Biomedical Informatics Applications for Asthma Care: A Systematic Review

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Abstract  Asthma is a common condition associated with significant patient morbidity and health care costs. Although widely accepted evidence-based guidelines for asthma management exist, unnecessary variation in patient care remains. Application of biomedical informatics techniques is one potential way to improve care for asthmatic patients. We performed a systematic literature review to identify computerized applications for clinical asthma care. Studies were evaluated for their clinical domain, developmental stage and study design. Additionally, prospective trials were identified and analyzed for potential study biases, study effects, and clinical study characteristics. Sixty-four papers were selected for review. Publications described asthma detection or diagnosis (18 papers), asthma monitoring or prevention (13 papers), patient education (13 papers), and asthma guidelines or therapy (20 papers). The majority of publications described projects in early stages of development or with non-prospective study designs. Twenty-one prospective trials were identified, which evaluated both clinical and non-clinical impacts on patient care. Most studies took place in the outpatient clinic environment, with minimal study of the emergency department or inpatient settings. Few studies demonstrated evidence of computerized applications improving clinical outcomes. Further research is needed to prospectively evaluate the impact of using biomedical informatics to improve care of asthmatic patients.


Introduction  Asthma is one of the most common chronic medical conditions and affects an estimated 300 million people worldwide. In the United States, more than 20 million children and adults have asthma. It is responsible for significant patient morbidity and mortality, including an estimated 11.8 million lost work days for adults and 14.7 million lost school days for children in 2002, as well as 4,261 deaths per year. Medical care for asthmatic patients places a considerable burden on health care systems in the outpatient, emergency department, and inpatient settings. In 2002, asthma patients made 13.9 million office visits, came to emergency department 1.9 million times, and accounted for 484,000 hospitalizations. The US National Heart, Lung, and Blood Institute estimated the total cost of asthma care in 2002 to be $14 billion.

Although asthma is a common disease, great variation in the management of asthmatic patients exists and discrepancies between clinical practice and current therapeutic standards continue to occur. Published examples of suboptimal asthma management include under-estimation of disease severity by patients and high rates of persistent symptoms, under-treatment of symptoms by providers, low rates of outpatient follow-up after emergency room visitation and hospitalization for asthma, and low rates of preventive measures such as influenza immunization. As a result of practice variability, different organizations have developed practice guidelines for asthma care, including the widely accepted guideline created by the US National Heart, Lung, and Blood Institute through its National Asthma Education and Prevention Program. These guidelines were published as the first Expert Panel Report in 1991 with a second Report in 1997 and with revisions in 2002. The common goal of asthma guidelines is to provide an evidence-based and standardized approach to patient management. The US National Asthma Education and Prevention Program guidelines outline a multifactorial care plan that includes the use of objective measures for diagnosis and monitoring of therapy, the need for symptom prevention through environmental control measures, a comprehensive approach to medical therapy for the treatment and reversal of airway inflammation, and the need for patient involvement and education in asthma management. Studies of asthma management have validated these recommendations and shown improved outcomes when care is consistent with guidelines.

Despite the publication of these comprehensive guidelines, practitioner and patient compliance with guidelines has been low. Many barriers to guideline use and optimal management of asthmatic patients have been identified. Barriers include provider factors such as time pressure, limited knowledge of or belief in current best practice recommendations, administrative factors such as the inability to identify and track patient populations, and patient...
factors such as poor medication compliance and limited knowledge of effective disease self-management.\textsuperscript{16,19}

Computer applications for patient care are becoming increasingly common methods for addressing barriers to optimal medical care. They have been applied in a variety of clinical settings for the improvement of the process, delivery, and evaluation of medical care.\textsuperscript{20,21} Computer systems have been used to improve the use and adherence to practice guidelines, provide clinical alerts and reminders, and generate patient-specific treatment recommendations and educational material. Specific applications include electronic patient records and registries, computerized provider order entry systems, computer-assisted diagnostic systems, and computer-assisted education programs. Clinical computer systems have also been applied in a wide range of clinical settings, including outpatient, inpatient, acute care settings, and in patient homes. Also, their interventions have successfully targeted the full spectrum of involved personnel, including physicians, patients, nurses, and administrators.

Because of the multifaceted nature of asthma care and the development of comprehensive clinical care guidelines, asthma is a disease where computer-based applications may help to overcome the barriers to improving patient care. The goal of the systematic literature review was to characterize medical computing applications for asthma by examining the clinical domains and various aspects of patient care for which computer applications have been developed. We differentiated computerized asthma applications according to their level of development, implementation and evaluation, and examined the study designs applied for evaluating the applications’ impact on asthma care.

Methods

Selection Criteria

We targeted publications that described or evaluated a computer-based intervention or application to support clinical asthma care. Computer-augmented asthma care was defined broadly and included diagnosis or detection systems, applications for the prevention or monitoring of symptoms and outcomes, decision support tools for asthma treatment including electronic implementation of practice guidelines, and patient-centered education tools. We considered articles published in peer-reviewed journals, including review articles and surveys, and conference proceedings that described or evaluated such applications. Only articles in English with available online abstracts at the time of searching were included. Abstracts, poster presentations, and editorial publications were excluded, as were studies that did not involve patient care. Examples of excluded reports that applied informatics technologies not directly targeting clinical asthma care were studies that compared the efficacy of drug therapies, described the creation of a database, measured epidemiological statistics, or created a patient registry without applying the registry content for clinical care.

Search Strategy

We queried the following electronic publication databases from their start date through February 1, 2005:

- PUBMED\textsuperscript{®} (MEDLINE\textsuperscript{®}).\textsuperscript{22}
- OVID CINAHL\textsuperscript{®}.\textsuperscript{23}
- OVID CINAHL\textsuperscript{®}.\textsuperscript{24}
- PUBMED\textsuperscript{®} (MEDLINE\textsuperscript{®}).\textsuperscript{22}
- OVID Web of Knowledge\textsuperscript{®} - Web of Science\textsuperscript{®}.\textsuperscript{24}

Searches in PUBMED were performed using medical subject headings (MeSH\textsuperscript{®}) and keywords, while the other databases were only searched using keywords. Each search required the presence of the concept “asthma” in combination with any of the following terms: “medical informatics,” “decision support,” “informatics,” or “computer-assisted instruction.” Included MeSH terms were asthma, combined with medical informatics, decision support techniques, informatics, or computer-assisted instruction.

Review Criteria

For each reference, we obtained the title, abstract, authors, source, and date of publication. The two authors independently evaluated and classified the information of each reference as either relevant or not. Disagreements between the two reviewers were resolved by discussion until a consensus was reached. If the abstract did not include enough information to judge inclusion or exclusion, the full text of the publication, if available, was reviewed. If not available, the paper was excluded. The rates of positive and negative agreement were calculated prior to consensus discussion using each reviewer’s independent evaluation, and corrected for agreement by chance using Cohen’s kappa ($\kappa$).\textsuperscript{25}

Paper Evaluations

The full texts of all included publications were obtained and evaluated by one author (DLS). We developed a framework for categorizing and evaluating papers based on three primary criteria: 1) the clinical domain; 2) the development stage of the computer application; and 3) the study design.

Each paper was classified and assigned to one of the following four clinical domains, describing the area of patient care where the research was applied:

a) Asthma Detection or Diagnosis;
b) Disease Monitoring or Prevention;
c) Patient Education; or
d) Therapy (including guideline implementation) of acute or chronic asthma.

If a paper described multiple domains, the most emphasized aspect was chosen.

The development stage of a project is an evaluation of the level of maturity that the research has obtained. In contrast to other clinical research, biomedical informatics applications are often described while still in earlier developmental stages, and before clinical endpoints such as patient outcomes are evaluated. We used the “tower of achievement” model proposed by Friedman, which describes the various development phases of biomedical informatics applications.\textsuperscript{26} Each study was classified as being at one of the following, successive stages:

a) model formulation;
b) system development;
c) system installation; or
d) study of effects.
Model formulation refers to the creation of an idea for acquiring, representing, processing, displaying, or transmitting biomedical information or knowledge. System development is the actual creation of a computer-based system for clinical care, and is often a prototype or stand-alone system. System installation refers to the integration of a system into a clinical care environment and the study of how the system affects the surrounding workflow. Study of effects is the evaluation of the impact of a clinical computer system, both on patients and patient outcomes, as well as effects on the users and the overall impact on the organization and the delivery of health care. Each study was assigned a single level based on the highest level of development described.

We characterized the study design of each publication as one of the following types:

a) Survey;

b) Descriptive study (no intervention tested);

c) Retrospective analysis of an intervention; or

d) Prospective analysis of an intervention.

Additionally, the two authors independently assessed the design strength of each paper reporting a prospective study of a clinical intervention. The strength was evaluated using a study design evaluation instrument, published by Hunt et al.,21 that applies a 5-criteria scale to determine potential sources of biases. For each of the following criterion, a score of 0 to 2 was assigned based on the likelihood of avoiding study biases: 1) Method of subject allocation between the control and intervention groups (random, quasi-random, or selected controls); 2) Unit of allocation and analysis (by clinic, physician/provider, or patient); 3) Baseline differences between study groups (no baseline differences or appropriate statistical adjustments made for differences, baseline differences present and no statistical adjustments made, or unable to assess differences); 4) Type of outcome measure (objective outcome or subjective outcome with blinded assessment, subjective outcome without blinding but clearly defines and explicit criteria for each outcome, or subjective outcome without blinding of assessors and no explicit criteria for each outcome); and 5) Completeness of follow-up (>90%, 80–90%, or <80%). These scores were summed to give an overall evaluation score ranging from 0 (most potential study bias) to 10 (least potential study bias).

In addition, we assessed the allocation concealment of subjects (adequately concealed, inadequately concealed, and unclearly concealed), which is a measure for blinding investigators from knowing the next subject assignment and unclearly concealed), which is a measure for blinding investigators from knowing the next subject assignment and unclearly concealed), which is a measure for blinding investigators from knowing the next subject assignment and unclearly concealed), which is a measure for blinding investigators from knowing the next subject assignment.

Study characteristics for prospective trials were further examined by the clinic setting, the primary users, the target patient population, and the type of primary outcome measure. Clinical settings included: outpatient, inpatient, emergency department, patient home, multiple clinical settings, or no specified setting. The primary users of the systems included: clinicians, patients, administrators, or no users specified. The targeted asthmatic patient populations were: any patient age, only adults, only children, or unspecified. Finally, the primary outcome measure was a clinical, health-related measure (e.g., hospitalization or vaccination rates, asthma symptom reduction, or patient quality of life) or a non-clinical measure (e.g., patient knowledge or behavior, patient education, guideline adherence, or asthma trigger avoidance).

Results

We identified a total of 555 references from citation database queries (Figure 1), composed of 529 from PUBMED,22 10 from CINAHL,23 14 references from OVID EBM Reviews,23 and 2 references from ISI Web of Knowledge.24 These results represented 549 unique citations once duplicates were removed. From this set the two reviewers identified 64 relevant articles. The rate of reviewer agreement prior to consensus discussion between the two reviewers was 94.9% overall, and was 78.8% for included articles and 97.1% for excluded articles. The chance corrected agreement25 between the two reviewers was substantial ($\kappa = 0.76$; 95% confidence interval = 0.67–0.85).

Table 1 displays a summary of included articles.

Figure 2 shows the number of publications by time intervals. Publications increased in each successive time interval, with the majority of studies (54%) published in the last period (2000–2004). There were 28 studies (44%) published in clinical journals, 27 (42%) in biomedical informatics journals, five (8%) in epidemiological or medical quality journals, three (5%) in patient education journals, and one study appeared in a basic science environmental journal. The 64 included publications represented 51 unique projects; publications per project ranged from 1 to 3.

Clinical Domains

Eighteen papers (28%) from 17 projects involved computer-augmented asthma detection and diagnosis.28–45 These studies had three main areas of concentration: 1) Studies analyzing clinical data such as breath sounds, pulmonary function test results, or peak flow values to determine the presence or severity of asthma; 2) Studies using existing clinical and administrative data such as clinic notes, dis-
### Table 1: Included Publications. Ordered by Clinical Domain and Year of Publication.

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bDD: Detection or Diagnosis; MP: Monitoring or Prevention; PE: Patient Education; TG: Therapy or Guidelines
charge summaries, billing codes, or chief complaints to identify or classify asthmatics patients; and 3) Studies applying methods such as computer-based surveys or questionnaires to obtain information from patients in order to diagnose asthma or determine asthma severity.

The domain of computer-augmented asthma monitoring or prevention contained 13 papers (20%) describing 10 unique studies.46–58 These primarily described applications that allow patients to record their degree of symptom control, remind patients to use prescribed medications, or track the use of rescue medications. The type of implementation varied, including home-based tools such as web pages and patient-centered data collection tools that were designed for the ambulatory care setting such as the emergency department.

The domain of computer-augmented patient education contained 13 papers (20%) reporting on 9 unique studies.59–71 These studies all described computer based programs used by asthmatic patients. Examples of these applications include a computer game for children, a presentation of instructional multimedia clinical scenarios designed to improve recognition of asthma symptoms, a system to teach the avoidance of triggers such as dust mites, and a program to assess patients’ knowledge of proper therapy for asthma exacerbations.

The most common domain was the implementation or evaluation of a system to guide therapy or support clinical guidelines, accounting for 20 publications (31%), and 16 unique projects.72–91 Studies covered a wide variety of topics including computerized systems for determining optimal drug dosing regimens, implementation of computerized decision support systems for use in outpatient clinics, systems to critique care plans for asthmatics, and reminder systems to prompt clinicians to give vaccinations to eligible asthmatic patients.

Development Stages

Figure 3 shows the number of studies at each of the varying developmental stages, as described by Friedman.26 The majority of studies (63%) described projects that were in the model formulation or system development phase. The most basic stage, model formulation, accounted for 17 publications. These focused on the description of conceptual models and plans for future system implementation. Examples include a report detailing the design of a computer decision support tool for asthma management,83 an evaluation of the possible difficulties in translating published clinical guidelines into a computer-readable format,73 and a proposed design of a computer game to increase patient knowledge of asthma care.53 The next stage, system development, comprised the largest number of studies with 23 publications. These were primarily the reporting of results of small pilot, prototype, or feasibility studies. Examples include the remote monitoring of patients’ asthma symptoms,49 a system for collecting patient data in the emergency department waiting room,58 and a system to diagnose asthma from pulmonary function study results.28 Three studies were at the system installation stage. All 3 studies described the implementation of patient record systems for use in outpatient settings.46,78,81 The remaining 21 studies achieved the most advanced stage, the study of system effects. These studies evaluated the effects of computer applications on their users and on patient outcomes. Outcomes measured included the change in patient knowledge,61,62,68,70 rate of provider compliance with asthma care guidelines,85,87 the change in patient symptoms or hospitalizations, and the impact on clinic visit length and costs.84

Study Design

Figure 4 shows the number of reports for each study design category, and is subdivided by clinical domain. Of 29 studies that did not apply an intervention, 26 studies were descriptive and 3 reported results from surveys. The remaining 35 studies evaluated a hypothesis through an intervention, applying a retrospective or prospective study design. These were composed of 14 retrospective studies and 21 prospective studies including randomized and non-randomized controlled trials. Consideration of clinical domains revealed
that for detection and diagnosis projects, the majority (67%) were retrospective studies. Most studies involving asthma prevention or monitoring were descriptive in nature (8 of 13, 62%). Descriptive studies were also the most common study design for the therapy or guidelines domain, although 7 papers (35%) were prospective trials. For publications in the patient education domain, the most common study design was a prospective trial, accounting for 6 of 13 publications (46%).

**Prospective Trials**

Among the 64 studies we identified 21 prospective trials, summarized in Table 2. Of these, 8 were in the clinical domain of therapy or guidelines, three were in the monitoring or prevention domain, one trial involved asthma detection or diagnosis, and the remaining 9 studies were in the patient education domain. Results from the evaluation of the studies, following Hunt et al.,

![Table 2 - Results from 21 Prospective Trials, Ordered by Clinical Domain and Year of Publication](image_of_table)

CAI: Computer assisted instruction; CDSS: Computerized decision support system.

aDD: Detection or Diagnosis; MP: Monitoring or Prevention; PE: Patient Education; TG: Therapy or Guidelines.

bC: Clinical health related patient outcome; N: Non-health related outcome.

cRange = 0–10. From ref. (21).

dPresence or absence of a statistically significant improvement in the intervention group for the measured primary outcome.
studies (76%) randomized by patient. For baseline characteristics, fourteen studies (67%) made comparisons between study groups and corrected for any observed differences. Six studies (29%) did not report baseline comparisons between control and intervention populations, while the remaining study reported differences between study groups but did not make corrections. Another technique for minimizing bias is to use an objective outcome measure or to assess a subjective outcome in a blinded manner. This was done in 16 studies (77%), with the remaining 5 studies (23%) measuring subjective results without blinding. The final criterion was the completeness of study follow-up. The participant follow-up rate was >90% in most studies (17 of 21, 81%), 80-90% in one study, and less than 80% in three studies. None of the randomized controlled studies reported measures for subject allocation concealment and were classified as “unclearly concealed.”

Eighteen prospective studies (86%) were performed in an outpatient setting. Two studies occurred in the emergency department, both of which evaluated a computerized recommendation for aminophylline dosing. A single study was set in patients’ homes and studied the impact of a video-enabled internet application for improving asthma care. No studies examined in-hospital care of asthmatic patients. Consideration of the primary user group revealed that 14 (67%) applications were designed to be used by patients, and the remaining 7 by clinicians. The targeted asthma population included adult patients in 6 studies, pediatric patients in 10 studies, any age group in 3 studies, and was unspecified in the remaining 2 studies.

Among the 21 prospective trials, 13 measured a clinical and 8 a non-clinical outcome. Seven (54%) of the 13 studies with a clinical outcome reported a positive effect, while the remaining 6 found no statistically significant change. Improved clinical outcomes included decreased hospitalization rates, increased vaccination rates for asthmatic patients, and decreased need for rescue medication by patients. Among the eight studies assessing a non-clinical outcome, seven (88%) showed a statistically significant positive effect of the computerized intervention. The improvements included increased dust mite prevention measures, increased patient knowledge about asthma self-management, and improved adherence to guideline recommendations by clinicians.

Discussion

This systematic literature review explored the breadth and diversity of computer applications for asthma. Published studies in the field span four decades of research and the number of projects has been increasing over time. This reflects the rapid advance of computer technology and the application of biomedical informatics to patient care medicine. The many facets of care for asthmatic patients are well represented in the literature, including diagnostic, patient care, and educational applications. Overall, the covered topics were fairly evenly distributed, although the most common topic included applications that assisted with therapy and guideline implementation. Early studies commonly reported diagnostic and detection systems, often focusing on automated signal analysis techniques to diagnose asthma. More recently other types of applications have been empha-

Evidence-based care guidelines, such as those developed by the US National Heart, Lung, and Blood Institute, are widely accepted; however, their adoption level among providers remains suboptimal. Published standards of care present practical targets for measuring the quality of health care delivery and the success of systems designed to improve care can be evaluated against these goals. The development and dissemination of care guidelines alone is inadequate for solving the problem of unexplained variation in care. Barriers to guideline adoption and compliance include poor accessibility to the most recent recommendations, a perceived lack of time to follow recommendations, and a low perceived need to follow guidelines for common disorders. The application of biomedical informatics applications may represent a promising method for overcoming implementation barriers for asthma
care; we found, however, few studies that evaluated the impact of using computerized systems to implement asthma care guidelines. While great opportunity exists for future development, many challenges await. Comprehensive care for asthmatic patients is multidisciplinary and requires coordination and communication between patients and providers in the home, outpatient, and acute care settings. This will require a high degree of integration between computer systems such as electronic patient records across many locations. Additionally, there is a need to individualize asthma treatment plans and to revise therapy based on patient response. Simply replicating static care guidelines into a computer system will be an inadequate solution to provide the individualized and dynamic care needed by patients. 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.

**Conclusion**

Research applying biomedical informatics techniques to the care of asthmatic patients is increasing; however, more research is needed. As electronic tools for patient care such as computerized decision support systems and electronic medical records become increasingly mature and more widely adopted, we expect that additional opportunities to improve the care of asthmatic patients through informatics solutions will arise. Future system developers will implement and evaluate more advanced asthma care systems in clinical settings.

**References**


