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Development and Implementation of the Home Asthma Telemonitoring (HAT) System to Facilitate Asthma Self-Care

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Abstract

National Asthma Education and Prevention Program (NAEPP) suggests using asthma action plans for patient self-care. Recent studies reported that many asthma patients had difficulties in following action plans on a daily basis and had low compliance to medication regimens. The goal of our study was to design and evaluate the Home Asthma Telemonitoring (HAT) system aimed to help asthma patients to follow their self-care plans according to the NAEPP recommendations. Our study resulted in the development of the system which provided patients with continuous individualized help in the daily routine of asthma self-care and notified heath care providers if certain clinical conditions occurred. This allowed early recognition of potentially dangerous situations and timely intervention. The evaluation of the HAT system underwent several stages. First we showed, that the HAT system provides reliable reciprocal exchange of all relevant information between a physician and asthma patient in home settings. Further evaluation demonstrated that lung function test results collected during home asthma telemonitoring are comparable to those collected under the supervision of trained professionals, and Internet-based home asthma telemonitoring can be successfully implemented in a group of patients without previous computer experience. Preliminary results of an on-going HAT evaluation showed higher patient compliance to asthma action plans in comparison to the compliance reported for patients in standard care. The clinical impact of HAT on asthma outcomes is being currently evaluated in a randomized clinical trial funded by NIH. HAT has a potential for improving clinical outcomes and quality of life in the studied patient population and may be a model for monitoring and self-management of patients with other chronic health conditions.

Keywords:

Telemedicine, asthma, self-care

Introduction

In recent years, asthma patient self-management, consisting of regular home peak expiratory flow (PEF) monitoring, use of prophylactic medication and patient action plans have become widely introduced in the management of patients with asthma [1]. An asthma action plan is a set of guidelines for management of asthma by patients at home, prescribed by their physicians, that advises patients on what actions should they undertake based on their current PEF values. According to the National Asthma Education and Prevention Program (NAEPP), PEF-based action plans are currently considered an integral part of asthma management programs [1]. Several independent research groups concluded that PEF-based self-management was associated with significant improvement of clinical outcomes and patient quality of life [1,2]. However, recent studies reported frequent patient failures in following asthma action plans on a daily basis, low adherence of asthma patients to self-management and medication regimens, and possible inaccuracy in PEF data reported by patients [2,3]. The same studies concluded that there is need to develop new approaches to help patients follow their self-care plans. The goal of our study is to develop and evaluate the Home Asthma Telemonitoring (HAT) system aimed (1) to help asthma patients to follow their self-care plans, and (2) to help health care practitioners to follow their patients' self-management process.

Methods

General Considerations for HAT Design

The HAT system is designed to conform with principles of patient-centered model of health care [10]. The design of HAT implements multidisciplinary approach to the chronic disease management by using current state-of-the-art knowledge about the educational, behavioral, cognitive and organizational components of asthma self-care process. The main objective of the HAT system is to minimize the burden of asthma monitoring both for patients and physicians and to simplify NAEPP guidelines

implementation in present-day ambulatory care delivery. To achieve this goal the HAT system is required (1) to support a constant information feedback loop between the patient and health care providers; (2) to take over all routine repetitive tasks; and (3) to provide real-time clinical decision support both for the patient and clinician.

Technical Design of the HAT System

The technical design of the HAT system is presented in the Fig. 1. The HAT system includes patient units, HAT server and clinical units. Each *patient unit* includes four modules: lung function, presentation, computing and communication. The patient unit may be built as a single stand-alone device or may be constructed as a combination of interconnected devices. The lung function module is aimed to collect information about asthma severity which is based on an objective evaluation of the level of airway obstruction and patient self-report about clinical symptoms and medication usage. The presentation module implements user-friendly patient interface for data presentation and manual entry. It can

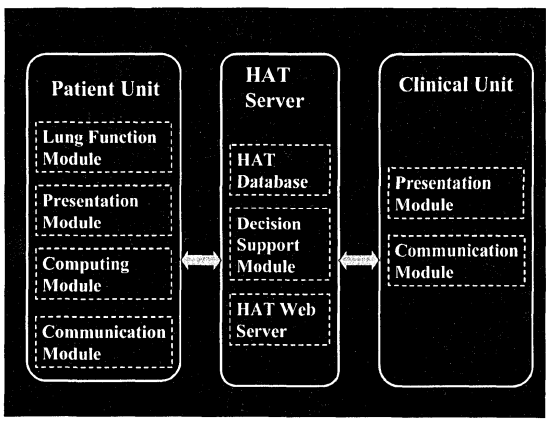

Figure 1. Technical design of the HAT.

be implemented in a wide variety of ways: from LCD screen on a stand-alone device to a color desktop display or TV set. The computing module is responsible for initial evaluation of the patient self-testing results and basic decision support functionality which is not dependant on remote connectivity. This functionality may be built-in in a stand-alone device or may be implemented as a component of software running on a patient computer. An important feature of the computing module should be an ability to update itself (including decision support logic and functional parameters) during communication with the HAT server. The communication module is responsible for communication with HAT server and may be implemented using different interfaces such as direct dial-up, DSL, ISDN, CDPD and many other data exchange protocols depending on local availability. The *HAT server* includes HAT database, decision support module and a web server. The HAT database stores all information pertinent to patient telemonitoring including data received from patient units, alerts generated by the system, nurse/physician notes, electronic patient-provider correspondence. Decision support module, which functionality is described below, is a core of the HAT system and implements constant analysis of all data traffic between HAT participants. The HAT web server implements a secure access to the data via Internet. It also provides patient- and physician-tailored features for asthma management. The components of the HAT server may be distributed between several computers or may run on a single computer. The HAT server can function in a conjunction with hospital information system and EMR or may function as a stand-alone product. The *clinical units* are used by medical personal to access data, to adjust certain parameters related to decision support or individual action plans, to review alerts, and to exchange messages between HAT participants. Each clinical unit includes a presentation module to display or enter information and communication module to connect to the Internet. The clinical units may be implemented using a variety of solutions: from cellular phone to an office computer.

Decision Support in the HAT System

The HAT system provides automatic decision support for monitoring and analyzing all information traffic between the patient and the system in real-time mode. The decision support is directed at ensuring patient compliance with the self-testing protocol, the validity of self-testing and for interpreting changes in patient data, and is performed by a combination of the patient unit and the remote HAT server. Allocation of the basic decision support functionality in the patient unit and more complex algorithms in the HAT server ensures availability of the basic decision support for the asthma patients even in the absence of remote connectivity. The patient unit performs an initial validity check of the lung function test and the consistency of the asthma diary data, and generates an immediate feedback to the patient based on these data. Further analysis is performed by the HAT server. Each time the HAT server receives new data, it retrieves previous results and analyzes all data to check whether predefined conditions are met (which are specific for each patient and are consistent with that patient's action plan). The system also periodically checks patient's compliance with self-testing. If predefined conditions are met, the system automatically sends an alert to medical personnel and/or the patient. The computerized alerts are generated if: (1) patients do not perform self-testing on schedule; (2) patients do not adhere to their medication regimen (according to their self-report); (3) patients do not follow their action plan (according to their self-report of what they did in response to current symptoms and PEF values). All alerts are checked by the patient's nurse on a daily basis. Patients who are non-compliant with any aspect of their self-care plan, are contacted by the nurse who evaluates the reasons for non-compliance and provides remedial assistance or patient support. If alerts occur in the evening or weekends the system will call the patient automatically. Patients' physicians receive periodic reports and are notified immediately in the case of an emergency.

Structure of a HAT Session with an Asthma Patient

Each HAT-patient session is divided into monitoring, analysis and educational components (Table 1). The monitoring component interacts with the patient to collect data for the asthma diary (symptom and medication use questionnaire) and from the flowmeter (device to assess airway obstruction). The analysis component interprets the received data according to the patient's asthma action plan and detects clinically significant events and patient non-compliance.The analysis component identifies which part of a patient's asthma action plan that patient should follow and which alerts, if any, should be generated. The educational component includes two parts. The first part is based on the results of the analysis component and provides the patient with immediate interpretation of the self-testing. The patient is educated on how to follow the action plan according to the interpretation results and receives asthma information tailored to the current disease status. The second part of the educational component does not depend on the self-testing results and is aimed at providing general asthma education. This part is organized in the form of multi-choice questions and "Tips of the day." The design of HAT utilizes concepts of behavioral change (behavioral capability, self-efficacy, outcome expectation, reinforcement), which were successfully used previously in automated systems for management of chronic health conditions [4].

Behavioral Background for the HAT Design

The design of HAT uses Social Cognitive Theory (SCT) as its major theoretical behavioral foundation. SCT synthesizes concepts and processes from cognitive, behavioral and emotional models of behavioral change [5]. SCT constructs relevant to the HAT design include behavioral capability, self-efficacy, outcome expectation and reinforcement. In addition, the educational content of HAT is broken down into small digestible parts, which is consistent with concepts from Consumer Information Processing [6].

Behavioral capability includes knowledge of "what to do" and "how to do it" as well as the skills needed to perform it. Behavioral capability is considered a necessary prerequisite for performing a behavior, but is insufficient to guarantee performance. Self-efficacy expectations are a person's beliefs about one's capability to perform a specific behavior.

Table 1 - HAT-Patient Interactions During a HAT Session

	Greeting and personal salutation
	Ask patient to assess current asthma symptoms (wheezing, cough, chest tightness, shortness of breath, etc.)
	Ask patient to assess any limitation of physical activity caused by asthma
	Ask patient to report exposure to the asthma triggers (pets, pollens, etc) and their intensity
	Ask dose and frequency of use of each maintenance asthma medication
	Ask frequency of use of beta-agonist (rescue) inhaler
	Ask patient to use flowmeter to measure PEF (data from flowmeter are automatically transferred to the palmtop and sent to the central server together with asthma diary data)
	Evaluate the data and provide feedback to the patient, including the PEF-based asthma update
	Based on current data, advise patient on action(s) to take that follow patient's individual asthma action plan
	Ask patient one multi-choice question from asthma knowledge database
	Educate in response to the answer (if the answer is correct, provide "Tip of the day" - a short asthma related topic)
	Closing: summarize important points; give brief positive reinforcement; remind about next session

Self-efficacy beliefs have been found to be related to whether or not a person will attempt a task and also to how long a person will persevere. Outcome expectations are a person's beliefs concerning the effects of engaging in certain actions. Realistic outcome expectations can enhance self-efficacy. Reinforcement is defined as response to a person's behavior that increases or decreases the chances of recurrences. Table 2 highlights how the constructs of SCT apply to the HAT design.

The above mentioned behavioral constructs were successfully used in other computer-based health-related behavior interventions [4,7]. Although the constructs need to be applied in different ways to affect different types of health behavior (alcohol use, smoking, eating, etc), they are applicable to diverse health-related behaviors.

HAT Reports

HAT system generates two types of reports: a Provider Report and a Patient Report. The Provider Report looks like a computerized laboratory test report with a "flow sheet" format. Information for a single item (for example, the number of days the patient experienced wheezing during the previous week) appears on a single line, with the values displayed chronologically from left to right. Any entry important enough to bring to the provider's attention is flagged with an asterisk next to the item. The report includes monitoring information on symptoms, adherence to each maintenance medication expressed as a percentage of prescribed doses taken, and peak flow meter use.

Table 2 - Application of Concepts from SCT to the HAT Design

Concept	Application
Behavioral Capability	Users/patients are given information about specific behavioral actions (asthma trigger avoidance, medication change in response to decreased PEF, etc), and stepwise training and suggestions for how to incorporate desirable behavioral patterns into their daily lives
Self-efficacy	The use of praise, feedback, and setting achievable goals are used to increase patients' perceptions of their self-efficacy
Outcome Expectations	HAT repeatedly informs the patients that following their asthma self-care plan will reduce respiratory symptoms and increase quality of life
Reinforcement	User/patient receives praise and encouragement for following asthma self-care plans. The asthma nurse contacts patients in case of non-compliance to educate and reinforce patient compliance

The adequacy of asthma patient's knowledge is presented to the provider regarding symptoms, asthma triggers, asthma exacerbation and action plans when symptoms worsen, medications, and accessing medical care appropriately. At a minimum, the Provider Report is sent monthly. In addition, whenever the patient reports that he is having significantly worse asthma symptoms, a special Provider Report, a so-called Alert Report, is immediately sent. If an Alert Report is sent during normal working hours, the HAT system will fax the report to the office of the patient's responsible physician. The HAT system will also call the office to notify the staff that an Alert Report is being faxed. In addition, the physician is able to review all results, collected by HAT, at the designated Web page at any time.

The patients also receive monthly reports that contain the same information, but presented in a narrative format. The report also links the patient's knowledge or behavior with their level of symptoms and functioning. For example, if the patient is not adherent to his/her maintenance medication and is having symptoms, the report will suggest that the patient's symptoms would improve if he/she adhered to the maintenance medication regimen. In addition, the data trends for the last several months of monitoring are stored locally in palmtop memory and are available for the patient's review.

The Role of the HAT Nurse

An asthma nurse is an integral part of the HAT intervention. The nurse is responsible for checking the alerts generated by the HAT system on a daily basis. She responds to alerts according to established guidelines and contacts the patients to counsel and educate them. The non-compliance alerts are usually resolved by the responsible nurse without physician intervention. The patient's physician will be notified about these events in the monthly reports. However, the physician will be notified about alerts immediately if serious clinical deterioration occurs in patients who do not comply with their self-care plans (e.g., a patient who has a PEF<50% of personal best PEF and who fails to start oral corticosteroid therapy as prescribed by the his/her action plan). The thresholds for each alert and the frequency of the nurse's responses to them are determined according to the NAEPP guidelines [1].

Results

Current Implementation of the HAT System

The HAT System has been fully implemented in Boston Medical Center and currently provides an on-going support for asthma patients according to the NAEPP guidelines. As it was specified in the *Methods* section HAT includes a patient unit, a decision support server and a clinical station. The patient unit consists of an electronic flowmeter and a palmtop (Fig. 2). The majority of our patients reside in low-income inner city areas and do not have computers. Because of its low price and small size, we found that a palmtop can serve as an optimal computing module for the HAT patient unit in such setting. We can also use other computer models running Windows CE/95/98/2000/ME as a part of the patient unit. The majority of commercially available electronic flowmeters may be used for the patient unit. Patients perform a lung function test using the flowmeter and enter

answers to asthma diary questions on the palmtop on a regular basis. The flowmeter transmits the test results via a serial interface to the palmtop. The patient can also use the palmtop to transmit a personal message to medical personnel. Immediately after the completion of the self-testing, all data are sent by the palmtop to a remote clinical information server which stores the data in a database. The data can be sent over a standard telephone line or over a wireless network. Patient data for the last four months are also stored in the palmtop and are available for the patient's review. During each self-testing session, the patient receives feedback messages generated automatically, or sent by medical personnel, via the same system.

Several minutes after the completion of home self-testing, all results are stored in the HAT database server which implements a secure Web interface. Any computer equipped with a functional Web browser can serve as a HAT clinical station from which the eligible medical personnel can review and analyze patient data almost immediately after the completion of the self-testing.

Evaluation Studies of HAT

The evaluation of the HAT underwent several stages. First, we showed that the HAT system provides reliable reciprocal exchange of all relevant information between a physician and asthma patient in home settings [8]. Further evaluation [9] demonstrated that (1) lung function test results collected during home asthma telemonitoring are comparable to those collected under the supervision of trained professionals, and (2) Internet-based home asthma telemonitoring can be successfully implemented in a group of patients without previous computer experience.

Figure 2. HAT patient unit.

Preliminary results of an on-going HAT evaluation showed higher patient compliance to asthma action plans in comparison to the compliance reported for patients in standard care. The clinical impact of HAT on asthma outcomes and patient compliance is being currently evaluated in a randomized clinical trial funded by NIH.

Conclusion

There is a clear need to provide effective home monitoring for asthma patients. The HAT System is designed to monitor asthma patients and to help them in day-to-day management of their disease. HAT has a potential for improving clinical outcomes and quality of life in this patient population and may be a model for monitoring and self-management of patients with other chronic health conditions.

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