the paired *t*-test.

TABLE 3. COMPARISON OF MORNING AND NIGHT PEAK EXPIRATORY FLOW (PEF) READINGS AND WEEKLY PEF VARIABILITY BETWEEN INTERVENTION AND CONTROL GROUPS

PEFR (L/min)	Statistical parameters	Intervention group (n = 82)			Control group (n = 71)			Group difference	
		Baseline	Week 12	Change from baseline	Baseline	Week 12	Change from baseline	Baseline	Change from baseline
Morning PEF	Mean $\pm$ SD	223.1 $\pm$ 55.5	241.9 $\pm$ 81.4	18.7 $\pm$ 49.4	219.2 $\pm$ 58.0	230.0 $\pm$ 57.9	10.9 $\pm$ 40.0		
	Median	214.6	220.0	15.5	212.7	229.6	13.4		
	Range	128.2–385.0	126.7–594.3	–67.4–243.0	125.0–361.9	147.5–374.2	–124.4–88.2		
	95% CI	206.1–240.2	216.8–266.9	3.5–33.9	201.9–236.4	212.8–247.2	–1.0–22.7		
	p-value			0.017 ^c			0.072 ^c		
Night PEF	p-value (T-C)							0.565 ^a	0.202 ^a 0.574 ^b
	Mean $\pm$ SD	232.5 $\pm$ 55.3	255.6 $\pm$ 86.7	23.1 $\pm$ 56.5	224.7 $\pm$ 57.6	235.9 $\pm$ 61.6	11.1 $\pm$ 41.6		
	Median	223.3	244.1	12.5	213.8	232.1	10.8		
	Range	141.4–389.4	123.3–655.5	–66.7–312.0	107.5–356.6	142.5–428.4	–124.2–133.0		
	95% CI	215.5–249.6	228.9–282.3	5.7–40.5	208.0–241.5	218.0–253.8	–0.9–23.2		
Daily Variability	p-value			0.010 ^c			0.070 ^c	0.376 ^a	0.123 ^a 0.540 ^b
	p-value (T-C)								
	Mean $\pm$ SD	8.6 $\pm$ 4.7	10.3 $\pm$ 7.0	1.7 $\pm$ 7.5	9.2 $\pm$ 5.9	9.2 $\pm$ 8.6	0.1 $\pm$ 9.9		
	Median	7.0	9.3	–0.3	7.2	6.9	–0.6		
	Range	1.8–23.0	1.1–27.1	–10.1–17.9	2.6–27.2	1.0–47.1	–13.8–40.9		
	95% CI	7.1–10.0	8.1–12.4	–0.6–4.0	7.4–11.0	6.7–11.8	–2.9–3.0		
	p-value				0.149 ^c		0.970 ^c	0.643 ^a	0.952 ^a 0.211 ^b
	p-value (T-C)								

^aTreatment effect by two-way ANOVA with treatment, center, and treatment-by-center interaction.
^bTreatment-by-center interaction by two-way ANOVA with treatment, center, and treatment-by-center interaction.
^cpaired *t*-test.

Asthma monitoring and therapeutic adherence

The results of asthma monitoring and therapeutic adherence are shown in Table 4. There was reasonable improvement in PEF performance and in the technique of inhalation with DPI or MDI controllers in both groups after the trial period but not to the extent of a significant difference. In contrast, although the adherence rates for daily asthma diary entry and inhaled corticosteroids in the intervention group declined during the study, these rates were significantly higher compared with the control group at the end of trial period ($p < 0.05$). In the control group, the rates of adherence to daily asthma symptoms entry and use of inhaled corticosteroids after the 12-week trial declined from the original rates by 42.9% and 48.8%, respectively.

Pediatric asthma control tests

In order to evaluate the outcome assessment of the Internet-based monitoring system, the details of the response to each question of the pediatric asthma control tests (PACT) in both groups before and after the trial period were compared (Table 5). In each item, there was no

between-group or within-group difference in score at the end of the 12-week study compared with baseline. On the other hand, in comparisons with regard to percentages of well-controlled (total score above 25) and not controlled (total score below 20) in each group, there was a significant improvement of the well-controlled rate in the intervention group (70.4% and 9.1%) compared to the control group (55.3% and 13.2%).

Asthma knowledge, quality of life, and satisfaction of Internet-based asthma monitoring system

Both the control and intervention groups showed a significant increase of asthma knowledge scores after the trial. To determine whether there was a significant difference between the groups, the control and intervention groups were compared using the Cochran-Mantel-Haenszel statistic, controlling for the baseline knowledge scores through stratified analysis. The percentage of correct answering for all the questions regarding the asthma knowledge and self-management for disease control was significantly greater in the inter-

TABLE 4. TRIAL PERIOD COMPARISONS OF ASTHMA MONITORING AND THERAPEUTIC ADHERENCE

Variable	Visit-specific comparisons			
	Baseline		12 weeks	
	Intervention group (n = 88)	Control group (n = 76)	Intervention group (n = 82)	Control group (n = 71)
Monitoring adherence				
Peak flow meter technique score (%)	83.5	85.6	99.7	93.5
Number of asthma diary entries per patient per month	27 ± 3.2	21 ± 4.5	23 ± 4.3	15 ± 5.3 ^a
Adherence to asthma diary (%)	96.0	93.2	82.5	53.4 ^a
Therapeutic adherence				
DPI or MDI plus spacer technique score (%) ^b	82.1	80.3	96.5	93.4
Adherence to inhaled corticosteroid (controller) (%)	83.5	82.3	63.2	42.1 ^a

^aSignificantly different from corresponding value for baseline ($p < 0.05$).

^bDPI, dry powder inhaler; MDI, metered dose inhaler.

TABLE 5. TRIAL PERIOD COMPARISONS OF PEDIATRIC ASTHMA CONTROL TESTS (ACT)

<i>Pediatric asthma control tests evaluated in the past 4 weeks</i>	<i>Visit-specific comparisons</i>			
	<i>Baseline</i>		<i>12 weeks</i>	
	<i>Intervention group (n = 88)</i>	<i>Control group (n = 76)</i>	<i>Intervention group (n = 82)</i>	<i>Control group (n = 71)</i>
Complete following questions by child				
How is your asthma today? (0–3)	2.2 ± 0.5	2.1 ± 0.4	2.8 ± 0.1	2.1 ± 0.5
How much of a problem is your asthma when you run, exercise or play sports? (0–3)	2.1 ± 0.6	2.2 ± 0.3	2.7 ± 0.1	2.3 ± 0.3
Do you cough because of your asthma? (0–3)	1.8 ± 1.1	2.0 ± 0.4	2.5 ± 0.3	2.2 ± 0.5
Do you wake up during the night because of your asthma? (0–3)	2.1 ± 0.7	2.1 ± 0.6	2.3 ± 0.2	2.2 ± 0.6
Complete following questions by caregiver				
During the last 4 weeks, how many days did your child have any daytime asthma symptoms? (0–5)	3.5 ± 1.3	3.6 ± 1.5	4.5 ± 0.3	4.0 ± 0.5
During the last 4 weeks, how many days did your child wheeze during the day because of asthma? (0–5)	4.1 ± 0.3	4.2 ± 0.5	4.6 ± 0.3	4.3 ± 0.4
During the last 4 weeks, how many days did your child wake up during the night because of asthma? (0–5)	3.8 ± 1.0	4.0 ± 0.7	4.3 ± 0.4	4.2 ± 0.6
Total score of child ACT ^a				
Numbers of well controlled (ACT > 25)	52 (59.1)	40 (52.6)	62 (70.4) ^b	42 (55.3)
Numbers of not controlled (ACT < 20)	18 (20.4)	12 (15.8)	8 (9.1) ^b	10 (13.2)

^aSignificantly different from corresponding value for baseline ($p < 0.05$).

^bDPI, dry powder inhaler; MDI, metered dose inhaler.

vention group (93.2%) compared to control group (70.3%) at the end of trial. In evaluation of the quality of life (on a scale where 7 was best and 1 was worst) in asthmatic children and their caregivers, both groups reported reasonable improvement of quality of life after the trial, but only the caregivers of asthmatic children randomized to the intervention group showed significant improvement after the study (6.5 ± 0.5) compared to before the study (4.3 ± 1.2 , $p < 0.05$).

An after-study survey regarding opinion of telemedicine and satisfaction with the Internet-based asthma monitoring system was conducted in the families who had been randomized to intervention group. The findings showed a favorable attitude among the caregivers toward telemedicine with respect to improvement of their knowledge and self-help management of asthma, and they also reported reasonable satisfaction with the Internet-based

asthma monitoring system with regard to caring for asthmatic children (data not shown).

DISCUSSION

Many studies have supported the view that long-term monitoring of asthma severity and using action plans for self-management can reduce asthma exacerbations, optimize drug therapy, and decrease the cost of asthma management.²⁶ But in daily practice, many asthma patients have difficulties in following action plans on a daily basis and have low compliance to medication regimens, especially with regard to asthmatic children and their caregivers.²⁷ Therefore, Internet-based management systems have been developed to try to improve user-friendliness in self-management and monitoring. Our case-controlled study is one of a very few similar studies on asthmatic children.

We demonstrated that an Internet-based management tool, the Blue Angel for Asthma Kids, has the potential for improving asthma outcome compared with conventional treatment over a period of 12 weeks.

The last few years have seen the development of various kinds of tools for improving asthma care. Guendelman et al.¹⁷ demonstrated that interactive telephone-based education for 12 weeks produced better asthma control than did the use of a conventional asthma diary. This asthma education tool differs considerably from our asthma management tool in that ours contains a real-time response to the patient's daily input of asthmatic symptoms and an action plan for the patient as well as an accumulated data bank that is retrievable for case managers and physicians to help physicians decide on the level of treatment. An Internet-based asthma monitoring system was developed by Finkelstein,¹¹ who used portable spirometers and pocket-sized palmtop computers for registering lung function and symptoms. This system was found to be user-friendly in a study of 31 asthmatic subjects.¹³ However, the study was not designed to assess the ability of the system to improve asthma treatment. These two studies nevertheless indicate that Internet-based asthma monitoring and education form a promising tool to improve asthma outcomes.

Recently, Rasmussen et al.,²⁸ in Denmark, conducted a randomized trial of Internet-based monitoring of asthma for 300 asthmatic adults during a 6-month period. They found that treatment and monitoring with the Internet-based management tool led to significantly better improvement in the Internet group regarding asthma symptoms, quality of life, lung function, and airway responsiveness. Our study on asthmatic children also showed that an Internet-based asthma management program was feasible for children and their caregivers, and could result in better asthma care, as demonstrated by improved asthma symptoms scores and daily PEF values in children randomized to the intervention group.

In our study, the improvement in asthma control was more pronounced in the Internet group than in control group, which suggests that Internet management of asthma is benefi-

cial. Several children reported after the trial that they liked Blue Angel because it was fun and it reminded them to take their medications. In contrast, several children who received the asthma diary reported that they either lost it or forgot to enter information in it. Many children who kept conventional diaries reported that they had forgotten to take their medications. Although asthma symptoms declined more for the Blue Angel group, symptoms also declined for the control group (Table 2). This decline may have partly resulted from the consistent standardized asthma education given to children in both arms of the study and the availability of a nurse coordinator, which was a new intervention for the clinic. This finding may reflect enhanced care by the hospital staff resulting from adherence to GINA guidelines. Therefore, we believe that the benefit derived from implementation of the Internet tool of Blue Angel is to some extent caused by the opportunity to register symptoms continually and thereby obtain learned management skills that helped the children comply with their treatment regimens.

Our study results also showed that the adherence rates of therapeutic and diagnostic monitoring, the global assessment of asthma control, the knowledge of asthma self-management, and the quality of life of caregivers were all significantly higher in the intervention group compared with the conventional asthma care group. Many believe that the Internet can enhance a shift from institution-centric to patient-centric systems that empower individuals with chronic conditions to play an active role in the management of their diseases.²⁹ Both the control and intervention groups received the same optimal clinical care, education program, and support from asthma management teams. The reason for the additional benefit of the Internet-based asthma monitoring program beyond the benefits from conventional asthma care, we believe, may be due to the autonomous characteristic of the program and the interactive-feedback learning mechanism that provides asthmatic children and their caregivers who are Internet users the confidence to handle asthmatic symptoms and self-management, which is lacking in the one-way instruction of conventional asthma care.

In our study, the duration of the trial was too short and the sample size too small to yield marked group differences in the occurrence of emergency visits and hospital admissions. Moreover, despite the marked advantage of the Blue Angel monitoring system over the conventional asthma diary, daily use in both groups declined as children approached the end of the trial. These declines probably reflect the anticipated end of the study, the lack of perceived additional benefit of monitoring, and, for Blue Angel users, saturation with the educational messages. This trend would suggest that the benefit of self-monitoring with a device like Blue Angel might be especially strong at critical care management times (e.g., at the start of care for asthma or after an acute asthma exacerbation, an emergency visit, a hospitalization, or a step-up in severity class). Consequently, further analyses are needed to assess whether the treatment algorithm and educational program incorporated in the Internet tool should be adjusted or regularly updated.

This study demonstrates that effective self-management education is a potent intervention for improving asthma care in children, yet it might be argued that such an intervention would increase the medical expense and financial burden of physicians who are not reimbursed for the cost of education. These concerns ignore the fact that without appropriate care, children with poorly controlled asthma are more likely to end up in hospital or specialty settings. This argument is supported by a recent report from Runge et al.³⁰ who found that from a payer perspective, the benefit-cost ratio of the traditional educational program is 0.55. Adding the Internet-based educational program (IEP) improved the ratio to 0.79. Subgroup analysis also demonstrated that within 1 year, the savings exceed the intervention costs in children with moderate or severe asthma. They concluded that the IEP offers the potential to decrease the burden of disease and to realize incremental morbidity cost savings.

In conclusion, we found that the Internet-based asthma monitoring program produced better control of asthma in children over a period of 3 months. Compared with a conventional asthma management program, monitoring asthma symptoms and functional status

with Blue Angel increases self-management skills and improves asthma outcome. This system offers a model for a new level of connectivity for health information that supports customized monitoring, information technology (IT)-enabled nurse case managers, and the delivery of longitudinal data to clinicians to support the care of children with persistent asthma. We believe that systems such as the one described are well-suited, perhaps essential, technologies for the care of children and adults with chronic conditions such as asthma, and that the future will see further developments of such monitoring and electronic devices for the benefit of both patients and physicians.

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