Using SMS to Provide Continuous Assessment and Improve Health Outcomes for Children with Asthma

Tae-Jung Yun[1,3], Hee Young Joeng[1], Tanisha D. Hill[2], Burt Lesnick[2], Randall Brown[2], Gregory D. Abowd[1], Rosa I. Arriaga[1]

[1]Georgia Institute of Technology
85 5th Street NW, Atlanta, GA 30332
{tjyun, hyj,abowd}@gatech.edu, arriaga@cc.gatech.edu

[2]Georgia Pediatric Pulmonology Associates
1100 Lake Hearn Drive, Suite 450
Atlanta, GA 30342
{tdhill, blesnick,rbrown}@gppa.net

[3]Samsung Electronics CO. LTD
416 Maetan-3Dong Paldal-Gu
Suwon, South Korea

ABSTRACT

Effective communication between health professionals and patients positively influences chronic health management, as does increased patient awareness of their symptoms and general knowledge of the condition. In this study, we leverage the use of mobile phones by pediatric patients and report results from a four-month randomized controlled trial (RCT). We examined: 1) how a SMS system impacted the health outcomes of asthmatic children; and 2) how physicians used a Web service showing the data gathered from the SMS system. Our results show that" 1) the simple act of communicating knowledge and symptom awareness information via SMS leads to improved pulmonary function for pediatric patients; and 2) physicians would use the data sent from the SMS system to monitor their patient's asthma management status.

Categories and Subject Descriptors

H5.m. [**Information interfaces and presentation (e.g., HCI)**]: Miscellaneous.

General Terms

Design, experimentation.

Keywords

Health, mobile phones, SMS, chronic care, pediatric asthma, controlled study.

1. INTRODUCTION

The World Health Organization (WHO) estimated in 2008 that 300 million people suffer from asthma and that asthma is the most common chronic disease among children [31]. Asthma is the most prevalent chronic respiratory disorder in the U.S., affecting approximately 17.3 million individuals, including over 5 million children [1]. It is responsible for the most school absences caused by chronic conditions [29]. Long-term data show that both the prevalence and morbidity of asthma in the U.S. are on the rise [1].

As sobering as these statistics are, there is a new sense of hope for managing chronic health conditions because of another increasing trend, the adoption of mobile phones and text messaging. There are billions of mobile phones exchanging tens of billions of text/SMS messages daily, meaning that it is increasingly likely that a child living with asthma can have access to SMS. This observation leads us to ask whether the child's mobile phone use can be leveraged to help with asthma management. We present results from an initial empirical study aimed at answering that question.

There are several known factors that influence effective management of a chronic condition, including: open communication between patient and health care providers [4,5]; a patient's awareness of symptoms and knowledge of her/his condition [24]; and level of adherence to medical regimens [28]. Effective communication may prove as important as proper medication choice in the long-term success of asthma control [4]. Medical care for pediatric patients that have moderate to severe asthma includes regular visits to their pulmonologist (every 3 to 4 months). Despite knowing that communication is vital, there is often no communication between the patient and physician between these visits unless there has been an episode that landed the child in the emergency room [22]. Some questionnaires such as the Asthma Therapy Assessment Questionnaire (ATAQ) were developed to assist physicians in identifying children at risk [25]. However, these questionnaires are only administrated when pediatric patients visit their doctors and not all doctors use them. In this paper we present the design and evaluation of a system that leverages SMS messaging to facilitate continuous communication between a child with asthma and a physician who treats that child based on the Health Belief Model (HBM) [24] and findings in prior studies [22]. Responses to the SMS queries were fed into a web-based visualization tool for the physician. Our main findings are that: 1) *the SMS system provided physicians with continuous assessment of their patients' asthma management between doctor's visits*; and 2) *the simple act of communicating a child's asthma status interspersed with knowledge about asthma via SMS leads to improved pulmonary outcomes for pediatric patients*. This remarkable result deserves further exploration.

We will briefly overview the related work in the area of mobile computing technologies and chronic health management, and then describe the details of the SMS-based communication system we developed and evaluated in a controlled study of 30 children all being treated by the same pediatric pulmonology clinic in a major metropolitan U.S. city. We designed the study to explore our technology intervention during the period between two scheduled visits to the pulmonologist. We analyzed the results we have collected so far to address the direct and indirect health benefits. We discuss our findings in light of research indicating that a very interesting, yet poorly understood, facet of chronic care is the way healthcare providers and patients communicate with each other [10,15]. Our research addresses this issue directly. Our system

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and findings support the notion of 1) ecological validity, the extent to which the evaluation is conducted under realistic conditions; and 2) the degree of integration of the technology with the environment to assess intervention technologies [8]. We discuss some limitations of our study and suggest future directions for pursuing this line of research.

2. RELATED WORK

In this section, we will overview the research related to mobile phones and health. As we stated earlier, our use of mobile phone technology was targeted to support continuous assessment and communication between patients and physicians as well as patients' awareness about their symptoms and knowledge about asthma. We summarize past research that reinforces the importance of communication between stakeholders of chronic care and how technologies have been used and evaluated towards this goal. Finally, we will discuss the Health Belief Model (HBM), which provides an important theoretical underpinning to explain the role of perceived severity of disease as "Individual beliefs" and knowledge acquisition as "Modifying factors" influencing management of chronic illness.

2.1 Mobile Applications for Health Management

The ubiquity of mobile phones, as well as this platform's increasing computational and sensing capabilities, has made it an ideal experimental platform for mobile health research. Examples include predictive and persuasive means of monitoring and reflecting health-related activities, either to support general wellness [6] or to track important objective indicators of a chronic condition (e.g., glucose levels or drug dosage) [18,23]. Most of this work required additional instrumentation that was coordinated through the mobile phone, with the promise that future smartphone platforms would contain all of the necessary capabilities.

To avoid additional hardware and software requirements, researchers have opted to use the short message service (SMS) that is readily available on mobile phones. One study offered patients simple SMS reminders about use of medication, which helped patients comply with daily medication regimens [21]. The Centers for Disease Control (CDC), has used SMS to provide information about HIV test centers, and to deliver weekly flu maps across the United States (http://www.cdc.gov/widgets/SMS/alt/). Text4Baby is an educational program of the National Healthy Mothers, Healthy Babies Coalition that provides a free mobile information service designed to promote maternal and child health.

Data plans that allow access to general Internet services are available via mobile phones, though not as prevalent as SMS service. An early use of this capability for mobile health was a web-based asthma diary study where patients could enter information concerning their asthma symptoms and medication use [3]. The asthma diary improved interaction between physicians and patients when used, but patient reporting diminished over the duration of the study because Internet use was not part of the participant's everyday life. A follow-up study addressed the issue above by using both a web-based diary and SMS [2].

2.2 Communication between Stakeholders in Chronic Care

Communication is one of the significant elements of social influence and a critical process to support behavior change. This communication may occur in either formal (healthcare providers and patients) or informal relationships (friends and families). It is particularly relevant for patients suffering from chronic diseases, because better communication leads to better health outcomes [10,15].

Following the increase in mobile device use, mobile applications for chronic care are increasingly being researched in health informatics [30]. For example, a wide deployment of computing devices can support the communication of health information. Patients, caregivers, and healthcare providers can use computing devices anywhere and, thus, have the potential to send or receive health related information anytime [12]. One of the current health management areas where a mobile application has been employed is in supporting communication between patients and physicians [26]. Communication tools to support patients and health care providers include: 1) telemonitoring to monitor patients at a distance; 2) teleconsulting to enable consultation between geographically separated individuals; and 3) patient education [16]. The dominant technologies that support communication include web applications, e-mail communication, or mobile phone (SMS, voice mail). Some studies for general health management or chronic care were assessed in ecologically valid settings, but they provided patients with additional digital equipment and did not directly assess health outcomes [7,18]. Another challenge is that the communication mechanism needs to fit into the daily routines of clinical practitioners [16]. Evaluations of novel technologies in clinical settings is challenging because labor is costly and highly distributed across space and time in clinical settings such as doctor's offices and hospitals [8].

These factors influenced both the choice of the technology we used and our study design. We chose SMS on the pediatric patient's mobile phone because of the high adoption rates within the teen/youth population. A survey showed that 27% of North American teens used text messages at least once a month [26]. We used simple email alerts and a web-based visualization for the physicians, based on our observations of their work practices [22]. We designed the study to occur in the average four-month period between regular doctor's office visits by the child with asthma.

2.3 The Health Belief Model

Researchers have adopted health related theories and frameworks to design their technology interventions, even though these have been primarily for preventive health studies [7,11]. One of our research goals was to explicitly describe the theoretical constructs being targeted in our interventions. A theory that inspired us is the Health Belief Model (HBM) [24]. The HBM has been one of the most widely used conceptual frameworks in health behavior research. The HBM explains change and maintenance of health-related behaviors and guides the framework for health behavior interventions. This model includes several elements that predict when people will take action to prevent or control illness. Two components that we investigate in the present study are symptom awareness (perceived severity of disease) and knowledge acquisition. These two factors are crucial to individuals engaging in proactive behavior to improve their condition [24]. Patients in our study were not only queried about their asthma symptoms and

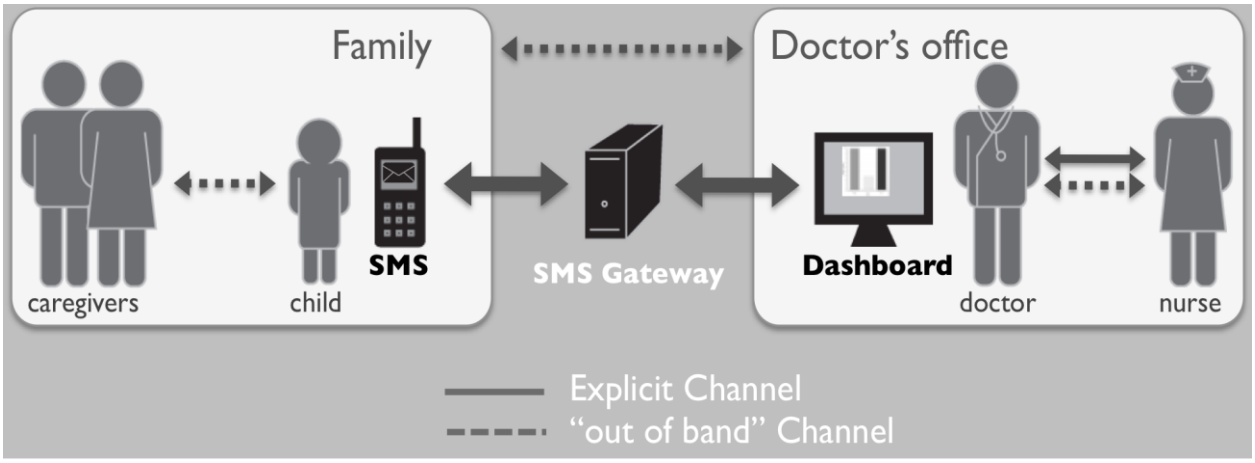

Figure 1. SMS/Dashboard system architecture

management, but were also provided with information about asthma.

3. SYSEM DESIGN

Children with moderate to severe asthma see their physicians three to four times a year. However, research indicates that there is little communication between the patient and physician during the time between visits [22]. As Figure 1 reveals, the ecology surrounding a child with asthma involves a number of communication channels, some of which our technology explicitly supports, and others which it supports only implicitly.

With the assistance of two pulmonologists, we designed a system with two parts: 1) an SMS service as an asthma survey and education tool for children with asthma; and 2) a Physician's Dashboard as an interface to review patients' status (the web-based visualization tool). The system explicitly supports the communication between the patient and physician and between the physician and other clinical support staff (e.g., a nurse), while it implicitly supports the "out of band" communication between the parents or other caregivers as well as between the doctor's office and the family.

3.1 The SMS Service

The SMS service sent questions about asthma management and questions about asthma knowledge directly to pediatric patients in a predetermined fashion. The patient decided what time of day they would like to receive the queries. For asthma management, we developed SMS-formatted questions based on a standard instrument used during doctor visits, the ATAQ [25]. The two pulmonologists helped us modify the ATAQ questions and produce other important questions that were not in the ATAQ itself. This required careful rewording of the questions to be age-appropriate and clear.

In addition, we formulated SMS-formatted asthma knowledge questions. The child would be asked whether a statement was true or false, and would be sent the right answer regardless of his or her response. Our SMS gateway was instrumented so that we could monitor the response rates of the participants.

We built two versions of the SMS service for the study: a query version and a query and knowledge version. Patients were randomly assigned to one of these groups, or to a third control group that received no SMS messages. Next, we describe each version.

3.1.1 Query version

In the query version, one of fifteen yes/no questions about the patient's asthma symptoms and management was sent out every other day. Patient data was aggregated and visualized in the Physician's Dashboard, described below.

As Table 1 indicates, each question was given a weight ranging from 0-3. (e.g., *taking rescue medicine (2 points))*. After patients had responded to the fifteen questions, the system calculated the *rolling ATAQ* scores that are the sum of the points for a given response set. This score categorized patients into three zones: Red: needs attention soon (a score of 3+ points); Yellow: might need attention eventually (1-2 points); and Green: OK (0 points). In addition, based on questions that indicated that the patient may be in trouble or headed for trouble, the system automatically categorized the patient into the Red zone (see Table 1). Our collaborating physicians helped to develop this scoring and classification scheme.

3.1.2 Query and knowledge version

The query and knowledge version is the same as the query version with the addition of fifteen true/false questions about general asthma knowledge on days that they did not receive queries (e.g., *Asthma is a psychological condition. F=False T=True*). The system separately calculated the rolling ATAQ scores and the knowledge scores. In order to increase the patient's knowledge about asthma, patients were told whether or not they correctly answered the question, and were then given information related to the specific question (see Figure 2). The patients' responses to the knowledge questions were also aggregated in the physician dashboard, and the system calculated the *rolling knowledge scores* whenever it had a new answer.

Table 1. Original ATAQ and modified questionnaire

(*: Weekly question)

ATAQ	SMS Queries: Modified Questionnaire for rolling ATAQ	Weight
In the past 4 weeks, did you have wheezing or difficulty breathing when exercising?	In the past 4 weeks, did you have wheezing or difficulty breathing when exercising?	0
In the past 4 weeks, did you have wheezing during the day when not exercising?	In the past 4 weeks, did you have wheezing during the day when NOT exercising?	1
In the past 4 weeks, did you wake up at night with wheezing or difficulty breathing?	In the past 4 weeks, did you wake up at night with wheezing or difficulty breathing?	1
In the past 4 weeks, did you miss days of school because of his/her asthma?	In the past 4 weeks, did you miss days of school because of your asthma?	1
In the past 4 weeks, did you miss any daily activities (such as playing, going to a friend's house, or any family activity) because of asthma?	In the past 4 weeks, did you miss any daily activities (such as playing or going to a friend's house) because of asthma?	0
In the past 4 weeks, did you use an inhaler or a nebulizer for quick relief from asthma symptoms?	*Did you use Albuterol/Xopenex for quick relief more than 3-times during a single day in the past 1 week?**	*2*
Not included	In the past 4 weeks, did you use Albuterol/Xopenex for quick relief more than 3 nights?	2
Not included	Have you taken controller medication every day in the past 4 weeks?	0
Not included	Are you dissatisfied with any part of your current asthma treatment?	0
Do you believe that your asthma was well controlled in the past 4 weeks?	In the past 4 weeks, do you believe that your asthma was NOT controlled?	0
Not included	Do you believe that you are NOT able to take your asthma medicine as directed?	0
Not included	Do you believe that your medicine is NOT useful in controlling your asthma?	0
Not included	In the past 4 weeks, did you use an oral steroid (Orapred, prednisone) to help treat your asthma?	3
Not included	*In the past 1 week, have you been to the emergency room or urgent care for your asthma?**	*3*
Not included	In the past 4 weeks, how many times have you been hospitalized because of asthma?	3

3.1.3 User interaction

Figure 2 shows several example interactions. The layout of the screens varied based on the specific mobile phone's text messaging capabilities. When a child with asthma received a message, he or she could reply to the message by entering 'y'/'n' or 't'/'f'. For knowledge questions, the SMS service sent the correct information regardless of the user's answer.

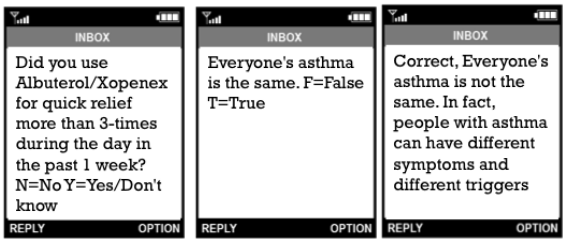

Figure 2. Text message examples (left: query, center: knowledge, right: knowledge feedback).

3.2 Physician's Dashboard

As noted above, the Physician's Dashboard was populated with their patients' SMS responses. This allowed physicians to monitor patients' status and to interact with their care team for administrating care outside of the physician's office. The web interface helped highlight patients in at least three different zones (Red: needs attention soon; Yellow: might need attention eventually; and Green: OK) (see Figure 3).

Figure 3. The Physician's Dashboard Screens.

This dashboard contained all of the relevant care information for each patient in the study, including summaries of asthma management status and/or knowledge based on patient responses to the SMS-facilitated surveys, and relevant identification information to link to the electronic medical record system used in the doctor's office. Occasionally, the physician would be sent email alerts to encourage them to view the dashboard. There were two situations that would trigger the sending of such an email alert. The first situation was when a patient answered "yes" to any

of a set of specific "Red Zone" questions (each such question had a weight of 3; e.g., questions about *taking rescue medicine, emergency room visits, taking oral steroid, and hospitalization*). This was intended to inform the physician that one of their patients had entered the Red Zone and may need immediate attention (see Figure 4). The second alert was sent whenever a fresh rolling ATAQ score had been calculated for a given child, which would happen every 30 days, assuming the child was responding to all awareness queries. These alerts were intended to remind the physician to review information on this child.

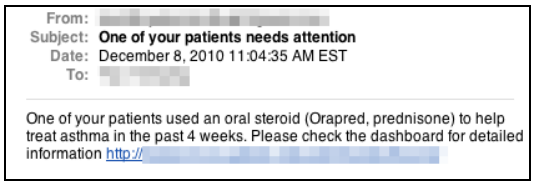

Figure 4. Email alert sent to physician

If, for any reason, a physician was concerned about the status of a patient when viewing his or her detailed information in the dashboard, an email could be sent to that physician's nurse directly from the dashboard (see Figure 5). The email contained some information about the patient, and the physician could customize the message to indicate actions the nurse should take (e.g., contact the patient's parents). Our system logged this email communication as well as a record of physician-to-nurse communication driven by the dashboard.

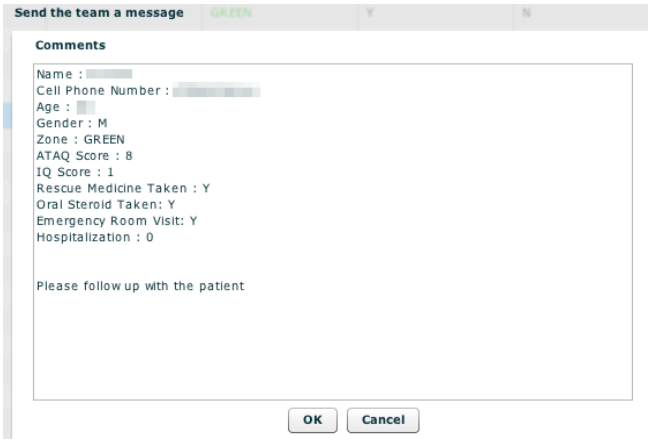

Figure 5. Follow-up email

4. STUDY DESIGN

In this section, we describe the details of the study. Physicians and pediatric asthma patients were enrolled in the study during the period between two office visits (usually around three or four months).

4.1 Hypotheses

Motivated by the Health Belief Model, we designed our system to investigate whether SMS was an effective communication technology to assess asthma management continuously, enhance communication between patients and physicians, and improve patient awareness of asthma management and knowledge of asthma during the period between two regularly scheduled visits. Our hypotheses for the study were:

H1: Pediatric asthma patients answering regularly-administered questions about their asthma management via SMS will demonstrate better health outcomes than a control group of asthma patients, as measured both by a quality of life questionnaire and a pulmonary function test.

H2: Pediatric patients answering regularly-administered questions about their asthma management via SMS ***and*** *receiving regularly-administered information via SMS intended to increase their knowledge about asthma will demonstrate better health outcomes, as measured both by a quality of life questionnaire and a pulmonary function test, compared to those receiving only regularly-administered SMS questions and controls.*

H3: The rolling ATAQ score calculated by the answers of the SMS queries will provide valid assessments of pediatric asthma management on a more frequent basis when compared to the original ATAQ score.

4.2 Participants

We conducted this study at a private practice in a large metropolitan city. All 11 physicians at the practice were recruited. In order to participate in our study, pediatric patients had to be ten years of age or older, have their own mobile phone, and be able to read at a 5th grade level. In addition, children had to be regular patients who had met the healthcare providers at least once before they participated in the study. After patients decided to participate in our study, we recruited their caregivers. And then we randomly assigned the 30 children to one of the three groups: 1) the Control group, which received no messages from the SMS service; 2) the Query group, where they were asked to respond to questions about their asthma symptoms (using the query version of our system); or 3) the Query & Knowledge group, where they were queried about their asthma management status and given information to improve their asthma knowledge (using query and knowledge version of our system). We decided on the number of pediatric participants based on our resources, as well as the *a priori* calculated sample size (effect size dz = 0.8, total sample size = 12). Patients who agreed to be in this study received $25 at the end of the first doctor's visit and after completing a series of pre-study materials, and another $25 after a final exit interview after their second doctor's visit. After assigning participants to groups, we excluded 3 physicians who did not have any patients in the study. Table 2 shows the sex and age of the participants at the time of the first visit.

Table 2. The age and sex of participants

	Control (n = 10)	**Query (n = 10)**	**Query & Knowledge (n = 10)**
Sex (Female/Male)	5/5	5/5	5/5
Age	14.1±2.5	14.2±2.0	12.5±2.4

4.3 Method

The duration of the study was the time between two scheduled visits to the doctor's office, typically 3-4 months. Patients that were assigned to the intervention groups received SMS messages everyday (Query & Knowledge group) or every other day (Query group). Physician participants could access the dashboard to review the status of their participating patients and receive alerts via email when a patient was in the red zone. We will describe our study method in three phases (see Table 3).

Table 3. Research tools used in each phase

	1st doctor's visit	Between visits	Follow up visit
Patient	• Asthma knowledge test • Pre-survey • PAQLQ • Pulmonary function data	• SMS log	• Asthma knowledge test • Post-survey • PAQLQ • Pulmonary function data • Interview
Caregiver	• Pre-survey • PACQLQ		• Post-survey • PACQLQ • Interview
Physician	• Pre-survey	• Dashboard log	• Post-survey • Interview

4.3.1 First doctor's visit

At the time of the first doctor's visit, caregivers were given a consent form for themselves, and another to provide consent for their child to be in the study. For their portion of the study, they were asked to fill out a set of surveys about their technology usage and the *Pediatric Asthma Caregiver Quality of Life Questionnaire (PACQLQ)* [13] to measure the problems that are most troublesome to the parents (primary caregivers) of children with asthma. Once the child agreed to participate in the study, we collected basic demographic information. The child also completed surveys about technology usage, asthma knowledge, and the *Pediatric Asthma Quality of Life Questionnaire (PAQLQ)* [14], to assess the functional problems (physical, emotional and social). The clinical research staff conducted a pulmonary function test data to record Forced Expiratory Flow (FEF) 25–75%, which is an indication of the lower airways' function and provides a biological indicator of their asthma status [17]. Patients were told that their physicians would be able to view the responses they sent via SMS.

Each of the participating physicians was scheduled for an introductory survey. During this time we gave them a brief tutorial on how to use the Physician's Dashboard to monitor their patients' SMS data if possible. Physicians were made aware that they might not have access to the Physician's Dashboard if they did not have patients selected to participate in the study or only had patients that were randomly assigned to the control group.

4.3.2 During the study

Our system logged SMS data transactions and the usage of the Physician's Dashboard.

4.3.3 Follow up visit

After the follow up visits, patients were administered a number of surveys including the asthma knowledge test, PAQLQ, ATAQ, and pulmonary function test. Parents were given surveys that included the PACQLQ. We conducted interviews with the participants to understand how they used the SMS service. These interviews were recorded and transcribed for further analysis.

5. RESULTS

This section consists of three parts: 1) characteristics of communication technology usage in pediatric asthma patients and their caregivers; 2) intervention results; and 3) utilization of our intervention. In all cases where we compare differences between groups, we will present both the p value and the effect size. The effect sizes, *r,* calculated based on Cohen's formula were interpreted according to Cohen's guidelines of < 0.2 for a small effect size, 0.5 for a medium effect size, and > 0.8 for a large effect size [9]. Thus, if we have medium or large effect size, the statistical outcomes are still valuable.

5.1 Characteristics of Participants Communication Technology Usage

Twenty-nine (out of 30) families reported that they had Internet access at home. Pediatric participants were using the Internet about the same amount of time (1.5 hours per day) as their caregivers (2 hours per day). Only six pediatric participants and nine caregivers had used the Internet as a tool for asthma management, and two families reported that they had used SMS for asthma management before the study. However, they had never used these media regularly for asthma management.

For mobile service usage, *all families but one* had a text plan even though six families had public insurance (which can be seen as evidence of having a low income). While twenty-one caregivers had a data plan, only thirteen children had a data plan. Half of the pediatric participants sent over 300 text messages a month.

5.2 Health Outcomes

5.2.1 Baseline at the first doctor's visit

Our results indicate that the three intervention groups did not differ on any meaningful clinical or psychosocial characteristics. We did not find significant age, asthma knowledge, quality of life perception (PAQLQ, PACQLQ), or pulmonary function (FEF 25-75%) differences across all participants. In terms of the scores of asthma knowledge test, we found that age was significantly correlated with the scores ($r = 0.65$, $p < .0001$). Caregiver's quality of life score (PACQLQ) was significantly correlated with their child's quality of life score (PAQLQ) ($r = 0.655$, $p = .008$). Caregiver's quality of life score (mean: 5.4) was higher than pediatric patients' quality of life score (mean: 4.97). Thus, we replicated a result from the literature, which caregivers tend to overestimate quality of life when compared to the child's own perception [20].

5.2.2 Outcomes

We have complete data for fifteen pediatric asthma patients and six physicians. The progress of participants during the course of this study is shown in Table 4. Fifteen patients did not have a follow up visit after their initial visit and a full four-month intervening period. The children who did not have a follow up visit had no difference between the rolling ATAQ scores and the response rates to the SMS queries compared to children that completed the study existed. Since it was our goal to use an ecologically valid process, we did not encourage participants to attend a follow up visit.

Table 4. Enrollment table of the pediatric participants through the study and the age, sex, insurance type of participants at the follow up visits.

Flow

	Control	Query	Query & Knowledge
Initial Allocation	n = 10	n = 10	n = 10
Analysis	No follow up (n = 5) Analyzed **(n = 5)**	No follow up (n = 6) Analyzed **(n = 4)**	No follow up (n = 4) Analyzed **(n = 6)**

Analyzed Data

	Control	Query	Query & Knowledge
Sex (Female/Male)	3/2	2/2	2/4
Age	14.2±2.2	14±2.2	12.7±2.4

Insurance	Control	Query	Query & Knowledge
Private	4	2	3
Medicaid	1	1	2
Self paid	0	1	0

The time between two visits for the 15 completed participants ranged from 94 to 151 days (median 105, about 3.5 months). This is the expected lapse between office visits for children with moderate to severe asthma. As of the time of this writing, all 15 participants had no scheduled follow up visits.

To test hypothesis *H1*, we compared the pre-post differences of PAQLQ and FEF25-75% between the control and the other two groups (see Table 5). We found that *patients answering regularly-administered questions about their asthma symptoms and management* ***did not*** *demonstrate better health outcomes*, as measured both by quality of life questionnaire and pulmonary function test, as compared to control. Hence, we reject hypothesis *H1*.

Table 5. Clinical and psychosocial outcomes.

	Control (n = 5)		Query (n = 4)		Query & Knowledge (n = 6)	
Var.	***Pre***	***Post***	***Pre***	***Post***	***Pre***	***Post***
Knowledge	13.6±1.5	14.4±1.8	13.5±1	13.3±1.5	13.0±2.0	14.8±1.2
PAQLQ	5.6±1	6.0±0.9	5.4±1.4	5.8±1	4.2±1.4	4.6±2.2
PACQLQ	5.6±1.5	5.9±1.2	5.6±2.7	5.7±1.5	5.1±1.3	6.1±1.3
FEF25-75%	2.84±0.4	2.78±0.6	2.97±1	2.98±1	2.75±1.2	3.38±1.1

To test hypothesis *H2,* we compared the pre-post differences of PAQLQ and FEF25-75% between the Query group and the Query & Knowledge group, and the Control group and Query & Knowledge group. PAQLQ improvement in the Query & Knowledge group was ***not*** statistically different from the query group or the control group.

Statistically significant differences were found for the FEF25-75% in the Query & Knowledge group compared to the Query group (*t(8) = 3.11, p = .007, Cohen's d = 2.20, effect-size r = 0.74*), and compared to the Control group (*t(9) = 2.04, p = .036, Cohen's d = 1.36, effect-size r = 0.56*). Patients in the Query & Knowledge group also had significant improvement of asthma knowledge compared to the other two groups (*t(13) = 2.15, p = .026, Cohen's d = 1.19, effect-size r = 0.51)*. Thus, *pediatric patients answering regularly-administered questions about both asthma management and information via SMS demonstrated better pulmonary function and increased their knowledge about asthma compared to those receiving only regularly-administered SMS questions or no SMS questions.*

5.3 Utilization of the Intervention

To test hypothesis *H3*, we calculated the correlation between the rolling ATAQ scores in the SMS service and the ATAQ score at the follow up visit. Our rolling ATAQ scores at the follow up visits were significantly correlated with total scores in the original ATAQ at the follow up visits (*r = 0.91, p < .001*) (Figure 6). The PAQLQ scores, which we collected in the follow up visits, were significantly correlated with the rolling ATAQ scores at the follow up visits (*r = -0.89, p < .001*). However, the rolling ATAQ scores for the two-month period before the follow up visit were not correlated with the standard ATAQ scores at the follow up visits.

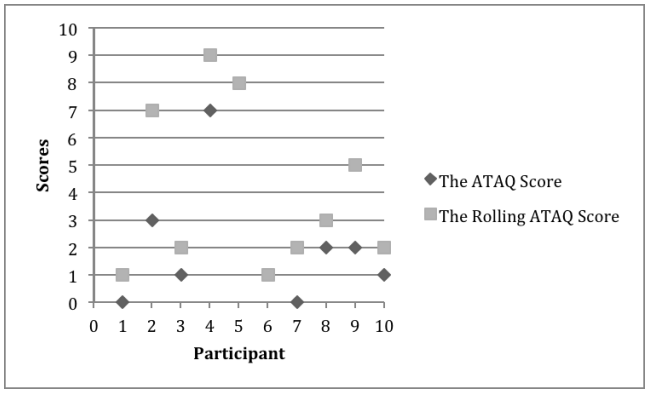

Figure 6. The (original) ATAQ score and the rolling ATAQ score at the follow up visits.

Thus, *the rolling ATAQ score calculated by the answers of the SMS queries provided valid assessments of pediatric asthma management on a more frequent basis when compared to the standard ATAQ score.*

Our SMS service sent a total of 785 queries to 10 pediatric patients who were in the two experimental groups. The overall response rate was 87%, ranging from 75% to 99% (Figure 7). We found that SMS usage did not decline during the study period. The average delay between questions and responses was 22 minutes. The dashboard system sent a total of 32 alerts to the physicians during the study. These alerts made the physicians log in the Physician's Dashboard 23 times (71% - 23 out of 32). Table 6 shows the types each alert sent and the number of logins of the dashboard system.

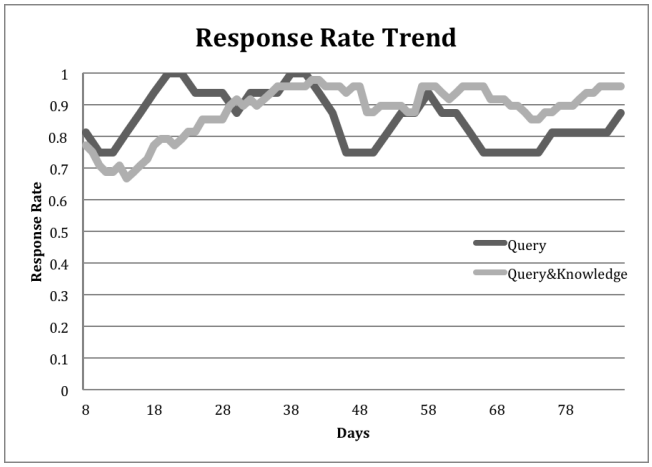

Figure 7. Daily response rate.

Table 6. The total number of alerts sent via email to each physician and the number of logins by each physician

	Rescue Med.	Oral Steroid	ER visit	Hospitalization	New Set	Total Alert	# Of Logins
P1	0	0	0	0	2	**2**	**0**
P2	1	0	1	0	2	**4**	**0**
P3	12	3	2	0	3	**20**	**16**
P4	2	0	0	0	0	**2**	**1**
P5	2	0	0	0	2	**4**	**4**
P6	0	0	0	0	0	**0**	**2**
Total	**17**	**3**	**3**	**0**	**9**	**32**	**23**

6. DISCUSSION

We successfully deployed a new intervention for pediatric asthma management in an ecologically valid setting using a widely adopted mobile technology, SMS. The new intervention was found to have some positive effects on health outcomes and asthma knowledge of the patients. Patients readily adopted it and maintained a high rate of response throughout the intervention period. Thus, our system can provide the physicians constant assessment of their patients' asthma between visits. Some of the physicians responded positively to the use of the SMS and dashboard technology. In particular, they altered their practice such that they would access the dashboard when they received e-mails alerting them that their patients had entered the Red Zone (i.e., may be having trouble with their asthma).

In this section we will discuss the main findings and challenges for future designs that emerged from our analysis.

6.1 Health Improvement Outcomes

We received partial support for our hypotheses. Namely, we found that the pediatric asthma patients that both answered questions about their asthma status and received information about asthma showed improved health outcomes, as evidenced by lung function analyses compared to the query only and control groups. This result is in line with the Health Belief Model (HBM), which indicates that both awareness as well as knowledge are crucial to individuals engaging in proactive behavior to improve their condition [24]. As one participant explained, "*It [knowledge] helps me become more aware of what causes asthma.*" Some participants mentioned that receiving text messages reminded them to take medicine. In one participant's words, "*If I forgot my medicine in the morning, and I got the text, [I] remembered what I had to do [take medicine] after I got the text.*"

The fact that the Query & Knowledge group also showed significant improvement in their asthma knowledge compared to the Query group supports our suggestion that health improvements were not simply due to the fact that the Query & Knowledge group received more messages than the Query group. It shows that they were attending to the content of the knowledge text messages.

We found differences in pulmonary function data, but not in quality of life questionnaires (PAQLQ), among the intervention groups. We can infer two reasons: 1) overall PAQLQ at the initial visit was so high that our intervention could not affect the change of the score significantly. The best score is 7.0, which means that the child has no impairments due to asthma. The range of each group's initial PAQLQ scores in our study was from 4.2 to 5.6. As Juniper [14] suggested, we could use the Minimal Important Difference (MID) defined as "the smallest difference or change in score which patients perceive as beneficial and would mandate, in the absence of troublesome side effects and excessive cost, a change in the patient's management". The MID for the PAQLQ is close to 0.5 on the 7-point scale. However, just comparing the mean difference between the groups with MID is inadequate, because patients are very heterogeneous in their responses to interventions [14] and a previous study found that pulmonary function was not correlated significantly with quality of life in patients with moderate to severe asthma. This correlation was only found in patients with mild asthma [19]. Since our patients had different severities of asthma, it could have affected our results.

6.2 SMS as a Communication Tool in the Clinical Setting

One of the challenges in our study was to design and develop a sustainable technology that could be used in the context of a clinical setting. Our SMS system was able to meet the challenge. Our service had a response rate greater than 87%, sustained over the 3-4 month duration of the study (Figure 6). A previous study with 12 participants reported a response rate of 69% for a two-month period [2]. Participants in our study (median age 13 years) were younger than those in the previous SMS study (38.5 years). The increased response rate in this study may be related to the fact that younger users lead the adoption and use of text messages [27]. Lastly, our system sent fewer text messages (one per day) than the previous study (four per day). As one participant described, "*It was fun. I wanted to have more questions a day. I can answer two times a day because I like it.*"

The other challenge for our system was to facilitate and improve current practices for pediatric asthma management. As we explained earlier it is part of the current clinical practices to administer the original ATAQ questionnaire (or similar instruments) during office visits. The original ATAQ questionnaire asks for data over the previous four weeks leading up to the office visit. Since children visit the physician at most three or four times a year, physicians have very sparse data with which to form an understanding of their patients' symptom history. Our SMS study showed that patients are willing to provide continuous data about their symptoms. Further, our results show that the rolling ATAQ scores at the final visit were significantly correlated with the standard ATAQ scores that were administered

during the office visit. This suggests that SMS administration may be a valid way of administering the ATAQ questionnaire, although this is a claim that must be validated through further research. Our study indicates that SMS data provides information about the patient that the physician would not have access to during a follow up visit. We found that the rolling ATAQ scores for the two-month period before the final office visit were not correlated with the ATAQ score at the final visit. This suggests that the rolling ATAQ scores can provide time-sensitive and unique information about the child's asthma symptoms during the span between two regularly scheduled visits and thus improve current clinical practice.

The high rate of response during the four month period of the study, the fact that most patients had text plans, and the similarities and differences between the rolling ATAQ and the validated ATAQ, together suggest that that the use of SMS for question and answer exchanges may be a cost- and labor-effective way to keep physicians updated about their patients asthma status between scheduled visits.

6.3 Impact on Clinical Practice

Another goal of this study was to facilitate or improve the communication between patients and caregivers (specifically physicians). Although the size of our study limits the inferences we can draw, we think it is worthwhile to mention some positive findings.

The log data shows that the physicians logged into the dashboard to review their patients' status. Patient interview data indicated that this in turn affected conversations that took place during their medical check-ups. For example, one of the participants repeatedly answered that he was using oral steroids to manage his symptoms. This response led to the child being put into the Red Zone, which also resulted in the delivery of an e-mail alert to the physician. When the patient visited the doctor's office, he explained how his doctor taught him what oral steroids are: "*She did talk about a lot of text messages. I was confused [about] oral steroid [as compared] with ProAir [rescue bronchodilator medication]. She taught me the difference between the two.*" This last example points out that some of the terminology in the system might limit its effectiveness. However, current terminology is often used in the doctor's office (and the physicians assumed that the children knew what this meant). Thus, presenting the various terms in the context of SMS queries could be an opportunity for physicians to confirm that their patients are aware of the distinctions between the different types of medicines. Another participant mentioned that her physician's access to her SMS responses led to a more focused conversation "*He already knew what I did, so he talked about what I was supposed to do.*" This shows that even though her doctor did not contact her between visits, he used the data from the dashboard, which the SMS service provided, and that affected the conversation during the subsequent patient visit.

There was evidence that our SMS system indirectly mediated communication between patients and their parents. A number of patients and parents mentioned similar comments to those below. For example, one patient mentioned that she did not know what a term was in one of the text messages she received so she asked her mother about it. "*I had to ask mom to tell me what it means . . . I didn't understand the question … 'have you taken controller medication every day in the past 4 weeks?'*"

6.4 Limitations

The fact that we were able to obtain statistically significant findings with such a small sample size (N=15) reflects the large effect size of the intervention. Our effect sizes were 0.74 in FEF 25-75% and 0.51 in knowledge improvement.

However the small sample size still does limit the generalizations that we hope to draw. It makes it difficult to develop themes for the qualitative data that we collected. Another limitation is that our samples were mostly people with middle income (as evidenced by the preponderance of private medical insurance). Our goal is to replicate this study with a larger, more economically diverse sample.

Another methodological issue to be addressed in future research includes ascertaining that the children understand the content of each SMS question. We worked closely with medical personnel to draft each of the questions delivered to the patients and were assured that they were appropriate to someone with a 5th grade level of literacy. However, some participants mentioned that they did not understand some of the questions they received.

7. CONCLUSION AND FUTURE WORK

SMS is ubiquitous, easy to use, and inexpensive. Our system demonstrated efficacy with improved health outcomes for a pediatric asthma sample. Given that other standardized questionnaires could be implemented via SMS, this approach may be relevant to other chronic conditions. An important strength of our current approach is that it can be easily adopted and maintained by patients and healthcare providers. The system could be built in such a way that healthcare providers could customize the database of text messages created for their patients. In short, SMS usage is ubiquitous and thus can be embedded into clinical practice.

Specifically, we found a high rate of SMS adoption among patients; high and sustained response rate during the period of the study, similarities and differences between the rolling ATAQ and the original ATAQ questionnaires. These results indicate that SMS may be a cost- and labor-effective way to keep physicians updated about their patients' asthma status between scheduled visits.

Since using computing technology in the clinical field is in the early stages of development, it is difficult to assess the influence specific features of text messages have on pediatric asthma management. These features include the frequency with which SMS messages are sent, latency to response, and effect of tailoring messages to individual patients. The latter is important in light of data from other chronic diseases that show that tailored-SMS messages lead to greater improvement in behavior changes then do untailored messages. Similarly, although we had a response rate of 87% for 3-4 months, tailored response messages may also lead to improved response rate over a longer duration. Since participant engagement is a critical factor, it is important to investigate the effects of individualized text in pediatric asthma research supported by SMS.

While we focused on physicians and patients in this study, our findings indicate that parents could also have benefited from having access to their child's SMS responses. Our data shows that there is discordance between children and caregivers in terms of how often they said they talked about asthma with each other (parents reported much better communication than children). Parents reported that while they want their child to manage his or

her asthma in an independent manner, they also want to know what the child is doing. Thus, future systems may address this issue and provide a channel for caregivers to understand their child's needs (e.g., parents' dashboard).

Finally, our study indicates that patients communicate over online social networks twice as often as they do using SMS. This medium could lead to successful asthma management interventions. Related to this is the fact that engaging a child's social network may lead to better asthma management.

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