An Internet-based store-and-forward video home telehealth system for improving asthma outcomes in children

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Abstract: The adherence and disease-control outcomes associated with the use of an Internet-based store-and-forward video home telehealth system to manage asthma in children were studied.

Pediatric patients with persistent asthma were provided with home computers and Internet access and monitored biweekly over the Internet. All patients were seen in the pediatric clinic at 0, 2, 6, 12, and 24 weeks. Half of the patients received asthma education in person and half via an interactive Web site. Adherence measures were assessed by therapeutic and diagnostic monitoring. Therapeutic monitoring included digital videos of patients using their controller medication inhaler. Diagnostic monitoring included an asthma symptom diary and a video of peak flow meter use. Videos were submitted electronically twice a week by using in-home telemonitoring with store-and-forward technology. Feedback was provided electronically to each patient. Disease control was assessed by examining quality of life, utilization of services, rescue-therapy use, symptom control, satisfaction with home telemonitoring, and retention of asthma knowledge. Patients were randomly assigned to an asthma education group (Internet versus office), and the data were analyzed by comparing results for study days 0–90 and 91–180.

Ten children participated. A total of 321 videos of inhaler use and 309 videos of peak flow meter use were submitted. Inhaler technique scores improved significantly in the second study period. Submission of diagnostic monitoring videos and asthma diary entries decreased significantly. Peak flow values as a percentage of personal best values increased significantly. Overall, there was no change in quality of life reported by patients. However, the caregivers in the virtual-education group reported an increase in the patients' quality-of-life survey scores. Emergency department visits and hospital admissions for asthma were avoided. Rescue therapy was infrequent. A high rate of satisfaction with home telemonitoring was reported.

Internet-based, store-and-forward video assessment of children's use of asthma medications and monitoring tools in their homes appeared effective and well accepted.

Index terms: Asthma; Compliance; Computers; Inhalers; Internet; Patient information; Pediatrics; Quality of life

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Asthma is the most common chronic disease of childhood, and management of the disease is a major source of expense for any managed care health organization.[1,2] While currently available medical therapy can be highly effective, failure of outpatient therapy (hospitalizations or emergency department visits) is common. Key elements of therapy include inhaled corticosteroids or other medications for long-term asthma control and correct use of metered-dose inhalers (MDIs) and dry powder inhalers (DPIs). Therapeutic failure is almost always related to inadequate or incorrect use of medications.[3-5]

Improved education and monitoring of children with asthma have been shown to be highly effective in controlling symptoms and preventing failure of outpatient therapy.[6-11] Although appropriate ambulatory care is more cost-effective than episodic unscheduled care and hospitalization, frequent follow-up for education reinforcement and moni-

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toring is costly and inconvenient.[11] In recent years, investigators have described the use of real-time telemedicine tools to supplement outpatient monitoring.[12-21] This technology has been effective for and accepted by children even in low socioeconomic groups.[12,18-20]

Recent surveys indicate that 62% of adults have personal computers[22,23] and 50% of families have Internet access.[24] 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. Because this method allows for daily monitoring, it may help increase patients' adherence to treatment regimens. Store-and-forward technology is dissynchronous communication in which electronic data are captured and transmitted by the sender and retrieved by the receiver at a later time.[25] Web-based store-and-forward systems have an advantage over the real-time monitoring that has been reported thus far, because the patient and the provider do not need to be online at the same time.

The purpose of our study was to develop an Internet-based store-and-forward video monitoring system for patients with asthma, demonstrate its use in pediatric patients, assess a range of outcome measures, and determine whether virtual follow-up over the Internet can be effective for managing asthma.

Methods

Interventions. Pediatric patients ages 6–17 years with persistent asthma were recruited from among the population of patients with asthma in our pediatric clinic and enrolled in the study. Written informed consent was obtained from the parents or guardian of all children, and assent was obtained from all children older than seven years.

Each patient was provided a home computer system, a video camera, a microphone, and cable access to the Internet. The computers were installed by a pharmacist (the case manager), and each family received in-home instruction in the use of the equipment. Every patient was evaluated by a pediatric pulmonologist. The initial evaluation included a history and physical examination and pulmonary function tests. The physician classified the asthma as to its severity and determined the appropriate management plan by using the criteria of the National Heart, Lung, and Blood Institute.[26] All patients were taking inhaled corticosteroids for long-term asthma control, and all used a spacer with their MDI or used a DPI.

After enrollment, patients used the digital video camera and computer to record peak flow meter readings and their daily use of the MDI or DPI two times a week. Rather than using specialized, expensive equipment for recording and forwarding the peak flow information, commercial off-the-shelf technology for the computer and camera was used. A video of the patient using the peak flow meter and the inhaler was recorded twice a week with an ordinary digital camera. The parent or child read the peak flow level aloud on camera. The peak flow readings were recorded consistently in the morning or evening, before a medication dose was taken. On another video, the patient's use of a corticosteroid MDI or DPI was recorded. A daily asthma symptom diary was also recorded. The videos and diary were forwarded to the case manager.

Twice a week, the case manager reviewed the videos of patients' peak flow meter use and inhaler use and daily symptom diaries and scored the patients' technique of using the inhaler and the peak flow meter on the basis of the standard instructions given to patients.[27] She sent patients e-mails about their peak flow data, the symptom diaries, and inhaler technique and reviewed the written asthma action plan and home management plan, also twice a week. To comply with Health Insurance Portability and Accountability Act regulations, no patient-specific identifiers were used in electronic communication.

All patients were monitored in person by the pulmonologist and the case manager according to an asthma clinical pathway at enrollment, two and six weeks, and three and six months.

Patient education. To test the feasibility and effectiveness of Internet-based asthma education, patients were randomized with a random-numbers table to one of two study groups: Internet-based education (the "virtual group") or office-based traditional education (the "office group"). The office group had scheduled office visits to receive asthma education. The virtual group received all education online.

Patients in the virtual group input their peak flow readings and daily asthma symptom diaries on the Web site, while office-based patients recorded this information in a hard-copy diary and brought it with them on their follow-up encounters. The office group received asthma education from the case manager during scheduled asthma clinical pathway visits. The virtual group received asthma education via an educational Web site. The patients were instructed to access the Web site at two and six weeks and three and six months after enrollment.

Families could telephone or e-mail the case manager whenever they felt it necessary. The case manager assisted families with the patients' asthma action plan and home management plan as needed. She could also recommend an appointment with the pulmonologist for patients in either group if they needed further evaluation or intervention, as determined by telephone or electronic communication.

Outcome measurements. Patients in both groups were asked to complete an asthma symptom diary

each day, to complete quality-of-life and asthma knowledge surveys at selected follow-up visits, and to perform spirometric tests before the study. The Pediatric Asthma Quality of Life Questionnaires for the patient and the caregivers were completed by the patient and the caregiver at enrollment and six months (used with permission by the original author).[28] A survey of satisfaction with home telemonitoring was completed at the end of the study. Patients in the office group completed these surveys in person during the office encounters, while the virtual-group patients completed them on the Web site.

Outcomes assessed included measurements 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 (by computerized prescription-refill record and asthma diary) and DPI or MDI with spacer technique (by videos review). Diagnostic monitoring included reviewing the asthma symptom diary and the video of peak flow meter use. Adherence to electronic assessment was also measured.

The measures of disease control included lung function (spirometric and peak flow data), the Pediatric Asthma Quality of Life Questionnaire, utilization of services (emergency department visits, hospitalizations, unscheduled visits for asthma attacks), rescue therapy use (refills of β-adrenergic-receptor agonists and short courses of oral corticosteroid treatment), symptom control (symptom-free days and diary symptom score), parent satisfaction with home telemonitoring (survey scores and total participant time), and asthma knowledge retention (testing before and after education).

Comparisons of scores for days 0–90 and 91–180 were made by using differences in the individual scores (scores for days 0–90 minus scores for days 91–80). Significance was calculated with a paired *t* test. The significance of differences in continuous outcomes (e.g., satisfaction survey scores and participant time) between patients in the virtual 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 virtual and office groups for other outcomes with integer scores were analyzed with the Mantel-Haenszel test for ordinal data, which tests for differences in mean scores. This test does not assume that outcomes are normally distributed. Since this was a pilot feasibility study, a power analysis was not conducted.

The study was approved by the institutional review board's scientific review and human-use committees.

Results

Ten pediatric patients (five boys and five girls; mean ± S.D. age, 7.6 ± 2.0 years) with persistent asthma completed the study. The mean ± S.D. age of virtual-group members was 6.6 ± 0.5 years, compared with 8.7 ± 2.5 for the office group. There was one boy in the virtual group and there were four in the office group. Asthma severity was mild persistent in four patients (one in the virtual group and three in the office group) and moderate persistent in six patients (four in the virtual group and two in the office group). The demographic characteristics did not differ significantly between groups. Four patients had normal spirometric data before the study (forced expiratory volume in one second [FEV_1], >80% of predicted), and six patients had mild obstruction (FEV_1, 60–80% of predicted).

Although there were no differences in outcome measures between the virtual and office groups for the entire 180-day study period, differences were detected between study days 0–90 and 91–180 when the outcomes for all 10 patients were analyzed.

Therapeutic adherence was reflected in the submission of 193 videos of inhaler use during the first 90-day study period and 128 for days 91–180 (240 videos were expected in each period). The adherence rate for inhaler video submission in the first 90 days was 70% in the virtual group and 91% in the office group (Table 1). The overall adherence rates decreased in the second study period but were similar: 54% and 52% for the virtual and office groups, respectively. Inhaler technique improved during period 2 (87% in period 1 and 94% in period 2) ($p < 0.05$). The refill rate for controller medications was acceptable in both groups. Each patient requires a refill every four to six weeks, depending on the medication and the dosage frequency. The patients used a mean ± S.D. of 0.8 ± 0.6 controller inhaler per month in the first study period and 0.5 ± 0.3 in period 2.

There was reasonable adherence to peak flow measurement. A total of 194 videos recording the patients' use of peak flow meters were submitted during period 1 and 115 in period 2 (240 videos were expected in each period). The adherence rate for submission of these videos decreased from 81% in period 1 to 48% in period 2 ($p < 0.01$) (Table 2). The rate of symptom diary completion was disappointing, especially in the virtual group: 18.7% in period 1 and 6.7% in period 2. While the rate of diary completion was reasonable for the office group in period 1 (65.1%), this rate also declined (to 19.6%) as the study moved forward. Adherence with symptom diary submission decreased significantly in period 2 ($p < 0.01$).

All 10 patients had excellent control of their asthma during the study. Peak flow values improved from 84.3% of personal best (i.e., the highest peak flow reading achieved when

Table 1.
Therapeutic Adherence

Variable	Value					
	Days 0–90			Days 91–180		
	Virtual Group	Office Group	All	Virtual Group	Office Group	All
Total no. corticosteroid inhalers refilled	8	16	24	6	8	14
Mean ± S.D. no. corticosteroid inhalers per patient per mo.	0.5 ± 0.5	1.1 ± 0.6	0.8 ± 0.6	0.4 ± 0.3	0.5 ± 0.4	0.5 ± 0.3
Total no. videos of inhaler use sent	84	109	193	65	63	128
Mean ± S.D. no. videos of inhaler use submitted per patient	16.8 ± 3.4	21.8 ± 6.7	19.3 ± 5.6	13.0 ± 5.7	12.6 ± 11.5	12.8 ± 8.6
Adherence to submission of videos of inhaler use (%)	70.0	90.8	80.4	54.2	52.5	53.3
DPI or MDI plus spacer technique score (%)[a]	87.2	87.3	87.3	95.2	93.5	94.3[b]

[a]DPI = dry powder inhaler, MDI = metered-dose inhaler.
[b]Significantly different from corresponding value for days 0–90 ($p < 0.05$).

Table 2.
Diagnostic Adherence

Variable	Value					
	Days 0–90			Days 91–180		
	Virtual Group	Office Group	All	Virtual Group	Office Group	All
Total no. asthma diary entries	119	293	412	30	88	118[a]
Mean ± S.D. no. asthma diary entries per patient	23.8 ± 23.8	58.6 ± 39.4	41.2 ± 35.7	6.0 ± 7.9	17.6 ± 22.3	11.8 ± 16.9[a]
Asthma diary adherence (%)	18.7	65.1	41.9	6.7	19.6	13.1[a]
Total no. videos of peak flow meter use submitted	83	111	194	54	61	115[a]
Mean ± S.D. no. videos of peak flow meter use submitted per patient	16.6 ± 3.2	22.2 ± 7.5	19.4 ± 6.2	10.8 ± 6.1	12.2 ± 10.8	11.5 ± 8.3[a]
Adherence to submission of videos of peak flow meter use (%)	69.2	92.5	80.8	45.0	50.8	47.9[a]
Peak flow meter technique score (%)	99.7	99.2	99.5	99.3	99.9	99.6

[a]Significantly different from corresponding value for days 0–90 ($p < 0.01$).

asthma is well controlled) for both groups over the first three months to 91.8% over the second three months ($p < 0.05$) (Table 3). Unscheduled clinic visits due to acute exacerbation of asthma were rare. There were only five unscheduled visits in the six months, equivalent to one visit per patient per year. There were no emergency department visits or hospitalizations for asthma. Patients with good asthma control only rarely need β-agonist rescue therapy. A mean ± S.D. of 0.4 ± 0.6 β-agonist prescription was filled per patient per month in period 1 and 0.3 ± 0.4 in period 2. Similarly, rescue with short courses of oral corticosteroids was infrequent. In period 1, an average of 75.1% of days were symptom free, compared with 84.3% in period 2 (symptom diary entries were not provided consistently, however).

Asthma knowledge was good before the study and was only slightly better after the study (Table 4). Patients reported reasonable satisfaction with home telemonitoring and were reasonably satisfied with the time required to complete the electronic checks. Although the difference was not significant, the virtual group had lower satisfaction scores than the office group and was less satisfied with the time required to complete the education. There was no perception among patients that their quality of life was changed during the study. However, an increase of quality-of-life survey scores was reported by caregivers of patients in the virtual group.

Discussion

This is the first study we know of in which a Web-based system was used to monitor the adherence of children to asthma therapy at home over an extended period by frequent direct observation of inhaler technique. Given the importance of correct inhaler technique to the effectiveness of asthma therapy and the propensity of children to practice inadequate technique, this system provides a valuable means of ensuring compliance with outpatient treatment.

All 10 patients achieved excellent control of their asthma during the study, with no emergency depart-

Table 3.
Asthma Control[a]

Variable	Value					
	Days 0–90			Days 91–180		
	Virtual Group	Office Group	All	Virtual Group	Office Group	All
Peak flow values (% of personal best)	82.7	86.0	84.3	90.3	93.3	91.8[b]
Total no. unscheduled asthma clinic visits	1	1	2	0	3	3
Mean ± S.D. no. β-agonist uses in diary	3.0 ± 3.3	20.5 ± 24.9	10.8 ± 18.0	1.3 ± 1.5	21.3 ± 25.8	11.3 ± 19.7
Total no. β-agonist refills	7	4	11	4	6	10
Mean ± S.D. no. β-agonist refills per patient per mo.	0.5 ± 0.9	0.3 ± 0.4	0.4 ± 0.6	0.3 ± 0.3	0.4 ± 0.6	0.3 ± 0.4
Total no. short courses of oral corticosteroids	6	3	9	2	4	6
Mean ± S.D. no. short courses of oral corticosteroids per patient	1.2 ± 1.3	0.8 ± 0.5	1.0 ± 0.9	0.40 ± 0.6	0.8 ± 0.8	0.6 ± 0.7
% symptom-free days as recorded in diary	70.8	80.4	75.1	91.7	77.0	84.3
Mean ± S.D. total symptom-control score[c]	4.5 ± 0.6	4.4 ± 0.4	4.5 ± 0.5	4.1 ± 0.2	4.6 ± 0.8	4.4 ± 0.8

[a]No emergency department visit or hospitalization was reported.
[b]Significantly different from corresponding value for days 0–90 ($p < 0.05$).
[c]On scale where 4 = best and 16 = worst.

Table 4.
Asthma Knowledge Test and Survey Results

Variable	Mean ± S.D. Value		
	Virtual Group	Office Group	All
Knowledge test score (%)[a]			
Before study	82.0 ± 8.8	77.0 ± 5.2	79.8 ± 7.5
After study	84.8 ± 7.6	8.3 ± 5.5	84.0 ± 6.6
Satisfaction survey score[b]	4.0 ± 0.3	4.2 ± 0.6	4.1 ± 0.4
Satisfaction with time required to complete electronic checks[b]	3.8 ± 0.8	4.3 ± 1.0	4.0 ± 0.9
Quality-of-life survey score[c]			
Before study			
Caregiver	5.6 ± 1.2	6.4 ± 0.7	6.0 ± 1.0
Patient	6.6 ± 0.4	6.5 ± 0.7	6.5 ± 0.5
After study			
Caregiver	6.2 ± 1.0	6.4 ± 0.6	6.3 ± 0.8
Patient	6.6 ± 0.2	6.6 ± 0.6	6.6 ± 0.4

[a]% of questions answered correctly by the patient.
[b]On scale where 5 = best and 1 = worst.
[c]On scale where 7 = best and 1 = worst.

ment visits, no hospitalizations, and few unscheduled clinic visits for asthma. Excellent control was also reflected in infrequent use of β-agonists, a marker of high resource utilization identified in other populations with asthma.[28] This is not surprising; careful case management has been shown to decrease the high utilization of resources by children with asthma in our own and other settings.[3-10,29]

Most studies of telehealth for asthma have examined diagnostic outcomes by using electronic devices to monitor spirometric variables or peak flow in the home.[12,13,15,19,30,31] Our study emphasized therapeutic outcomes: the delivery of medication to patients, including controller-refill rates and inhaler technique. The children maintained excellent inhaler technique throughout the study. We attribute this to the biweekly monitoring of technique and feedback from the case manager. Previously in our asthma program, we found that only 30% of children were able to use the MDI and spacer correctly on their first attempt before pharmacist counseling. Despite training by a pharmacist, at the first outpatient follow-up (one to two weeks), only 40% of children used the inhaler correctly on the initial attempt.[32] The literature suggests that one would expect the same "decay rate" for inhaler technique to take place in absence of frequent reinforcement.[33] Although the adherence to biweekly evaluation dropped in the second half of our study, with patients finding time to submit only one video a week, inhaler technique scores continued to improve. The use of video and telemedicine technology to assess inhaler technique has been demonstrated previously, but not for an extended period and not in the patient's home.[18]

Adherence to the symptom diary in both groups was disappointing. The poor adherence in the virtual group (18.9% in the first three months and 6.7% in the second three months) may have been a function of the inconvenience of the symptom diary system. However, compliance in the office group was also low (65.1% in the first three months and 19.6% in the second three months). This brings into question the effectiveness of these tools in clinical practice. Completion of the diary, like daily peak flow monitoring, is

time-consuming and inconvenient. Other studies have demonstrated that the results of these diagnostic monitoring tools should be viewed with caution, as patients may not be completely honest about completing them.[34] This is consistent with the latest recommendations that the diary and peak flow meter be used episodically at times when the patient's clinical status or regimen is changing.[26]

Two of the study patients had been hospitalized a total of five times in the previous year for asthma; however, neither of them required hospitalization during the study. Although there were five unscheduled asthma clinic visits, none of the patients required care in the emergency department or were hospitalized. This may be due in part to the accessibility of the pharmacist case manager, who was on call for the patients 24 hours a day. Also, two of the unscheduled visits involved a patient whom we later discovered was having anxiety attacks.

Home telehealth for the control of asthma in children is likely to become increasingly sophisticated and useful. Researchers in previous studies used real-time videoconferencing, non-Internet-based communication (such as the telephone), or store-and-forward text data for managing patients.[12,14,15,19,21,30] We believe that our study is the first to integrate store-and-forward video technology with Internet-based case management of children with asthma in the home.

Conclusion

Internet-based, store-and-forward video assessment of children's use of asthma medications and monitoring tools in their homes appeared effective and well accepted. The use of this tool may improve adherence to asthma medications, especially those requiring careful technique.

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