Chapter 10
Computer-Based Applications in the Management of Asthma

Ross Shegog and Marianna M. Sockrider

Introduction

Asthma has emerged as a significant chronic disease affecting an estimated 300 million people worldwide (Masoli et al. 2004), including over 20 million people in the United States. Poor asthma control results in significant morbidity including lost work days for adults and school days for children (11.8 million and 14.7 million, respectively, in 2002), preventable mortality (estimated at 4,261 deaths per year), and also contributes substantially to the burden of health-care expenditures (estimated at a total cost of $16.1 billion in 2004) (Schiller and Bernadel 2004; NHLBI 2004). Prevalence of childhood asthma, as estimated in the 2007 National Health Information Survey, remains at historically high levels with 9.1% of children (6.7 million) estimated to have asthma (Akinbami et al. 2009). Controlling asthma is a public health challenge. Complicating this are reported discrepancies in how asthma is managed by health-care providers and patients. These discrepancies include under-estimation of disease severity by patients (Worstell 2000), under-treatment of symptoms by health-care providers (Wolfenden et al. 2003), low rates of outpatient follow-up after emergency room visits and hospitalizations (Smith et al. 2004; Cabana et al. 2003), and under-utilization of preventive measures such as influenza vaccination (Figaro and Belue 2005).

Clinical guidelines can help to curtail these practice deficiencies by providing evidence-based and standardized approaches to the management of asthma (NHLBI 1991, 1995, 1997, 2002, 2007; British Thoracic Society 1990; Woolcock et al. 1989; Spector and Nicklas 1995; Creer et al. 1999; Jadad 2002; GINA 2006). These clinical practice guidelines have been widely disseminated to health-care providers and are freely accessible through the Internet. However, the success of guidelines is predicated on health-care providers adopting and implementing them. Although providers report a high awareness of the guidelines, specific practices such as prescribing anti-inflammatory controller medications, giving patients written action plans, and using objective measures of lung function have remained at low-to-moderate rates (NHLBI 1991, 2002; Grant et al. 1999; Gregson et al. 1995; Lieu et al. 1997; Dawson et al. 1995; Legorreta et al. 1998; Finkelstein et al. 2002). In the past 15 years since the publication of the first NAEPP guidelines, a slow but steady adoption of key guideline messages appears evident (Ruchi and Weiss 2009). Reasons for practice variances include cognitive and motivational factors such as lack of familiarity with specific guideline recommendations or skills to implement them; low efficacy or outcome expectations; clinical practice constraints, such as time and reimbursement for education; guideline-specific factors such as lack of clarity or inadequate evidence of effectiveness; and health system decision support (Cabana et al. 1999; Cabana et al. 2000; Cabana et al. 2001; Ruchi and Weiss 2009). Asthma guidelines are purportedly one of the more commonly adopted when compared to other chronic disease guidelines (Flores 2000). Despite this, application of asthma guidelines is a behavioral and organizational challenge.

Computer applications offer potential to enhance the application of asthma management guidelines. The refinement of clinical and behavioral asthma care practices and the evolution of computer-based technology

R. Shegog (✉)
Center for Health Promotion & Prevention Research, UT School of Public Health, 7000 Fannin, Suite 2668, Houston, TX 77030, USA
e-mail: ross.shegog@uth.tmc.edu

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have led to a steady increase in studies evaluating the use of computers in asthma management. Computer-based applications have been described throughout the therapeutic stream of asthma management (Fig. 10.1). A recent review lists 64 publications devoted to informatics applications in asthma, but few of those have moved from the testing environment to widespread use in patient care (Sanders and Aronsky 2006). This chapter will briefly describe the emergence of computers in health-care and examine empirical research on using computer-based applications in the management of asthma. Research will be described in three operational domains: (1) in support of clinician practice and decision-making, (2) to educate patients and/or health-care professionals in asthma management and skills, and (3) to allow patients to monitor asthma self-management practices and control.

Emergence of Computer Applications in Health-Care

Computer-based applications for asthma management have evolved in tandem with the evolution of computer technology. The transition from the industrial age to the information age in the latter twentieth century ushered in dramatic computing advances in health-care from medical practice to education and research (Morris 1994; Sanders and Aronsky 2006). Early developments were focused on Health Information Systems (HIS), large computerized data bases used to store health and administrative information, communicate orders, and/or report results from pharmacies and laboratories (e.g., Technicon Medical Information Systems, Mountain View, CA.; the HELP system, Latter Day Saints Hospital, Salt Lake City, Utah; and the HIS at the National Institutes of Health Clinical Center, Bethesda, MD.) (Staggers et al. 2001). Support for clinical practice was limited in the 1970s and 1980s, with computerized billing functions often superseding care functions (Ozbolt et al. 1990). By the late 1980s, HIS vendors (e.g., Shared Medical Systems, HBOC, Center) began developing and marketing clinical applications. Early diagnostic and medical record data bases were the vanguard for applications that mirror the expanding demands of modern disease management. These include applications for maintaining patient records, clinical decision making (e.g., diagnostic systems, expert systems, decision support systems), management education (e.g., computer-assisted instruction programs), and information resources (e.g., Internet sites, electronic textbooks) (Hunt et al. 1998; Shiffman et al. 1999).

Medical Record Systems

A shift to managed care in the 1980s and 1990s brought a changing focus from the traditional physician-orientation to a payer-orientation that emphasized health promotion, disease prevention, and cost containment (Staggers et al. 2001). New information technology (IT) support developed to integrate health-care delivery networks from diverse types of healthcare settings. Computer-based patient records (CPRs) or electronic medical records (EMRs) emerged to track patient care within managed networks, enabling strategic goals to fuse business and clinical operations. These systems became

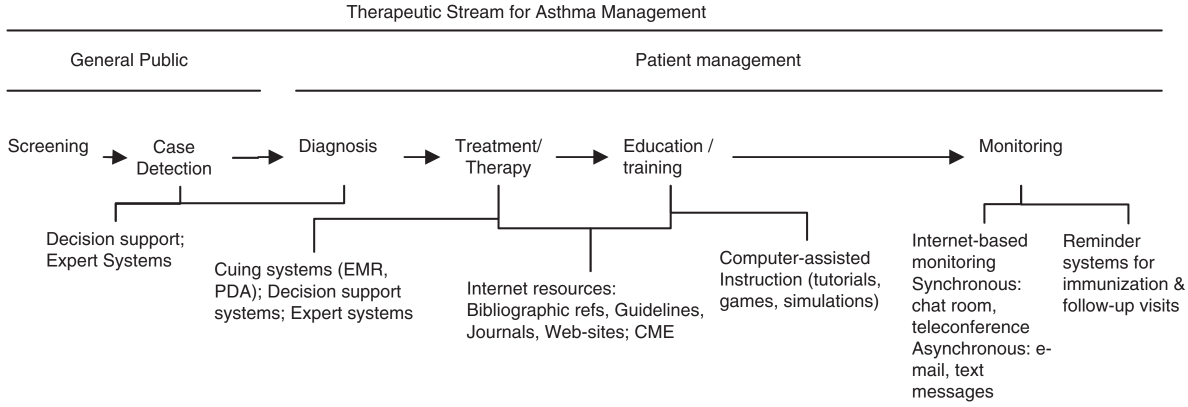

Fig. 10.1 Applications in the management of asthma

part of the Institute of Medicine's recommendations for improving patient records by managing clinical data through the lifespan and across interdisciplinary teams (Dick and Steen 1991). By providing data that is consistent, accurate, accessible, and with minimal redundancy, CPRs have been projected to save tens of billions of dollars in hospital care costs due to earlier clinical intervention and fewer patient visits. By the end of the 1980s, computing and communication technology had converged as telephone lines were superseded by coaxial cables and then fiberoptic lines. Open network architecture and interconnection protocols allowed compatibility of computers from different vendors (Morris 1994). Complimentary advances have included data standardization through groups such as the American National Standards Institute (ANSI), Healthcare Informatics Standards Board Vocabulary Working Group and the computer-based Patient Records Institute Working Group on Codes and Structure (Chute et al. 1998). The legal, privacy, and security issues in handling shared data are also being addressed through policy initiatives such as The Health Insurance Portability and Accountability Act (HIPAA) of 1996. This act calls for strict limits on disclosure and use of healthcare information and mandates individual health information protection (Christiansen 1999).

Expert Systems and Decision Support Systems

Computer-based expert systems are programs that are designed to mimic expert human performance in a narrow domain. An expert system comprises a knowledge base and an inference engine (Alessi and Trollip 1991; Giarrantano and Riley 1989). The knowledge base contains the content of the program, including decisions to be made based on the gathered clinical data, questions that provide required clinical data, and decision rules that operate upon that data. The inference engine is the program that uses the components of the knowledge base to provide conclusions to the user (Alessi et al. 1991; Giarrantano and Riley 1989).

Early clinical decision making applications developed in the 1950s focused on assisting in medical diagnosis (e.g., Iliad, DxExplain, Internist-I, MYCIN, and QMR) (Staggers et al. 2001). These applications provided broad-based support in diagnosing a range of diseases but lacked integration into existing CPRs causing providers to enter data into separate programs.

Computer-based tools that help to improve physician's evidence-based decision making (EBDM) can be categorized as *passive* tools that can be searched (including on-line guidelines, journals, texts) and *active* tools which continuously survey computer-physician interactions and are programmed to intervene under defined conditions (Schneider and Eisenberg 1998; Haug et al. 1999). Active tools can be broadly termed as decision support systems (DSSs). Functions of DSSs can include: (a) alerting the care provider to situations of concern, (b) critiquing previous decisions, (c) suggesting interventions at the direct request of the care provider, and (d) conducting retrospective quality assurance reviews, or combinations of these (Haug et al. 1999; Shiffman et al. 1999). The utility of DSSs in medical practice has been demonstrated in enhancing clinician adherence with practice guidelines including drug dosing (Johnston et al. 1994; Walton et al. 1999), diagnosis and referral of high-risk patients for respiratory assessment (Chase et al. 1983), and in acute medical care (Johnston et al. 1994; Hunt et al. 1998; Shiffman et al. 1999; Creer 1993). Cumulative evidence suggests that computerized medical DSSs can improve clinician compliance with practice guidelines and improve preventive and active care, especially when delivering patient-specific advice at the time and place of a consultation (Johnston et al. 1994; Grimshaw and Russell 1993; Tierney et al. 1986).

A systematic review of the functionality and effectiveness of computer-based decision support systems found that they improved guideline adherence and documentation and contributed to the improved process, delivery, and evaluation of medical care (Johnston et al. 1994; Hunt et al. 1998; Shiffman et al. 1999). Recommendations for future asthma care include the enlistment of health information technology (Ruchi and Weiss 2009). Despite this, development of these systems is still evolving slowly with relatively few being widely implemented into medical practice (Hunt et al. 1998; Johnston et al. 1994; Austin et al. 1996; Shiffman et al. 1999; Sanders and Aronsky 2006).

Computer-Assisted Instruction

In recent decades, computer-based applications have evolved for patient and family health education and behavior change in health promotion, disease prevention, and disease management (Skinner and Kreuter 1997; Brennan et al. 1991; Brown et al. 1997; Dijkstra et al. 1998; Rhodes et al. 1997; Bartholomew et al. 2001; Gustafson et al. 1987; Williams et al. 1995). Collectively, such programs have been shown to positively affect learner attention, motivation, memory, and comprehension, while also promoting active learning, attitude change, and increased transfer of learning (Alessi and Trollip 1985; Lieberman 1997; Rimal and Flora 1997; Niemiec and Walberg 1987; Skinner and Kreuter 1997; Clark et al. 2009).

Information Resources

Interactive health communication (IHC) has been broadly defined as "the interaction of an individual-consumer, patient, caregiver, or professional – with or through an electronic device or communication technology to access or transmit health information to or receive guidance and support on health-related issues" (Science Panel on Interactive Communication and Health 1999). Increased accessibility (through the World Wide Web (WWW), increased transmission speed, portable digital devices (PDAs), and wireless communication) is enabling greater use of the technology by providers and patients who are less constrained by location (hospital, clinic, home, and school). This technology is heralding a change in how providers and patients communicate about health-care issues. As the Internet emerges as a principal source of health information (Pew Internet American Life 2006), the role for health-care providers is changing from health information "providers" to health information "brokers" who may guide judicious selection of e-health-related information in websites and online chat rooms. The evolution of hardware has led to increasing use of integrated handheld technology (PDAs, cell phones, iPods™) which has barely gained attention in the evaluation literature to date (Chang et al. 2003).

Applications in Support of Clinician Practice in Asthma

National Heart Lung and Blood Institute (NHLBI) NAEPP guidelines delineate four essential elements of asthma management: diagnosis and monitoring using objective measures of lung function; control of inflammation and bronchospasm through pharmacotherapy; environmental trigger identification and avoidance; and patient education and collaboration in care (NHLBI 1991, 1995, 1997, 2002, 2007). Computer-based applications used by clinicians to achieve the following clinical guideline objectives are described in this section: diagnosis and case detection, objective monitoring of lung function, support in implementing therapeutic guidelines, and engendering the physician-patient collaborative partnership.

Diagnosis and Case Detection

Case detection and diagnosis of asthma are critical first steps in management (National Heart Lung and Blood Institute 1997). Sanders and Aronsky (2006) reviewed 18 evaluation studies (from a pool of 64 informatics studies in asthma) devoted to diagnosis and case detection. These include applications that analyze clinical data (e.g., using pulmonary function tests or peak flow values) to determine presence and severity of asthma; programs to identify asthma patients on the basis of administrative data (e.g., discharge summaries, billing codes); and computer-based surveys to screen for asthma or characterize disease severity and control (Sanders and Aronsky 2006). Historically, diagnostic functions have provided some of the earliest clinical decision making support in asthma as well as other chronic diseases.

Broad-based expert systems (e.g., Iliad, MYCIN) have provided input to physicians on diagnosis of varied diseases including asthma and more recently have been devoted to successfully detecting asthma or assessing its severity (Redier et al. 1995; Ray et al. 1995; Shegog et al. 2004). Examples of such systems include *AsthmaExpert*©, which has been favorably compared to 3 pre-existing severity-scoring systems (Gautier et al. 1996) and OASYS-2, a computer-assisted diagnostic aid for the visual analysis of peak expiratory flow plotted records, found feasible in confirming cases of occupational asthma (Gannon et al. 1996; Burge et al. 1999). Systems have also been reported that compare favorably with human examiners in detecting airway obstruction through the classification of breath sounds (Tinkelman et al. 1991; Rietveld et al. 1999) as well as differentiating tidal breathing patterns (van der Ent et al. 1996).

Automated systems can significantly reduce manual chart review burden while maintaining adequate levels of precision. Evaluations of chart review systems for health-care organizations have included a system to identify acute exacerbations in pediatric asthma (Aronow et al. 1995a, b), a natural language processing system to identify diagnostic, co-morbidity, and smoking status in discharge summaries for asthma patients (Zheng et al. 2006), and a system to identify the prevalence of asthma (Vollmer et al. 2004). Documentation from a *Computer-Assisted Triage System*© (CATS) was reported to compare satisfactorily to written records for all visit detail items and 9 out of 10 triage detail items and less favorably for nursing observations and medical details (Kabir et al. 1998). A study of EMR impact on delays of diagnosis of asthma in children did not show a significant difference in delays before the implementation of the EMR vs. delays subsequent to implementation, though a positive trend was indicated (Yoo and Molis 2007).

Electronic versions of data acquisition surveys such as the Pediatric Asthma Quality of Life Questionnaire and Pediatric Asthma Caregivers Quality of Life Questionnaire are becoming available and have the added value of immediate scoring and graphical feedback (Mussaffi et al. 2007). A validation study comparing electronic to written collection methods for the International Study of Asthma and Allergies in Childhood Questionniare indicated no appreciable difference in the quality of data collected in a sample of Dutch adolescents (Raat et al. 2007). Computer-based data acquisition of medication prescription information from patients has shown acceptable validity (Porter et al. 2006). Medication adherence, however, represents a greater challenge. In a study assessing the effect of interview mode on self-reported adherence to a corticosteroid regimen indicated that while all modes (audio computer-assisted self interviewing (ACASI), face-to-face interviews, and self-administered paper and pencil questionnaire) showed a discrepancy between self-report and objectively measured adherence, the ACASI condition showed the most discrepancy (Bender et al. 2007). At least in the domain of adherence, the advantages of ACASI were not demonstrated as they have been in other health domains (i.e., risky sexual behavior and illicit drug use).

Though beyond the scope of this chapter, asthma case detection systems have been used for both epidemiological research and community screening in the general population (Grassi et al. 2001; Hirsch et al. 2001); predicting at-risk children from outpatient populations (Lieu et al. 1998); predicting mortality risk in adult outpatients (Tierney et al. 1997); predicting chronic obstructive pulmonary disease (COPD) in asthma patients (Himes et al. 2009), and predicting emergency room utilization based on environmental data (Bibi et al. 2002). Other applications include genetic data bases for asthma phenotypes (Wjst and Immervoll 1998), electronic nose applications to discriminate between patients with asthma and controls through the analysis of volatile organic compounds in exhaled air (Dragonieri et al. 2007), and community-based approaches such as the application of geographic information systems (Rob 2003; Peled et al. 2005; Peled et al. 2006). Collectively, such systems appear to have public health utility, and demonstrate appropriate sensitivity and specificity.

Objective Monitoring of Lung Function

Objective measurement of lung function continues to be an essential element of the NHLBI NAEPP guidelines (NHLBI 2007). The measurement of lung function using spirometry provides a measure of disease severity and a means to track the disease's course and response to therapy (Miller et al. 2005; NHLBI 2007). Computer-based applications have been shown to successfully train patients to perform the spirometry technique, even in young children. An innovative computer-animated interactive system (*SpiroGame*©) was developed to teach and measure tidal breathing, encourage participation, and train preschool children to provide valid and reproducible spirometric test results (Vilozni et al. 2001). Children 3–6 years of age showed acceptable spirometry maneuvers through the use of the system which includes a game teaching tidal breathing technique before performing FVC maneuvers, an interactive visual interface, and a small, child friendly, ice cream cone-shaped pneumotachograph. Submission of digital video through the Internet has been demonstrated as a method of assessing peak flow meter technique in 7–16-year-old children (Chan et al. 2003; Chan et al. 2007). This asynchronous approach is described more fully under home monitoring later in this chapter.

Implementing Therapeutic Guidelines for Asthma

As the asthma guidelines have continued to be refined, so have computer-based applications designed to facilitate their use in clinical practice. In a review of informatics application for asthma management, Sanders and Aronsky (2006) report 20 publications (31% of publications reviewed) devoted to implementing or evaluating applications in support of clinical guidelines. These included systems in support of drug dosing, outpatient clinic practices, critiquing care plans, and vaccination reminder systems.

Prototypes have been described based on both the British Thoracic Society and NHLBI NAEPP guidelines (Austin et al. 1996; Shiffman et al. 2000). Studies in the United Kingdom have found mixed results in the application of DSSs for clinician decision making and patient outcomes. Epistemological and computational models for system design of a DSS under the aegis of the GAMES-II project was reported by Austin and colleagues though clinical outcomes have not been reported (Austin et al. 1996). A web-based, guideline-based DSS for acute asthma was assessed for its effect on clinician decisions using clinical scenario testing (Thomas et al. 1999). The DSS improved decision making across disciplines and modalities. Nonpulmonary nurses using the asthma DSS scored the same as experts (89% vs. 88%) and medical residents using the DSS scored significantly better than residents using a pen and paper application (92% vs. 84%). Also supportive was that patients whose physicians used a DSS in general practice clinics in the UK had fewer acute asthma exacerbations and initiated fewer practice consultations for asthma by 6 month follow-up than patients whose physician did not use a DSS (McCowan et al. 2001a, b). Less encouraging results using a DSS were found in a study of general practitioners and nurses in general practice clinics in N.E. England (Eccles et al. 2002). Measures taken 12 months before and 12 months following the introduction of the asthma DSS found no improvement in consultation rates, process of care measures, or reported patient outcomes. This study highlighted the importance of training and system design to avoid reported low levels of system adoption. A randomized controlled trial of 246 physicians, 20 outpatient pharmacists, and 706 of their patients with asthma and chronic COPD failed to show an effect of computer-generated care suggestions from clinical workstations to enhance physician and pharmacist adherence to evidence-based guidelines (Tierney et al. 2005). Conversely, computer clinic workstations have been an effective medium for delivery of interventions to effect physician ordering behaviour (Tierney et al. 1990) and to establish computerized physician order entry (CPOE) systems to help standardize order sets, reduce practice variation, and promote best practice (McAlearney et al. 2006).

Use of a handheld system based on the NHLBI NAEPP guidelines was associated with increased physician adherence to guideline recommendations including measures of lung function (peak flow and O_2 saturation) and pharmacotherapy (beta agonist use) though use of the system also resulted in prolonged and more costly visits with no demonstrated improvement in intermediate-term patient outcomes (Shiffman et al. 2000; Karras et al. 1999). The majority of users applied the system in real time concurrently with patient care and appreciated its cuing and reminder functions (Shiffman et al. 1999).

A traditional usability barrier to the computer-based support of guideline implementation has been that DSSs have not been integrated into EMRs causing providers to access different programs and duplicate data entry. In follow-on work, Shiffman and colleagues successfully translated the NHLBI guidelines into workflow decision support for the Logician™ EMR system. To date, the principles governing design activities and the steps to achieve integration into the existing workflow have been published (Shiffman et al. 2004). This work reflects a next generation of integrated decision support.

Descriptive and feasibility studies have also been conducted on another integrated system, "*Asthma Critic*," a "non-inquisitive" program designed to review or critique physician's diagnostic and treatment plans for asthma and chronic COPD using existing data already available in the EMR, hence requiring no additional data input from physicians (Kuilboer et al. 2002; Kuilboer et al. 2003). The system provides feedback of two types: critique as a patient specific comment based on the current clinical data, and transformed clinical measurement including calculation of measurement values (e.g., predicted peak flow based on gender, age, and height). A prospective feasibility study of over 100,000 electronic case records from primary care practices determined that the program was able to detect asthma and COPD records ($n = 8{,}784$) and produce patient specific feedback, mostly related to prescription type (for patients ≥12 years of age) and route (for patients ≤12 years). A randomized clinical trial of "AsthmaCritic" in 32 practices (40 Dutch general practitioners) compared the program with usual practice and determined that it changed the manner in which physicians monitored patients (i.e. increased FEV1 and PEF measures and ratio of coded measurements), conducted treatment (i.e. decreased cromoglycate prescriptions), and changed data-recording habits (Kuilboer et al. 2006).

Decision-support systems and EMR's can represent complex solutions to enhance the implementation of evidence-based clinical guidelines. Low-end solutions, while less complex, can provide elegant alternatives. Microsoft Access™ has been modified for the creation of asthma action plans using the "form entry" function, providing a database that can be queried to document best practices, is user-friendly, and networkable (Mangold and Salzman 2005).

Computer-based applications, EMRs, and DSSs have potential in influencing provider behavior and provide a likely candidate to address the call to develop and critically assess innovative interventions that encourage providers to adhere to guideline recommendations for inpatient as well as outpatient populations (Kattan 2008).

Physician-Patient Partnership, Collaboration and Communication

While acknowledging the importance of collaborative self-management, existing asthma management guidelines are less specific on how to establish an effective patient-provider partnership and how patients can overcome barriers to asthma self-care (NHLBI 1997, 2002; Shegog et al. 2004; NHLBI 2007). Theoretically-based tailored interventions have proven effective in influencing clinicians to train and motivate their patients to perform self-management (Clark 1989; Clark and Zimmerman 1990; Clark et al. 1995). While computer-based CD-ROMs have been used as a medium for an interdisciplinary training program in helping care providers understand overlapping roles in the clinical management of asthma (Rodehorst et al. 2005) the practical guidance in applying such models, as well as communication techniques that are effective with patients, have not been systematically addressed in an easily applicable form for providers and thus have been more slowly incorporated in DSS design (National Heart Lung and Blood Institute 2007; Glanz et al. 1997).

The *Stop Asthma Clinical System* (*SACS*) DSS provides support to the health-care provider in using tailored behavioral intervention strategies as a means of assessing and addressing problems of adherence to medication taking and environmental trigger control while also supporting asthma severity determination, pharmacotherapy, and action plan development. (Shegog et al. 2004; Shegog et al. 2006a, b). The decision rules in this DSS are based on inductive and deductive knowledge acquisition approaches, as well as Social Cognitive Theory and the Transtheoretical Stages of Change methods and strategies (Bandura 1991; Prochaska and Velicer 1997). While feasibility for the application has been established, the affects of *SACS* on physician behaviors and patient outcomes has yet to be determined (Shegog et al. 2006a, b). A modified version of the *SACS* (*AE-BACKER*) has been evaluated in a randomized controlled trial of a self-management intervention delivered in an emergency department setting for children aged 1–18 years of age (Sockrider et al. 2006). Asthma educators used *AE-BACKER* to tailor intervention messages and provide a customized asthma action plan and educational summary. Treatment subjects had higher confidence to prevent/treat asthma episodes 14 days after intervention; reported more well-asthma visits by 9 months after intervention; and had significantly fewer return emergency department visits. Although a greater proportion of subjects in the intervention group reported well-asthma visits than subjects in the control group, this return rate was still <50%. Despite computer-based decision support the ability to link children with emergency department visits back to primary care for well-asthma care remains a challenge, and even when follow-up occurs, the impact on subsequent asthma control remains uncertain (Sockrider et al. 2006).

In service of enhancing the patient-provider partnership, Hartman and colleagues have developed a website, *MyExpertDoctor.com*©, designed to raise patient awareness about what questions to ask their physicians prior to a clinic visit to increase the likelihood of receiving asthma care consistent with evidence-based guidelines (Hartmann et al. 2007). Results of qualitative evaluation indicate that patients had positive shifts in attitudes regarding interaction with their physician and became more involved in asthma care. Porter and colleagues report on two studies of the *Asthma Kiosk* ©, a DSS program, accessed during an emergency department visit, that collects child patient data from parents on symptoms of chronic severity, current medications, assessment of care needs, and environmental risk and provides output to clinicians that highlights level of chronic severity, symptom data supporting the severity rating, current controller medicines, mismatches between severity medicine and use of controllers, and asthma-specific needs regarding environmental risks, access to care and medicines, and educational topics (Porter et al. 2004; Porter et al. 2005; Porter et al. 2006). Patients rated the *Asthma Kiosk* © favorably as a good use of time and knowledge, easy to use, and not burdensome (Porter et al. 2004) and it was found to be a valid source of patient medication data (Porter et al. 2005). Parent satisfaction with care was measured by information-sharing by providers and by perceived involvement in their child's care during the ED visit. There was no change in information-sharing with patients reporting that they received as much information as they wanted at baseline and during the study. Satisfaction ratings worsened on the involvement rating from baseline to follow-up, possibly due to providers' inattention to concerns that were communicated via the kiosk (Porter et al. 2006). These results support the contention that to have an impact on patient outcomes, providers not only require salient patient information of the kind provided by programs such as *Asthma Kiosk*, but also they need to believe the correctness of the information they receive and take action to provide effective tailored recommendations using behavior change strategies to promote self-management as offered in programs like *SACS* or *AE-BACKER* (Clark et al. 1995).

Applications for Asthma Management Education

Patient and family education is essential for successful management of asthma as a chronic disease (NHLBI 1991, 1997, 2002, 2007; USDHHS 2003). Without adequate education, management recommendations on following a written action plan, correctly administering medications, and taking appropriate actions early in the event of an asthma exacerbation are rendered ineffective (Cabana and Tao 2005; Toelle and Ram 2004; Clark et al. 2009). The expansion of asthma educational programs has been driven, at least in part, by a growing acceptance that patients be actively involved in the management of their chronic disease and in treatment decisions (NHLBI 1991, 1997, 2007). The practical importance of teaching patients and their families self-management skills to lessen the impact of chronic illness has been well elucidated (Clark and Zimmerman 1990; Thoresen and Kirmil-Gray 1983; Bailey et al. 1992; Clark et al. 1993; Guevara et al. 2003). Such skills include adherence to medical regimens as well as the complex cognitive-behavioral tasks of self-monitoring, decision-making, and communicating about both symptoms and treatment regimens (Clark and Zimmerman 1990; Thoresen and Kirmil-Gray 1983; Bailey et al. 1992; Clark et al. 1993).

The benefits of asthma education programs include improved knowledge, feelings of competence, use of specific self-management behaviors, adherence to medical regimen, decreased emergency room and unscheduled doctor visits, reduced financial burden of asthma, enhanced partnerships with health-care providers, and quality of life (Evans 1992; Clark et al. 1986; Peterson et al. 2001; Klingelhofer and Gershwin 1988; Wigal et al. 1990). More recent systematic reviews have indicated improved objective measures of lung function, frequency of asthma symptoms, and health-care utilization (Velsor-Friedrich and Srof 2000a, b; Gibson et al. 2002; Wolf et al. 2002).

Recommendations for contemporary asthma education programs include that they (1) recognize the multiple factors that influence asthma and its control; (2) assess the individual's risk factors and needs in achieving control; (3) be individualized and tailored to the patient's asthma characteristics; (4) be more closely based on sound self-management and learning principles so that the patients and families can assume greater responsibility to self-manage their own asthma; (5) account for the importance of context and contextual variables (physical and social environments) on asthma management; (6) involve significant family members in intervention activities; (7) use venues where learning can be optimized (e.g., schools); and (8) be integrated into the provision of medical care in an efficient form to allow convenient implementation in the context of a clinic visit (Creer et al. 1990; Creer et al. 1992;

Kotses et al. 1990; Kotses et al. 1991; Velsor-Friedrich and Srof 2000a, b; McPherson et al. 2001, 2005; Clark et al. 2009). This section will describe evaluations of computer-assisted instruction programs that address these recommendations. Trends in professional training and the Internet as an information resource will also be briefly described.

Computer-Based Instruction for Asthma

The number of published empirical trials of asthma related computer-based instruction (CAI) is increasing. Reviews of computer-based interventions have listed as few as one study on asthma education in 2001 to as many as 13 in 2006 (Revere and Dunbar 2001; Osman et al. 1994; Sanders and Aronsky 2006; Bussey-Smith and Rossen 2007; Stinson et al. 2008). CAI now utilizes the full advantages of multimedia computing, providing interactive, tailored lesson content in engaging forms such as games, tutorials, quizzes, or simulations that are self-paced, more easily disseminated, and provide a range of visual (animation, graphics, video) and auditory (sound effects, music, voice over) strategies (Table 10.1).

Pediatric Asthma Education

Children with chronic conditions are playing a much more pivotal role in their management and treatment decisions, leading to an expansion of asthma education programs designed for their use. McPherson et al. (2005) describe two major computer-based educational approaches for children with asthma: stand-alone games and Internet-enabled programs. Gaming has long been considered a core educational strategy for computer applications and is currently enjoying an emergence with Serious Gaming and Gaming for Health initiatives (Serious Games Initiative 2006; Games for Health 2006). Early use of CAI gaming with children with asthma (7–12 years of age) was investigated using a computer game, *Asthma Command* © (Rubin et al. 1986; Rubin et al. 1989). The game content included symptom recognition, "aggravators," medicines, appropriate use of health providers, and encouragement to attend school. Children who played *Asthma Command*© for 40 min every 6 weeks for a period of 10 months in the outpatient clinic showed significantly improved knowledge and self-reported asthma management behaviors compared to children who did not have this exposure. A revised version of this program, *Asthma Control* ©, was created to reflect changes in the expert guidelines including the importance of preventive medication and expanded simulated environments and educational content (Homer et al. 2000). Children 3–12 years of age who used *Asthma Control*© in hospital, primary care or health clinic settings increased asthma knowledge and could report more environmental triggers than those children receiving usual care. They also showed improvement in a range of asthma management outcomes equivalent to children receiving usual care, which suggests the potential for computer-based applications to be a cost-effective educational approach in the long term (McPherson et al 2001).

A school-based program, *AirAcademy: The Quest for Airtopia* ™, was introduced as part of a 4th grade general health curriculum for students (9 and 10 years of age) (Yawn et al. 2000). It uses a science fiction theme to cover topics including anatomy of the lung, pathophysiology of asthma, environmental triggers, symptoms, therapeutic compliance and management, and goals of asthma management. Children using *AirAcademy*™ showed significant improvement in knowledge scores at 4-week follow-up compared to children not using the program.

These early studies reported change in knowledge about asthma and its management. As advances were being made in the theoretical and empirical underpinnings of self-management behavior, the design and evaluation of computer-based applications have moved from a focus on impacting knowledge to include other determinants of self-management behavior. *Bronki the Bronchiasaurus*™ is a Nintendo ™ psychomotor game where children guide a cartoon character to manage asthma including taking medicines, using an inhaler, recognizing and avoiding asthma triggers, monitoring peak flow, and using a sick day plan (Lieberman 1997, 2001). Multiple choice questions also cover an array of asthma management topics. Children, 6–16 years of age, who played the game for 40 min in an outpatient setting showed significant improvements in asthma knowledge, self-efficacy for asthma self-management, and self-efficacy for communicating with their parents about asthma. In another outpatient study, children

Table 10.1 Advantages and disadvantages of computer-based instruction and online resources

Advantages of CAI

- Convenient: Accessible at time and place convenient to user, and to geographically disparate populations
- Safe: Allows for safe exploration of concepts and applications
- Interactive: Often requires active input and response from users
- Flexible: Can be used as a stand-alone program, adaptable to changing data, can provide personalized and tailored instruction/information, operated at the users' own pace, search and personalized display capabilities
- Social: Can provide a sense of community through bulletin boards, e-mail, virtual worlds, can enhance communication with peers
- Motivational: Attractive to users, especially youth
- Attractive: Incorporates multimedia applications
- Accessible and egalitarian: Easily disseminated to underserved populations

Disadvantages of CAI

- Accessibility: May be dependant on cost and location causing disparities ("digital divide")
- Literacy: Depends on user's ability to read, many websites are in high-level English
- Interactivity: Often websites are simply "page turners"
- Turnover: Programs are often superseded in terms of sophistication and content
- Quality: Website content quality is variable and may be dated, a number of checklists to assess website quality exist but none are definitive, expert moderation is required in chat rooms and bulletin boards
- User demographics: It is still unclear who benefits most from using CAI and which factors are salient predictors of success (e.g., I.Q., disease severity, education level)
- Cost: Up-front costs are often high and development processes are long and detailed

Adapted from (Glasgow et al. 1999; Owen 2002; McPherson et al. 2001; D'Alessandro and Dosa 2001; Croft and Peterson 2002; Oermann et al. 2003)

using the program for 30 min showed significantly greater self-efficacy for asthma self-care activity than children watching a 30-min videotape about asthma self-care (Lieberman 2001).

STARBRIGHT World™ is an on-line virtual experience designed for hospitalized children that has generated research across health domains (Starlight Foundation 2009). In this application children can learn about asthma or other diseases and interact with other users online. Children, 8–18 years of age, many with asthma, who used STARBRIGHT World™ during their hospitalization showed increased knowledge about asthma compared to those experiencing traditional hospital educational and recreational activities (Hazzard et al. 2002). The experience of the on-line virtual community did not significantly increase perceived social support from peers or coping skills compared to the traditional hospital experience.

Recent evaluation studies have been reporting findings that promise greater impact on behavioral and clinical outcomes of asthma. Outpatient children 7–14 years of age who accessed a self-management computer program from home called *The Asthma Files©* had greater knowledge and locus of control at 1 month and were less likely to have required oral corticosteroid or time off school during a 6-month follow-up period when compared to children not accessing the computer program (McPherson et al. 2001). Other outcome parameters including FEV1, PEF, and unscheduled visits to the clinic or hospital were not significantly different. In two separate studies evaluating Internet-enabled applications for outpatient education Krishna et al. (2003) have shown promise in supplementing conventional asthma care with interactive multimedia education to improve knowledge and reduce the burden of childhood asthma. Children 7–17 years of age visiting a pediatric pulmonary clinic who received an Internet-enabled multimedia asthma education program in addition to face-to-face patient education significantly increased asthma knowledge, decreased asthma symptom days, and decreased number of ER visits compared to children receiving patient education alone (Krishna et al. 2003). These children were also using a significantly lower average daily dose of inhaled corticosteroid (beclomethasone equivalent) at 12 months follow-up. A subsequent version of this program entitled "*Interactive Multimedia Program for Asthma Control and Tracking*"© (*IMPACT*) comprised Internet-based scenarios, and exercises on causes, triggers, and treatment of asthma in 44 linear lessons that was supervised by health-care professionals (Krishna et al. 2006). Children 7–18 years of age and parents of children 0–6 years of age who used the program demonstrated significantly improved knowledge (child and parent), reduced days of asthma symptoms, emergency care, and school days missed, and reduced activity limitation compared to children and parents using verbal and printed information. Quality of life and lung function indices were not significantly improved.

Another Internet-based asthma education program was able to significantly impact quality of life and lung function, as well as missed school days and asthma-related emergencies (Runge et al. 2006). Four hundred and thirty eight youth (8–16 years of age) were assigned to either a standardized patient management program (SPMP) or to a SPMP with the adjunct Internet-based program and compared after 12 month follow-up. In addition to the previously mentioned outcomes, the combined SPMP/Internet programs also demonstrated positive cost-benefits.

By approximating real life situations, simulations offer great potential to increase transference of asthma management skills to real world behaviors. Findings from studies examining these types of programs are yielding mixed results. Hopper (2005) described an online simulation that used branching-logic in a frame-based application targeting skills training in inner city youth at Atlanta's *Zap Asthma*© headquarters. A sample of 12 inner city children 7–14 years of age provided initial formative evaluation on the application which simulates decision making regarding environmental triggers, medication use, and self-assessment. Field testing and usability testing indicated no significant comprehension or navigation problems but impact and outcome evaluation results have yet to be reported. In *Wee Willee Wheezie*©, asthma management is simulated in life-like settings with the goal to avoid the simulated consequences of exacerbations of asthma and trips to hospital (Huss et al. 2003). Children 7–12 years of age who accessed the program from home for 20 min showed no significant difference on knowledge, symptom, self-management, lung function, or quality of life variables when compared to children who used a non-asthma health related computer game.

A simulation game, *Watch, Discover, Think, and Act* (*WDTA*)©, was designed to include a self-regulation meta-cognitive framework as a central program theme in addition to asthma-specific skills training (Bartholomew et al. 2000a, b). Self-regulation can be described as a sequence of steps of goal setting, self-monitoring, problem identification (self-judgment), solution identification, action (self-reaction), and evaluation (Clark and Zimmerman 1990; Clark et al. 1981; Creer et al. 1992; Bandura 1991; Clark et al. 1984; Macro Int'l 1994). These cognitive skills have been identified as important in assessing and solving asthma related problems as well as more traditional academic problems (Clark et al. 1981, 1984; Creer et al. 1992; Hindi-Alexander and Cropp 1981; Fireman et al. 1981; Creer and Winder 1986; Schunk 1983, 1986; Zimmerman 1986, 1989; Zimmerman and Ringle 1981). Programs that teach self-management behavior in the context of a meta-cognitive framework of self-regulation have shown promise (Clark and Zimmerman 1990; Thoresen and Kirmil-Gray 1983; Creer et al. 1992; Kotses et al. 1990; Clark and Partridge 2002; Clark et al. 2007). The *WDTA* program was found to positively impact self-efficacy and attributions to asthma management in children 9–12 years of age in a laboratory-based impact evaluation (Shegog et al. 2001). Inner city children, 8–16 years of age, who used *WDTA* in outpatient settings rated the program as motivationally appealing and had fewer hospitalizations, better symptom scores, increased functional status, greater knowledge of asthma management, better self-reported self-management behavior, and greater clinic return rates than those receiving usual care only (Bartholomew et al. 2000a, b; Shegog et al. 2006a, b). In a subsequent school-based evaluation of multifaceted screening and educational intervention that included the *WDTA* program, children receiving the intervention demonstrated improved knowledge, self-efficacy, and self-reported self-management including reported trigger management, exercise pretreatment, and self-management of episodes at home (Bartholomew et al. 2006). While feasible for school use, the multi-component nature of the school-based intervention made the particular effects of *WDTA* program, in comparison to other intervention components, difficult to determine.

Adult Asthma Education

Education programs for adult patients tend to take three primary forms: conventional instruction as tutorials; programs that assist in disease monitoring (described in the next section); and Internet resources offering a smorgasbord of information and materials for self-tailored use (described later in this section). Relatively few evaluation studies have been published on stand-alone applications for adult education, with most being in outpatient settings.

Computer-generated personalized booklets have been found to compare favorably to traditional face-to-face asthma education at outpatient or surgery visits in adult outpatients (Osman et al. 1994). The significant findings included 54% fewer hospital admissions than the control group and 80% reduction in sleep disturbance. While not a computer-based intervention in the strictest sense, this study provides an adjunctive use of data management to provide personalized and tailored printed interventions that include the drug regimen used by the patient. Another clinic-based program, *Breathe Smart*©, targeted parents of children with asthma (<12 years of age) and comprised a touch screen interface with photos and graphic media (Fall et al. 1998). Though the program was well received by parents, there was no significant knowledge increase at 1-month follow-up in parents who used the program in a single outpatient clinic visit.

Computer-based applications can be effective as stand-alone programs; however, their efficacy is often greatest when used as an adjunct with conventional education or face-to-face interaction with clinic personnel. A CAI drill and practice program was developed for adult outpatients to instruct them on asthma management and equipment techniques (i.e., peak flow) using a quiz format (Takabayashi et al. 1999). Although older patients (>65 years) required more time, most patients had no difficulty using the program and stated it was beneficial and validated their understanding of asthma. Clinical outcomes were mixed in the small study sample with 8 of 26 patients having decreased emergency visits while 2 patients had deteriorated control. Mixed results were also found for a combined 30-min computer program followed by a 30-min discussion with a specialized asthma nurse in a sample of young adults, 18–25 years of age (Sundberg et al. 2005). Those using the program had significantly increased FEV1, especially among atopic patients. No other benefits were observed in ER visits, symptoms, knowledge, lung function, or quality of life.

The efficacy of using supplementary CAI for environmental trigger control has also been assessed. At 12-week follow-up, patients with dust mite allergy who used a CAI program in addition to conventional instruction (physician verbal and written guidance) scored significantly higher on adherence to avoidance strategies and had lower house dust mite allergen levels in the bedroom compared to control subjects who had conventional instruction alone (Huss et al. 1991; Huss et al. 1992a, b).

Professional Asthma Education

Health-care providers require training programs in the clinical process and management of disease, and continuing medical education (CME) for accreditation purposes. Increasingly, training programs are relying on computer-based applications to provide learning opportunities. Peterson et al. (2001) surveyed hospital -based teaching programs to assess the interest and feasibility of using computer-based delivery for asthma education to train health-care professionals (Peterson et al. 2001). At the time of the survey, 69% of hospital training programs had computers available with 60% linked to the Internet. Eighty five percent of programs reported they could use a computer-based program if one was available though cost and time constraints remain the primary barriers. The development and evaluation of how CAI fits into medical school curricula has been suggested as a future focus of CAI (Adler and Johnson 2000).

With the focus of "just-in-time" learning opportunities for the health-care provider, the computer-based decision support systems offer the potential for "hands-on" training and education in real time. This raises the question as to the effectiveness of the current generation of computer-based education programs. Published evaluations of computer-assisted CME and training programs in asthma education are lagging behind their implementation though some web-based programs are being reported as suitable for delivering educational materials to primary care physicians locally and internationally (Sly et al. 2006).

The Internet provides a breadth of professional resources. Resources generally comprise, but are not limited to, professional associations, pulmonary and medical journals, asthma information sites, disease foundations, and general health information sites. Examples of these links for the pulmonary practitioner can be viewed at the University of Missouri health web page http://intmed.muhealth.org/pulm/pulm_links.html. Further, recent developments in Internet, multimedia, and wireless broadband can facilitate information access to databases devoted to providing support for EBDM including the Cochrane Library, Best Evidence, Clinical Evidence, and the National Guideline Clearinghouse (Jadad 2002; Bero et al. 1998). Relatively few published articles have devoted themselves to professional resources on the Internet and those that have are frequently dated due to the continually evolving offerings (Smith 1999a, b).

The Internet as an Asthma Management Resource

The Internet is also a resource for information on asthma pathophysiology and management for patients and families. Originated through the U.S. government's Advanced Research Projects Agency in 1969, the Internet was designed to be a sustainable network, allowing communication between computer users from one university to another, while allowing routing and rerouting in more than one direction in the event of parts of the network being inoperative (Staggers et al. 2001). It has since evolved into a diverse interaction of "virtual" communities that share information or human experience, mushrooming into a public, cooperative, and self-sustaining facility accessible to hundreds of millions of people worldwide (the World Wide Web).

While potentially beneficial, the Internet can also be a confusing information resource for patients to navigate. For example, when the word "asthma" was entered into three search engines resultant "hits" totalled 2,740,320 (Oermann et al. 2003). Further, the structure of decentralized control makes it difficult to enforce quality-control on sites raising concern about the potential harm caused by health-related Websites through misleading or incorrect information (Kiley 2002; Robinson et al. 1998). The criteria used by people with chronic disease (including asthma) and their caregivers to assess websites, as determined using qualitative survey methods, are information content, presentation, interactivity, and trustworthiness (Kerr et al. 2006). To ease confusion and provide formal criteria, organizations including the American Medical Association (AMA), British Healthcare Internet Association, Health on the Net (HON) Foundation, and the Health Summit Working group have each developed rating tools to objectively evaluate websites (Kim et al. 1999; Health Summit Working Group 1997; Chang et al. 2003). Broadly, these criteria are (1) credibility including sources or references, currency, relevance, site evaluation, (2) content including accuracy, disclaimers from authors or sponsors, completeness, (3) disclosure including purpose and profiling, (4) links including selection, architecture, content, and back linkages, (5) design including accessibility, logical organization, ease of use, and internal search capability, (6) interactivity including mechanisms for users to provide feedback, and (7) caveats including agendas that users need-to-know (Chang et al. 2003).

These criteria have been used to review asthma education on the WWW. The significant strides that have been made in disseminating resources on asthma to the general public have been published that categorize sites into those providing general information, multipurpose sites, and discussion lists (Higgenbottom and Smith 2002) as well as websites catering to adolescents (Chang et al. 2003). Cabana (2005) has echoed the overall results of these evaluation studies, stating that resources on the web vary in their quality and content, often fail to meet the information needs of patients and make little innovative use of technology. An assessment of 145 asthma websites from four major search engines determined that the mean number of HON principles met was 6.3 of 8 (only 14 sites conformed to all), and the mean number of asthma educational concepts was 4.9 of 8 (only 20 sites contained all of these) (Croft and Peterson 2002). The sites also scored low on accessibility. The reading level required to use the websites was greater than 10th grade and only 9 sites had multilingual asthma education content. Few websites used innovative or interactive components with many websites being little more than "electronic books." A subsequent study evaluated asthma websites for patient education using Yahoo™, Google™, and AOL™ search engines and found just ten websites meeting HON criteria and NHLBI content criteria and being recommended for patients and parents of children with asthma (Oermann et al. 2003). The authors also caution that these websites were not excluded on the basis of higher than recommended reading levels. Findings have been similar in international studies that cite highly variable information, and lack of core asthma educational concepts and justifiability (Berland et al. 2001; Heung-Woo et al. 2004).

The challenge of the WWW does not reside in content quality alone. Accessibility, in technical and communication terms, has also represented a challenge. While "adoption of the Internet as a health information resource continues to lag among vulnerable populations who could benefit the most, including patients of lower socioeconomic status and the elderly" (Murray et al. 2003), it is also true that more individuals are gaining access to this resource. "Historically, no communications technology (including the telephone) has been adopted as rapidly as the Internet" (Glasgow et al. 1999). While a segment of the population is becoming increasingly directive of their health-care, there is also a segment which is not "plugged in" and which is still operating in a pre-electronic mode requiring the health-care system to be flexible to handle both conditions (Murray et al. 2003).

An advantage of the Internet is the contact that can be provided for people across a wide geographic distribution to the health-care professional. As previously described, this can be through knowledge assessment and simple feedback (Krishna et al. 2001) or more complex approaches of transmitting detailed management information to ensure they are adhering to the asthma management plan (Chan et al. 2003).

Applications to Monitor Asthma Management and Control

Successful management of a dynamic chronic disorder such as asthma requires consistent monitoring to detect early signs and symptoms and initiate rescue plans, to control airway inflammation, to recognize and avoid environmental triggers, and to maintain collaborative care (NHLBI 1997; Wainright and Wootton 2003). Computer-based monitoring applications have been designed to assist patients in these self-management activities (Chang et al. 2003; Rasmussen et al. 2005). Computer-based monitoring applications comprise a monitoring component and a communication component (Chang et al. 2003). The monitoring component includes individual assessment with feedback that compares patient data such as current lung function (e.g., peak flow, spirometry) or medicine use with past values. Ideally feedback is based on established national guidelines and accounts for the individual patient's characteristics including goals, behaviors, environment, signs, and symptoms. The communication component comprises some form of telecommunications technology. This might be through the Internet or non-Internet-dependent telemedicine systems (Schneider and Eisenberg 1998a, b). Communication can be synchronous or asynchronous. Synchronous communication occurs in real time and includes chat-room modules or teleconferences for conversations between patients that can be monitored by health-care professionals. Synchronous or real-time connections have been described as inconvenient for patients and providers and too dependent on temperamental video connections (Chan et al. 2007). Asynchronous communication, also described as "store and forward" technology, allows patients to accrue data which can be forwarded to health-care providers for subsequent review. This can include e-mails or text messages that might contain a symptom diary-associating peak flow, environmental triggers, activity level, and feelings so that the health-care provider can understand the antecedents of asthma control. This can also include video exemplifying specific management techniques. Monitoring systems also usually encompass an educational component to reinforce information received from the health-care provider (Chang et al. 2003). Examples include commonly asked questions and answers, a library of education materials, video clips, brochures related to asthma, and website links.

Computer-based monitoring has the potential to facilitate the patient-provider communication, provide the opportunity for the patient to work with their own data in real time, to have ongoing management education, and reduce the chance of decay of knowledge and skills gained from previous management education (Finkelstein et al. 1998; Finkelstein et al. 2000; Finkelstein et al. 2001). The number of published evaluation studies is growing with Sanders and Aronsky (2006) reporting 13 papers (20% of their total reviewed pool) devoted to monitoring and prevention. Of these, 10 studies focused primarily on applications allowing patients to record the degree of symptom control, reminding patients to use prescribed medicines, or for tracking the use of rescue medicines. Applications for patient-centered, home-based monitoring of asthma management are described in this section.

Home Internet Monitoring (Management Monitoring Studies)

The rise of the Internet has increased the viability of home-based monitoring. Results to date are encouraging. An Internet-based asthma diary with a feedback system, integrated asthma action plan, and treatment decision support system for use by adult patients was assessed over a 6-month period and led to a significant reduction in symptoms and airway hyper-responsiveness, and improved quality of life and lung function when compared to clinical assessment by specialists or general practitioners (Rasmussen et al. 2005). The opportunity to continually register symptoms provided patients with a more accurate picture of disease severity. This, coupled with greater adherence to their asthma action plan and more efficient monitoring, helped the Internet subjects take the recommended dose of inhaled corticosteroid and maintain asthma control.

The feasibility of this store and forward technology had been established in a separate study where spirometry data (PEFR and FEV) from the Vitalgraph® 2110 home spirometer were uploaded into a PC for subsequent review and analysis and found to generate accurate and reliable data with 67.4% of morning and 71.7% evening recordings meeting acceptable criteria (Hamid et al. 1998). A more recent adherence study in children with persistent asthma used the AccuTrax™ Personal Diary Spirometer, which is a handheld device capable of measuring and recording PEF and FEV_1 values in conjunction with date and time (Burkhart et al. 2007). Daily telemonitoring of exhaled nitric oxide data (from a NIOX MINO™ airway inflammation monitor via PalmOne™ PDA) in children 6–18 years with mild-moderate asthma, though found to be feasible, was not found to provide an appreciable advantage from symptom telemonitoring alone (de Jongste et al. 2009).

Studies of the feasibility of Internet-based home monitoring for low income, inner city patients who have little or no prior computer experience have also been reported (Finkelstein et al. 1998; Finkelstein et al. 2000). A system comprising portable spirometers and pocket-sized palmtop computers for registering lung function and symptoms was evaluated over a 3-week period with a sample of 17 inner city adults with asthma (Finkelstein et al. 1998) and in another sample of 31 inner city adults (Finkelstein et al. 2000). Subjects felt that self-testing was important and uncomplicated, but the clinical impact of this system has yet to be reported (Finkelstein et al. 2001).

Monitoring systems have also been developed for children. The "*Health Buddy*"© (HB) telemonitoring program queries children on their asthma management and provides immediate feedback as well as transmitting trivia and asthma facts on a daily basis (Guendelman et al. 2002). Evaluation results at 6 and 12 week follow-up showed that children 8–16 years of age using HB had less limitation of activity, lower frequency of suboptimal PEF, more unprompted controller medication use, and less urgent calls to the hospital than children using a conventional asthma diary. Another study compared use of an Internet based store and forward system for submission of digital video of peak flow meter use and symptom diaries to office-based (face-to-face) education in improving peak flow and inhaler technique (Chan et al. 2003). Children who were 7 years of age with persistent asthma showed significant improvement in inhaler technique and peak flow values equivalent to children having face-to-face training. However, the investigators noted that there was a significant decline in electronic submission of monitoring videos and diaries from children over time. Therefore, they suggested that intermittent monitoring be instituted mainly at times when the patient's clinical status or regimen is changing (Chan et al. 2003). Similar results were found in a subsequent study examining the long-term comparison of an Internet-based asynchronous case management and education program with traditional face-to-face, office-based case management (Chan et al. 2007). At 12 month follow-up both groups had achieved asthma control suggesting a role for Internet-based case management as a long-term and cost-effective option for ongoing management. Those using the web-based application demonstrated better metered-dose inhaler technique scores and were more adherent to diary submission than those in the traditional face-to-face condition, though adherence to submission of monitoring data was still inconsistent. A study of electronic monitoring of nebulizer medication in inner city children with asthma was found to be more precise than self-report on diary cards and feasible for this population (Butz et al. 2005).

The LinkMedica™ resource site represents a collaborative between AstraZeneca, academic, and patient groups. This is a web service for asthma patients and health-care providers that includes an asthma diary for monitoring and self-management (Jadad 2002; Anhoj and Nielsen 2004). Patient and caregiver use of the site was assessed using quantitative and qualitative evaluations which determined two main uses of the site, "outside-in" in which an asthma management problem arises and users seek answers in the site, and "inside-out" where users focus on the use of the diary feature with little browsing activity. Studies of adolescent's perceived uses, barriers and benefits of the Internet (as well as short message service) for asthma self-management have been conducted. Support is provided on the potential of this technology for long term monitoring, particularly by those adolescents with poor asthma control (van der Meer et al. 2007) and for younger adolescent's who, in one study, were found to have a greater interest in learning about asthma (Rhee et al. 2006). Outcomes from a randomized trial of a tailored web-based asthma management program for urban African-American high school students supports this contention (Joseph et al. 2007; Joseph 2000). In a trial with 314 15–19-year-old teens 21-month follow-up indicated that students using the website, *Puff City*©, reported fewer symptom days, symptom nights, school days missed, restricted activity days, and hospitalizations for asthma compared to control students. Asthma control (average PEF, symptom scores), adherence, quality of life, and asthma knowledge were also positively impacted in a randomized controlled trial of *Blue Angel for Asthma*, an Internet-based multimedia asthma education program with interactive asthma telemonitoring and retrieval analysis system (Jan et al. 2007). The system was evaluated with 164 children (6–12 years of age) with persistent asthma for a period of 12 months.

The National Asthma Education Program Panel (NAEPP) guidelines have been used as a criteria for analyzing ongoing (bi-monthly) asthma data (symptoms, health-care utilization, and medication use) that is then used to provide medication management recommendations (increase, decrease, no change) to the primary care physician via computerized letters (Kattan et al. 2006). Children who used this system had more follow-up care visits, increased asthma visits in which medications were stepped-up when clinically indicated, and had fewer emergency department visits.

Electronic peak flow monitoring has been associated with better patient adherence than with conventional paper recording of peak flow readings (Reddel et al. 1998; Bruderman and Abboud 1997; Lieu et al. 1997). However, the small sample sizes and short duration of published studies make it difficult to generalize or comment on sustainability and a common finding is that monitoring behavior is quickly extinguished or subject to mixed adherence (Finkelstein et al. 1998; Guendelman et al. 2002; Streel et al. 2002). The "Health Buddy©" (HB) system, for example, was well received by the children but there was also a reported decline in use of HB (and also the asthma diary) over the course of the study. In the Internet-monitoring studies by Finkelstein and colleagues, adherence was at issue with only 29.5% of subjects independently reviewing their results at home at least once a week. Despite favorable responses from patients and doctors regarding credibility and reliability, users of the LinkMedica™ site were unwilling to use the site for an extended calendar period and patients stopped using the diary function after a short time. This suggests that the most salient use of the system may be at critical times in care management (e.g., at the start of care for asthma or after an acute exacerbation, an ED visit, a hospitalization, or a step-up in severity class) (Guendelman et al. 2002). Internet-based telemonitoring systems tested in more recent studies have often included a bundling of an educational program and ongoing monitoring in one application. The impact of these programs indicate a positive trend toward greater efficacy in impacting self-management and related outcomes (Kattan et al. 2006; Joseph et al. 2007; Jan et al. 2007).

Computer-Based Reminder Systems

Computer-based reminder systems provide monitoring or tracking functions and cue health-care providers to remind patients to return for clinic visits for prevention services. These systems have positively effected immunization rates and asthma management behaviors (Barnett et al. 1983; McDowell et al. 1989; Rosser et al. 1992; Johnston et al. 1994; Martin 2006). A reminder system used to identify children with asthma and to send a reminder letter followed by an autodial telephone message (sent 6 weeks later) caused a significant increase in influenza vaccines for children from 5.4 to 32.1% (Gaglani et al. 2001). Similar results have been found in a study of children in four private medical practices in Denver where the influenza immunization rate for those receiving a staged reminder letter and postcard was 42% compared to 25% in control subjects (Daley et al. 2004). Reminded subjects were more likely to have an office visit and less likely to have a missed opportunity to immunize. A computer-based reminder system that targeted adult asthma patients was evaluated in outpatient clinics (Curtin et al. 1998). The system comprised an automatic reminder accompanied by a care plan focused on self-management.

Computer-generated point of service reminders and annual birthday card reminders mailed to patients improved self-management and reduced hospitalizations. Intervention patients had significantly greater number of peak flow meter readings and use of the clinical guideline management plan (Asthma Game Plan), as well as fewer hospital admissions and ED visits.

Conclusion

Research on the feasibility, efficacy, and effectiveness of computer-based applications has determined their potential to support guideline implementation throughout the therapeutic stream of asthma management (Fig. 10.1). Future possibilities for computers in the management of asthma are vast and will continue to be linked to two parallel developments, that of new and more sophisticated computer-based systems and communication methods, and the continual evolution of best practice methods (pharmaceutical, technological, behavioral) in asthma management. Success will ultimately by measured when the innovative prototypic applications migrate from the "lab bench" to the broad clinic application. To facilitate this transfer of applications from the realm of scientific investigation to mainstream use will require stringency on the part of researchers, developers, and clinicians to attend to rigorous evaluations of their effectiveness and diffusion.

To date, the effectiveness of computer-based systems in improving asthma management is encouraging but not conclusive. Ongoing work is required. A review of primary care computing from 1980 to 1997 was aptly titled "a descriptive feast but an evaluative famine" (Mitchell and Sullivan 2001) and other authors noted the dominance of demonstration articles over comparison studies with few appearing in "core" medical journals (Adler and Johnson 2000).

In 1994, Johnson and colleagues noted that system assessment occurred primarily at earlier developmental phases, such as measuring reliability, accuracy, and acceptability and called for studies to progress from the lab to the clinical population in a systematic way (Johnston et al. 1994). A decade later, little has changed with respect to scientific validation of computer-based applications for asthma management. Sanders and Aronsky (2006) determined that only a handful of studies demonstrated "maturity," marked by influence (how routinely applications are used in patient care) and by rigor of study design (Sanders and Aronsky 2006). Prospective randomized clinical controlled trials were represented in only 16 publications and were limited mainly to primary care clinics with relatively few in emergency room care and hospital care (Sanders and Aronsky 2006). A relative dearth of efficacy and effectiveness studies of home-based computer applications has also been noted (Clark et al. 2009). Prospective informatics studies have been particularly lacking in the asthma domains of detection, diagnosis, and monitoring (Sanders and Aronsky 2006).

Claims for effectiveness of computer-based applications need to be assessed with the same rigor as any other therapeutic innovation. This will require study designs that can suggest causality such as randomized controlled trials. While clinical controlled trials continue to be the gold standard in evaluation of systems, Harris et al. (2006) point out that quasi-experimental designs, used extensively in the social sciences, could be more utilized in informatics evaluations. Unlike pharmaceutical trials, the use of computer-based systems preclude blinding the health-care provider to condition and clinical settings often preclude complete separation of intervention and control groups (Harris et al. 2006). Studies of patient outcomes bring the added burden of large numbers of participants and substantial budgets. These quasi-experimental designs are often more amenable for use in the constraints of health-care settings. Progress of research in this field will need to confront the challenges presented by a heterogeneity of study designs and varied measures of clinical outcomes if meaningful cross-study comparisons are to be made (Mattke et al. 2009).

While the current state of the literature appears somewhat top heavy with respect to design descriptions and feasibility studies, it is necessary that researchers not throw the "baby out with the bath water" and continue to publish design innovations and prototype testing. A criticism of existing literature, not confined to informatics, is that often critical information about programs is missing and there is wide variation in methods and content, meaning that replication is difficult and that most effective components are difficult to identify (Sudre et al. 1999). Researchers will also need to find a balance between reporting on innovative applications with the risk of fuelling the criticism that asthma intervention research is often underwhelming with results that report short-term knowledge change but not behavioral effects (Clark et al. 2009).

A consistent challenge with rapidly moving technology is that dissemination of programs outstrips their evaluation. A paradox exists where corporate or foundation collaborations produce programs that are disseminated but have limited empirical data to indicate their effectiveness. An example is the computer-assisted instruction program entitled "*Quest for the Code*"® (Starlight Foundation 2009) that comprises a game-like strategy, uses well known entertainers, and sophisticated multimedia interface. This program is one of a suite of programs available online through the Starlight Foundation, offering appeal and the potential for efficacious asthma education but having yet to be evaluated for effectiveness in the peer-reviewed literature.

The continued evolution of decision support systems raises a broader question as why such systems are not more ubiquitous in general medical practice. Reasons proffered for this include the labor and cost investments, lack of universal vocabularies to allow for integrated systems, need for more effectiveness trials, the legal and ethical issues related to medical decision-making, and the clinical viability of such systems (Staggers et al. 2001; Lehmann 2004; Johnston et al. 1994; Rosenstein 1999) (Table 10.2). For optimal dissemination, innovative decision-support systems should satisfy the principles of successful diffusion of innovation and demonstrate cost-effectiveness, usability, and clinical integration, all critical predictors of successful adoption (Rogers 1995); Helitzer et al. 2003; Dixon and Dixon 1994; Davis 1989).

For a computer-based application to be successfully disseminated, it must be considered to be effective in facilitating asthma care and reducing costs. There is a general lack of cost-effectiveness studies for computer-based applications for asthma management (Johnston et al. 1994; Wainright and Wootton 2003; Rosenstein 1999; Chang et al. 2003) despite cost-effectiveness being a fundamental antecedent to institutionalization. A recent systematic review of interactive computer-based asthma patient education programs indicated that none of the studies under review fully addressed the cost-benefit ratio of developing and implementing these computer programs (Bussey-Smith and Rossen 2007). This may be rectified as studies mature toward more trials of effectiveness and determine the gains from the direct and indirect improvements in cost, quality, and patient-focused outcomes.

Table 10.2 Challenges for developing and deploying computer-based systems in support of asthma management

(1) Strategic planning that links decisions about clinical strategy, care delivery process requirements, and investment in technology
(2) Developing standard and effective data models that describe clinical activities, data definitions, and approaches for data integrity
(3) Defining common practice standards (i.e., nomenclature, clinical vocabulary, and protocols)
(4) Addressing efficient, economic, and effective clinical practice processes before automation
(5) Investing in "people-ware" (i.e., clinicians and other user groups), particularly in education and training
(6) Collaborating, educating, and self-assessing for quality improvement in an unequivocally interdisciplinary way; rewarding creativity and innovations
(7) Exploring risk-sharing and partnership opportunities with vendors
(8) Refining cost-effectiveness approaches to support better long-term decisions

Adapted from (Mathews and Newell 1999; Adler and Johnson 2000; Staggers et al. 2001)

Computer-based applications in the clinic setting often present an irony. Systems can reduce medical errors, improve the use of treatment guidelines, reduce redundant testing, and enhance delivery of both physician and patient education at the point of care. These enhancements often come at a cost of the increased time taken in using the systems. Time management, ironically, is one of the reasons for instituting computer-based systems in the first place. Time constraints have been frequently cited in past studies as a critical barrier to adoption of clinic-based applications (Shiffman et al. 2000; Gadd et al. 1998; Cabana 2005). This presents integration and design challenges. Design criteria that make computer systems usable and time effective within the context of the often hectic clinic begins at the front-end of development with end-user input to guide development and include: (1) Obtaining the end-user's perspective, (2) Developing information appropriate in level and quality, (3) Connecting via wireless technology, (4) Maintaining security and privacy, (5) Justifying cost (Chang et al. 2003). Tangible strategies to mitigate time taken to use a DSS include thorough training, consistent system use, integration of DSS functions into existing EMR workflow and a design that organizes information, provides process and decision models, and suggest courses of action as seamlessly as possible. Computer-based applications can also provide allied health professionals with the opportunity for more input in collecting and providing information, relieving the time and task burden from the physician.

Asthma care is a multidisciplinary pursuit that requires coordination and communication between patients and health-care providers in home, outpatient, and acute care settings. This requires computer systems such as EMRs to be integrated across locations and the need to examine computer-based applications in varied settings (Sanders and Aronsky 2006). The outpatient clinic is the most common study setting. Relatively few studies have been conducted in inpatient settings. Studies of CAI, for example, have indicated that it is a strategy best used as a component of a multi-faceted approach, and not as a replacement to other educational and clinical management approaches (Revere and Dunbar 2001; Bartholomew et al. 2000a, b; McPherson et al. 2001; Fall et al. 1998).

In addition to the challenge of integration is the need to individualize asthma management plans and revise therapy based on patient response. Replicating static care guidelines into a computer system is an inadequate solution. Effective systems will need to track patient outcomes over time and be able to generate personalized care plans for both acute and chronic asthma care (Sanders and Aronsky 2006). Coupled with this is the need for application of behavioral theory to guide specification of program objectives, health behaviors, cognitive determinants of behavior (such as knowledge, attitudes, social perceptions, and self-efficacy), change methods, and evaluation and measurement protocols (Skinner and Kreuter 1997; Lieberman 1997; Rhodes et al. 1997; Revere and Dunbar 2001). Systematic approaches have been described that assist developers in the application of theory in computer-based applications and simulations (Bartholomew et al. 2001; Shegog et al. 2006a, b). Further, novel approaches to asthma management include the application of a computer-based decision-making paradigm for multiple risk behaviors such as cigarette, alcohol, and marijuana use that might exacerbate adolescent asthma management (Rhee et al. 2008).

It cannot be said that computer-based programs thus far created offer a blueprint for clinical practice because evaluation results have generally not been replicated and few studies have followed subjects longer than 1 year (Peterson et al. 2001; Klingelhofer and Gershwin 1988). Future evaluation challenges for computer-based applications for the management of asthma will include diffusion studies that examine the integration of computers into the clinical and management repertoires of health-care providers, effectiveness trials of alternative and emerging technological modalities such as the Internet, PDAs, iPods™, cellular phones (Lee et al. 2005); and economic analyses regarding the cost and time benefits of computer applications in clinic and hospital settings (Adler and Johnson 2000; Street and Rimal 1997). We have only begun to realize the benefits of computer-based applications for asthma management. If history is an indicator, then a future of exciting innovation is assured.

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