DESIGN AND IMPLEMENTATION OF A COMPUTERIZED ASTHMA MANAGEMENT SYSTEM IN THE PEDIATRIC EMERGENCY DEPARTMENT

By

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LIST OF ABBREVIATIONS

CPOE .....Computerized Provider Order Entry

ED..... Emergency Department

EMR .....Electronic Medical Record

NHLBI .....National Heart Lung and Blood Institute

VUMC..... Vanderbilt University Medical Center

CHAPTER I

Introduction

Childhood asthma is a substantial burden on the healthcare system. Asthma is the most common chronic childhood disease affecting 9 million children (12.5%) under 18 years of age (1, 2). Asthma exacerbations account for an estimated 14 million missed school days (2) and more than 1.8 million emergency department (ED) visits annually (3). Approximately 4 million children experience an asthma exacerbation annually. Children in lower socio-economic status are 6 times more likely to have been diagnosed with asthma (4). Racial disparities exist with black children having a 3 times higher likelihood of hospitalization and a 4 times higher likelihood of death when compared to white children (5). The chronic characteristic of asthma carries a considerable economic burden. Asthma exacerbations leading to ED encounters and hospitalizations account for >60% of asthma-related costs (6). In the US asthma is the third leading cause for hospitalizations among patients <18 years of age (7). Uncontrolled asthma can lead to exacerbations requiring the patient to seek immediate care, frequently in an ED setting.

Asthma urgent care requires early identification of the condition and involvement of a team of providers. Evidence suggests that treatment should be started quickly and the patient's response to treatment must be evaluated repeatedly. Upon arrival, patients are given an initial asthma severity rating using either an asthma scoring metric (8), peak flow measurement, or oxygen saturation reading. The patient's asthma severity should be reevaluated every 1-2 hours. With each assessment care decisions should be adjusted to the new severity level ideally leading to a disposition decision within 4-6

hours. Standardized care is challenging to provide in a hectic, fast-paced environment like the ED. Several asthma guidelines exist to support clinicians in providing adequate treatment including the guideline from the National Heart Lung and Blood Institute (NHLBI) (9). The guidelines are general rules clinicians should follow for optimal care. Frequently institutions adapt and refine recommended pathways to local care practices.

Clinical guidelines and pathways have demonstrated positive effects on patient outcomes. In an effort to decrease variation, providers, payors, federal agencies, healthcare institutions, and patient organizations support the development, implementation, and application of clinical guidelines. In recent years the number of nationally endorsed and locally developed guidelines has grown considerably. Unfortunately considerable barriers remain that limit the implementation and integration of guidelines in the daily routine of practicing clinicians. In 1976, Clem McDonald noted the "non-perfectability of man" emphasizing the importance of continuously reminding busy clinicians about completing patient- or disease-specific tasks when providing care (12). Although researchers have examined the benefits of paper-based and computer-based guideline implementations, sustainable approaches in a clinical environment remain infrequent.

Utilization of and adherence to asthma guidelines improves patients' clinical care (10, 11). Despite the wide dissemination of guidelines and asthma scoring systems, practice variation continues to affect adversely the treatment decisions for asthma patients. The emergency management guidelines direct treatment through peak flow readings, forced expiratory volume, and oxygen saturation. However, an asthma flow diagram provides general principles and requires local customization to account for

individual ED variations including medications and scoring. The temporal and situational nature of ED care makes it more challenging to keep up with the patient's actual health status.

In the ED early identification and accurate assessment of the severity of airway obstruction and response to therapy are fundamental to the improvement of health for patients with asthma. The NHLBI guidelines emphasize early recognition and treatment of asthma exacerbations (9), as well as appropriate treatment stratified by severity. Early identification of patients presenting with an asthma exacerbation is often an issue, leading to delays. The most frequent approach to implement asthma guidelines in a clinical environment is paper-based. However, paper-based guidelines encounter several barriers that limit their effectiveness in supporting clinicians during the decision making process. Among studies that identified asthma patients few were intended for real-time identification and none were integrated with other information systems (15). One ED-based study implemented a computerized, kiosk-like application to obtain patient information from parents (13). In a prospective study (14) the kiosk-generated care recommendations were presented on paper to the clinicians caring for the patients. The study had only marginal effects on patient care, which was primarily due to physicians' nonuse of the provided, paper-based information.

The goal of this project was to design and implement a computerized disease detection and reminder system for asthma care in the pediatric ED and embed the system in the clinicians' workflow. The workflow-embedded approach includes the combination of two components:

1) an automatic, real-time, computerized disease detection system; and
2) a workflow-integrated, computerized guideline implementation.

The primary hypothesis is that clinicians in demanding clinical environments would benefit from automatic reminders to use clinical guidelines for eligible patients. The study will examine whether the approach will increase the utilization of and adherence to the asthma guidelines and impact surrogate markers of clinical outcomes. To examine the individual contributions of the disease detection system and the computerized guideline implementation, the study will examine two Null hypotheses:

1) The automatic, real-time, computerized disease detection component will not increase clinicians' use of paper-based guideline compared to paper-based guideline use without the detection component.
2) The combination of the disease detection component with the disease management component will not increase clinicians' use of the guideline compared to the disease detection component combined with the paper-based guideline.

The specific aims of the project were to:

Aim 1: Perform a systematic review of the biomedical literature for asthma care management.

Aim 2: Design a real-time, computerized asthma detection system and integrate the system with the ED information system.

Aim 3: Implement and evaluate the asthma detection system on reminding clinicians to use the paper-based asthma guideline.

Aim 4: Implement the asthma guideline in the ED information system infrastructure; and evaluate the effect of the asthma detection system combined with the computerized guideline versus the asthma detection system combined with the paper-based guideline to evaluate decreasing time to disposition decision.

Chapter II addresses aim one and describes previous asthma guideline implementations and their success rate through a systematic review of the literature. This chapter provides background focused on whether the implementation of asthma protocols improves care in the inpatient and outpatient setting. Chapter III addresses aim two and hypothesis one. This chapter describes the design of the computerized asthma management system. Chapter IV addresses aim three and hypothesis two, and describes the implementation and evaluation of the phase I study examining the effect of the automatic disease detection system with the paper-based guideline. Chapter V addresses aim four and looks at a prospective evaluation of the fully-computerized asthma management system. Chapter VI summarizes the implications of the research, limitations, and directions for future studies.

CHAPTER II

Literature review

Introduction

Asthma is the most common chronic childhood disease, affecting 9 million children (12.5%) under 18 years of age (1, 2) and carries a considerable economic burden. Approximately 4 million children experience an asthma exacerbation annually resulting in more than 1.8 million emergency department (ED) visits annually and an estimated 14 million missed school days (2, 3). In the US asthma is the third leading cause for hospitalizations among patients <18 years of age (16). Asthma exacerbations leading to ED encounters and hospitalizations account for >60% of asthma-related costs (6).

Clinical guidelines and pathways have demonstrated positive effects on patient outcomes (17, 18). To help decrease variation in treatment, providers, payors, federal agencies, healthcare institutions, and patient organizations support the development, implementation, and application of clinical guidelines. In recent years the number of nationally endorsed and locally developed guidelines has grown considerably. Unfortunately, considerable barriers remain that limit the implementation and integration of guidelines in the daily routine of practicing clinicians. Although researchers have examined the benefits of paper-based and computer-based guideline implementations, sustainable approaches in a clinical environment remain infrequent.

Utilization of and adherence to asthma guidelines improves patients' clinical care (10, 11). Several asthma guidelines exist to support clinicians in providing adequate treatment including the guideline from the National Heart Lung and Blood Institute (NHLBI) (9). The guidelines include general advice that clinicians should follow for optimal care. Despite the wide dissemination of guidelines and asthma scoring systems, practice variations continue to affect adversely the treatment decisions for asthma patients as implementing asthma guidelines in busy clinical settings remains a major challenge. The aim of our systematic literature review was to determine if the implementation of asthma protocols affects care.

Methods

We conducted a systematic literature review to identify articles that studied the impact of implementing paper-based and computerized asthma care protocols and guidelines in any clinical setting, including treatment protocols, clinical pathways, and guidelines. Studies were eligible for inclusion if they examined asthma protocol implementation for clinicians or patients.

Studies were excluded if they had non-human subjects, were studies on efficacy and effectiveness of drugs, did not include an evaluation component, had no intervention tested, studied a clinician or patient educational intervention only, or were a case report, survey, editorial, letter to the editor, and non-English language reports.

We searched the electronic literature databases PUBMED® (MEDLINE®) (19), OVID CINAHL® (20), ISI Web of Science™ (21), and EMBASE ® (20) from their respective inception to November 28, 2007. The search was limited to studies published in English. In MEDLINE, all search terms were defined as keywords and Medical Subject Headings (MeSH®) unless otherwise noted; in the remaining databases, the search terms were defined only as keywords. The search strategy was based on the concept "asthma" combined with concepts representing any kind of asthma protocol implementation. Search terms included: asthma and any combination of checklist/s, reminder systems, reminder, guideline, pathway/s, flow diagram, guidelines, guideline adherence, protocol/s, care map/s, computer/s, medical informatics, or informatics. The PubMed query is shown below:

> asthma AND (medical informatics OR computers OR computer OR informatics OR checklist OR checklists OR reminder systems OR reminder OR guideline OR pathway OR pathways OR "flow

diagram" OR guidelines OR guideline adherence OR protocol OR protocols OR "care map" OR "care maps")

The title and abstract of all articles identified using the keyword searches were retrieved and reviewed by two of three independent reviewers (JWD, KWC, DA). Disagreements between two reviewers were resolved by consensus among all three participating reviewers. The bibliographies of identified review articles were examined and additional relevant studies were included. All included studies were examined for redundancy (e.g., findings of one study reported in two different reports) and duplicate results were removed. The full text of included articles was obtained and two reviewers (JWD, DA) screened the articles independently for inclusion. Disagreements were resolved by consensus. A 10% data extraction sample was compared to assess inter-rater reliability.

To obtain a better understanding of implementation approaches, studies were further categorized as "paper-based," "computer-generated," or "computerized." (22)

a) Paper-based implementation approaches included the use of paper within the patient's chart in the form of stickers, tags, or sheets of paper and patients were identified manually by office staff.
b) Computer-generated implementations included the application of computerized algorithms to identify eligible patients, but the reminder or protocol was printed out and placed in the patient chart or given to the clinician during the visit.
c) Computerized reminders included prompts that were entirely electronic, i.e., computerized algorithms identified eligible patients, and prompts were provided upon access to the electronic clinical information system.

We looked at all included studies to determine similar characteristics associated with implementing guidelines, study design, and study scoring. We assessed study quality following the methodology of Wang et al. and graded the study design from level 1 to 5 (23). The study levels were adapted as follows:

1. Level 1 studies were primary prospective studies, case-control groups of consecutive or random patients.
2. Level 2 studies were similar to Level 1 but with a smaller sample size.
3. Level 3 studies were retrospective studies, non-random designs, or non-consecutive comparison groups.
4. Level 4 studies had a reference standard or convenience sample of patients who have the target illness.
5. Level 5 studies were comparisons of clinical findings with a reference or convenience of unknown or uncertain validity.

The effects of the implementation on the performance were graded based on Hunt et al. (24). The intervention effects on health care practitioner performed and patient outcomes were examined. Studies were classified to have no change, a decreased change, or an increased change (improvement in effect).

We assessed success factors following the methodology of Kawamoto et al. (25). The success factors for each study were determined from the article's text. If the success factors of the implementation could not be determined or were not present in the article, we contacted the authors. The success factors were designed from and are intended to be applied to clinical decision support systems. We applied the

factors to all three study types with the maximum number of applicable features at X for paper-based systems, X for computer-generated systems, and the full 22 for computerized systems. The success factors are listed in table 2.

Agreement among reviewers to consider articles based on title and abstract was high (0.972 to 0.996), as determined by Yule's Q (26). $Yule'sQ = \frac{OddsRatio - 1}{OddsRatio + 1}$

Results

The literature searches resulted in 18,804 abstracts during the search period (Figure 1). After excluding 9,716 duplicates 8,980 articles were further excluded based on a review of the title and abstract, leaving 108 articles for further consideration. We retrieved the full text of the 108 articles and added 13 articles for full-text review that were identified from the bibliographies of the 108 full text studies. From the 121 articles we excluded 39 studies not meeting inclusion criteria based on the full-text information.

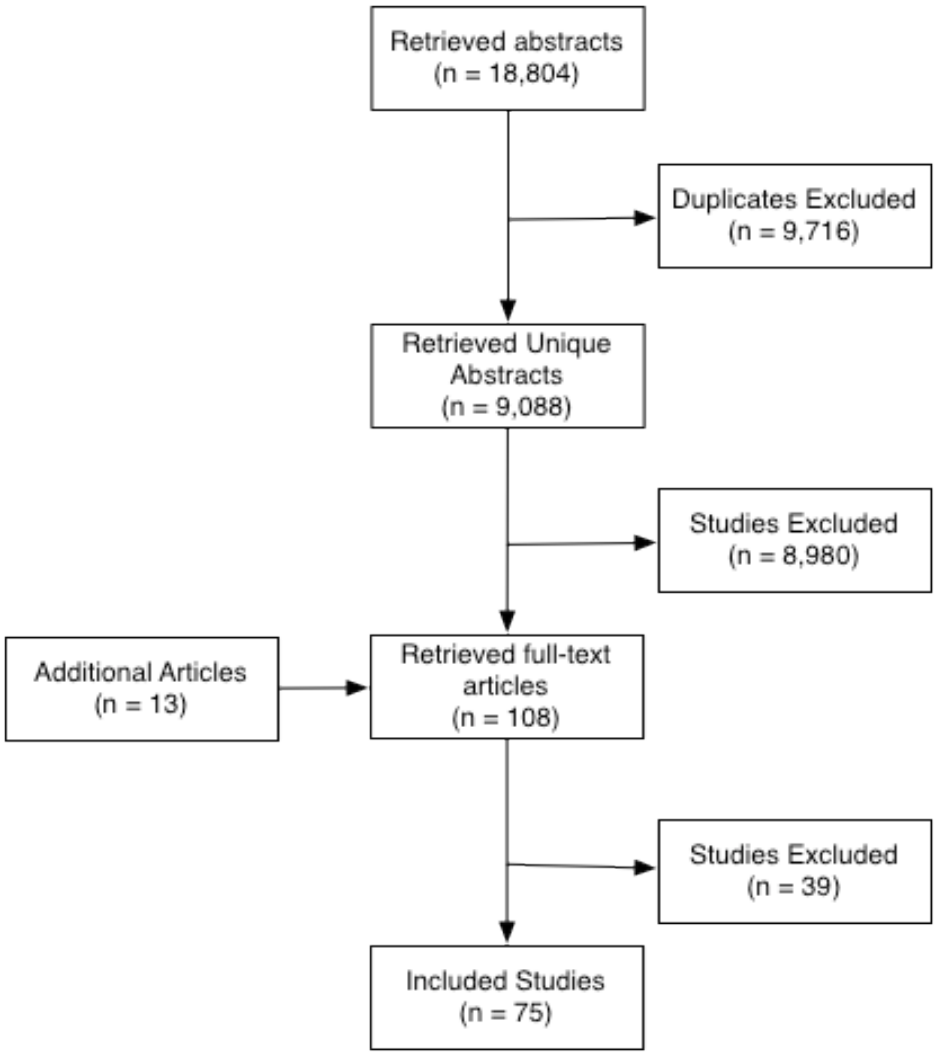


Figure 1: Article Flow.

Of the 39 articles excluded 2 looked at resource utilization, 10 looked at implementation/design/development/system description without an evaluation, 7 were drug trials, 1 was a review, 1 about asthma in general, 5 surveys, 1 education only, 1 simulation, 1 abstract only, 1 only provided data on the efficacy of guidelines (not an intervention), 4 no intervention, descriptive or protocol description, and 5 did not implement guidelines. We included 75 full-text articles for evaluation. For purposes of analysis we extracted data from 73 articles as 3 articles described the same intervention (27-29) and were only included once.

The study characteristics are shown in Table 1. The publication year of the studies is shown in Figure 2. Of the studies that reported a guideline 55 used site-specific guidelines, 42 used national guidelines, and 1 used another protocol. Thirty-one studies adapted a national guideline to be site-specific. Study periods ranged from 3 months to 96 months. Patient follow-up ranged from 10 days to 730 days. In 47 studies the physician was the clinician studied, nurses were studied in 19 studies, respiratory therapists in 7, and other clinicians in 3 studies. Of the studies that mentioned the clinician population, the range of participants was 8 to 270. Of studies that mentioned the total patient population size, the range of participants was 18 to 27,725.

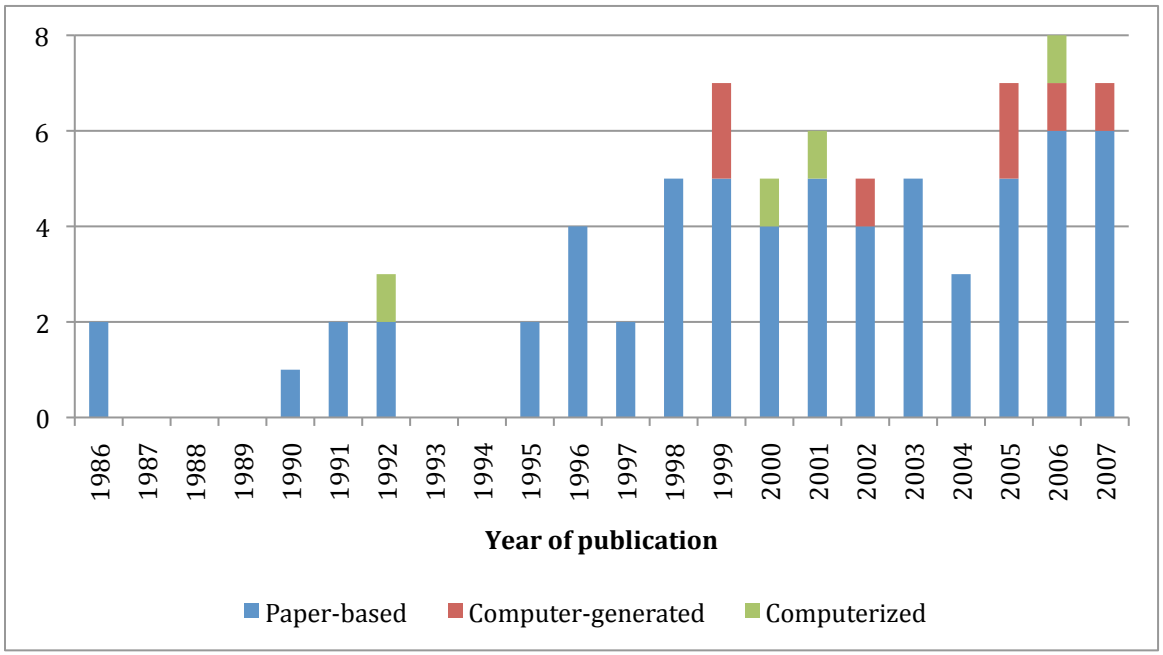


Figure 2: Number of publications by study year

Table 1: Demographics of included studies

Ref	Author	Year	Reminder type	Setting	Study Design	Randomized	Patient Population	Clinician Population	Setting	Center
30	Abisheganaden J	2001	Pa	Acad	Retro	0	Adult	MD	IN	Single
31	Abisheganaden J	1998	Pa	Other	Descrip	0	Adult	O	ED	Single
32	Ables A	2002	Pa	Acad	Pro	0	Adult	MD	OUT	Single
33	Akerman M	1999	Pa	nonAcad	Pro	0	Adult	MD	ED	Single
34	Alamoudi O	2002	Pa	Acad	Pro	0	Adult	MD	OUT	Single
35	Baddarm S	2006	Pa	Acad	Pro	0	Adult	MD	OUT	Multi
36	Bailey R	1998	Pa	Acad	Pro	0	Adult	MD	IN	Single
37	Baker R	2003	Pa	nonAcad	Pro	1	Adult	MD	OUT	Multi
38	Callahan C	2003	Pa	Acad	Pro	0	PED	MD	OUT	Single
39	Chan D	2007	CP	nonAcad	Pro	1	PED	O	OUT	Single
40	Chee C	1996	Pa	nonAcad	Retro	0	Adult	O	IN	Single
41	Chouaid C	2004	Pa	Acad	Retro	0	Adult	O	ED	Single
42	Cloutier M	2006	Pa	nonAcad	Retro	1	PED	MD	OUT	Multi
43	Cloutier M	2005	Pa	Acad	Retro	0	PED	MD	OUT	Multi
44	Colice G	2005	CG	Acad	Pro	0	Adult	RT	IN	Single
45	Dalcin P	2007	CG	Acad	Pro	0	Adult	O	ED	Single
27-29	Doherty S	2007	Pa	nonAcad	Retro	0	Adult	O	ED	Multi
46	Duke T	1991	Pa	Acad	Pro	0	PED	MD	ED	Single
47	Eccles M	2002	CG	nonAcad	Retro	1	Adult	MD	OUT	Multi
48	Emond S	1999	Pa	Acad	Retro	0	Adult	O	ED	Single
49	Feder G	1995	Pa	nonAcad	Pro	1	Adult	O	OUT	Multi
50	Gentile N	2003	Pa	Acad	Retro	0	Adult	MD	ED	Single
51	Gibson P	1996	Pa	nonAcad	Descrip	0	Adult	MD	IN	Single
52	Goldberg R	1998	Pa	Other	Pro	0	Adult	RN	OUT	Single
53	Guarnaccia S	2007	Pa	Acad	Descrip	0	PED	MD	OUT	Multi
54	Halterman JS	2006	Pa	Acad	Pro	1	PED	O	OUT	Multi
55	Heaney L	2003	Pa	nonAcad	Pro	0	Adult	MD	OUT	Multi
56	Jans M	2001	Pa	nonAcad	Descrip	0	PED	O	OUT	Multi
57	Jans MP	1998	Pa	nonAcad	Descrip	0	Adult	MD	OUT	Multi
58	Joe R	1992	Pa	Acad	Descrip	0	Adult	MD	ED	Single
59	Johnson K	2000	Pa	Acad	Pro	1	PED	RN	IN	Single
60	Kelly C	2000	Pa	Acad	Retro	1	PED	MD	IN	Single
17	Kuilboer M	2006	CP	nonAcad	Pro	1	Adult	MD	OUT	Multi
61	Kwan-Gett T	1997	Pa	Acad	Retro	0	PED	RN	IN	Single
62	Lehman HK	2006	Pa	nonAcad	Pro	0	PED	MD	OUT	Multi

63	Lesho E	2005	Pa	nonAcad	Pro	0	Adult	MD	OUT	Multi
64	Lierl M	1999	Pa	nonAcad	Pro	0	PED	RT	IN	Single
65	Lim T	2000	Pa	Acad	Pro	0	Adult	MD	IN	Single
66	Lukacs S	2002	Pa	Acad	Pro	0	PED	O	OUT	Multi
67	Mackey D	2007	Pa	Acad	Pro	0	Adult	MD	ED	Single
68	Martin E	2001	Pa	nonAcad	Retro	0	PED	MD	OUT	Multi
69	Massie J	2004	Pa	Acad	Descrip	0	PED	O	ED	Single
70	Mccowan C	2001	CP	nonAcad	Descrip	1	Adult	MD	OUT	Multi
71	McDowell K	1998	Pa	Acad	Pro	0	PED	MD	IN	Single
72	McFadden E	1995	Pa	Acad	Pro	0	Adult	MD	ED	Single
73	Mitchell E	2005	Pa	nonAcad	Pro	1	PED	MD	OUT	Multi
74	Newcomb P	2006	Pa	Acad	Pro	0	PED	RN	OUT	Single
75	Norton S	2007	Pa	Acad	Pro	0	PED	MD	ED	Single
76	Patel P	2004	Pa	nonAcad	Retro	0	Adult	MD	OUT	Multi
77	Porter S	2006	CG	Acad	Pro	0	PED	MD	ED	Single
78	Press S	1991	Pa	Acad	Pro	0	PED	O	ED	Single
79	Renzi P	2006	Pa	nonAcad	Pro	1	Adult	MD	OUT	Multi
80	Robinson S	1996	Pa	Acad	Pro	0	Adult	O	ED	Single
81	Ruoff G	2002	Pa	nonAcad	Retro	1	Adult	MD	OUT	Single
82	Schneider S	1986	Pa	Acad	Retro	0	Adult	MD	ED	Single
83	Shelledy D	2005	Pa	Acad	Pro	0	PED	RT	IN	Single
84	Sherman J	1997	Pa	Acad	Descrip	0	PED	MD	Other	Multi
85	Shiffman R	2000	CP	nonAcad	Pro	1	PED	MD	OUT	Multi
86	Stead L	1999	Pa	Acad	Retro	0	Adult	O	ED	Single
87	Stell I	1996	Pa	nonAcad	Retro	0	Adult	MD	ED	Single
88	Steurer-Stey C	2005	Pa	Acad	Pro	0	Adult	MD	ED	Single
89	Stormon M	1999	Pa	Acad	Pro	1	PED	O	IN	Single
90	Sucov A	2000	Pa	Acad	Pro	0	Adult	MD	ED	Single
91	Suh D	2001	Pa	Acad	Retro	0	Adult	MD	IN	Single
92	Szilagyi P	1992	CP	Acad	Pro	1	PED	MD	OUT	Single
93	Thomas K	1999	CG	Other	Descrip	1	PED	MD	Other	Single
94	Tierney W	2005	CG	Acad	Pro	1	Adult	O	OUT	Single
95	Town I	1990	Pa	Acad	Retro	0	Adult	MD	ED	Single
96	Wazeka A	2001	Pa	Acad	Retro	0	PED	O	IN	Single
97	Webb L	1992	Pa	Acad	Pro	0	PED	O	IN	Single
98	Welsh K	1999	CG	Acad	Retro	0	PED	MD	IN	Single
99	Wright J	2003	Pa	nonAcad	Pro	0	Adult	MD	OUT	Multi

Table 1 key: CG – computer generated, Pa – paper-based, CP – computerized. Acad –academic setting, nonAcad – non academic setting, Pro – prospective, Retro – retrospective, Descrip – Descriptive, PED – pediatric, O – other, MD – physician, RN – nurse, RT – respiratory therapist, IN inpatient, OUT – outpatient, ED – emergency department, Multi – multi-center trial

The most frequent study designs included a pre-post design (47 studies), followed by 41 studies that applied a prospective design, 20 population based case series, 20 consecutive case series, 10 randomized trials, 9 non-blinded trials, 8 nonconsecutive case series, 4 double-blinded trials, and 3 best-case series. Studies could be classified as having more than one design element. Most studies were performed at academic institutions (45) with 25 studies performed at non-academic institutions and 3 did not describe the setting. Studies looked at outpatients most frequently (35 studies), followed by the emergency department (28 studies) and inpatients (17 studies), with 4 studies looking at patients in other settings (e.g., the home). Some studies involve multiple settings. Most studies were performed in a single center (49) versus a multi-center environment (24).

Reminders consisted of paper-based (62 studies), computer generated (8 studies), fully computerized (5 studies), and other modalities (9 studies). The interventions were protocol-based (48 studies), treatment-based (34 studies), focused on the continuity of care (14 studies), scoring based (13 studies), and educational (9 studies). Thirty-five studies reported or described using an asthma scoring metric that was applied to guide treatment decisions. Fifty-seven studies listed some or all of the medications suggested for use in asthma management. Twenty-seven studies included clinician education and 21 studies included patient education (e.g., inhaler technique, asthma education and teaching). If the intervention method was described, 57 described measuring protocol adherence including chart review, severity scoring, checking orders, and the use of the physical protocol. Seven described work-flow interventions, and 1 looked at the timing of care during the patient's visit.

The effects of the intervention are shown in, Table 2. No study reported a decrease in health care practitioner performance or declining patient outcomes. 48 studies improved health care practitioner performance and 24 studies had no change in performance. 44 studies increased or improved patient outcomes and 29 resulted without affecting a change in outcomes.

Table 2: Intervention effects of included studies.

	No change	Decreased	Increased
Significant Effect on Health Care Practitioner Performance	24	0	48
Significant Effect on Patient Outcome	29	0	44

Study quality is shown in figure 3. Most studies (48%) were assessed as level 3 quality studies, i.e., retrospective studies, non-random designs, or non-consecutive comparison groups.

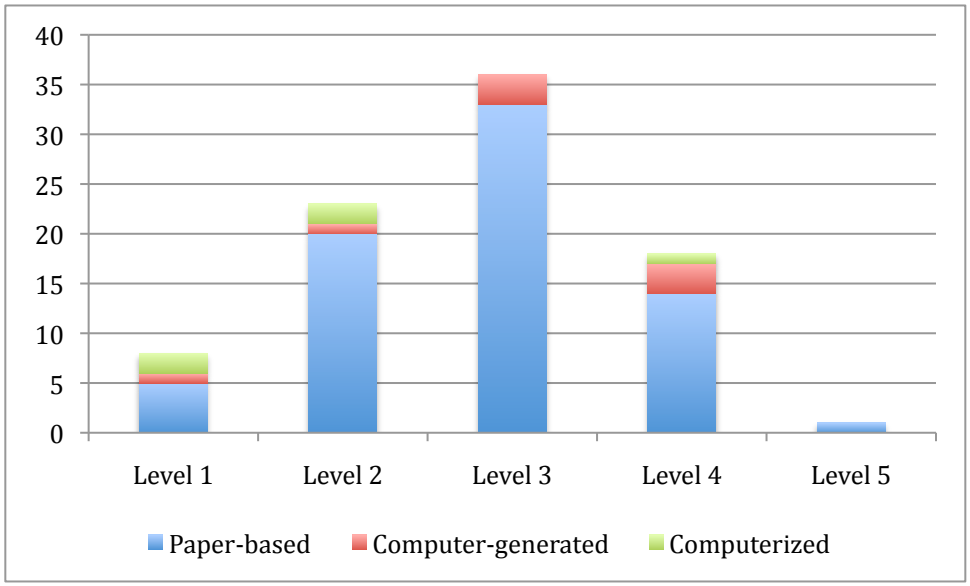


Figure 3: Study quality.

Among the 5 computerized studies, 3 studies with no change in the health care practitioner performance, 2 improved performance. There were 2 studies with no change in the patient outcomes and 3 studies that improved patient outcomes. Among the 8 computer-generated studies 4 resulted in no change in the health care practitioner performance, 4 improved performance. There were 5 studies with no change in the patient outcomes and 3 studies that improved patient outcomes. Paper-based studies had 18 studies with no change in the health care practitioner performance, 43 improved performance. There were 24 studies with no change in the patient outcomes and 38 studies that improved patient outcomes.

The success factors for each study are in Table 3. The number of success factors implemented ranged from 0 to 12, from a maximum of 22 possible. Computerized studies implemented an average of 5.6 success factors (range: 3 to 11). Computer-generated studies implemented an average of 5.7 success factors (range: 3 to 11). And paper-based studies implemented an average of 4.1 success factors (range: 0 to 12). The paper-based implementation was most often accompanied by convention education, the computer-generated implementations had clear and intuitive interfaces or prompts, and the computerized implementations provided recommendations and not just simple assessments.

Table 3: Success factors.

Success factors	Paper-based	Computer-generated	Computerized
Accompanied by conventional education	32	5	3
Clear and intuitive user interface with prominent display of advice	28	6	3
System developed through iterative refinement process	26	1	3
Local user involvement in development process	25	3	1
Active involvement of local opinion leaders	24	3	0
Assessments and recommendations are accurate	16	4	2
Saves clinicians time or requires minimal time to use	15	2	4
Provision of decision support results to patients as well as providers	13	3	2
No need for additional clinician data entry	12	2	2
Provision of recommendation, not just an assessment	11	2	5
Accompanied by periodic performance feedback	11	0	1
Integration with charting or order entry system to support workflow integration	10	3	2
Alignment of decision support objectives with organizational priorities and with the beliefs and financial interests of individual clinicians	8	1	0
Promotion of action rather than inaction	6	1	2
Justification of decision support via provision of reasoning	5	0	3
Automatic provision of decision support as part of clinician workflow	4	2	2
Justification of decision support via provision of research evidence	4	1	0
Use of a computer to generate the decision support	3	4	6
Provision of decision support at time and location of decision making	2	0	3
Recommendations executed by noting agreement	2	1	1
Request documentation of the reason for not following recommendations	1	1	0
System is fast	0	1	0

Discussion

Paper-based implementations are by far the most popular approach to implement a guideline or protocol. The number of publications on asthma protocol reminder systems is increasing. The number of computerized and computer-generated studies is also increasing. There appears an increasing trend towards use of information technology in guideline implementation. Pediatric and adult populations are studied equally. As a chronic condition outpatient studies were most frequent followed by ED-based studies and finally inpatient studies. Few studies reported randomization (18 studies) and a pre-post design was most common (47 studies). Seventy three percent of the studies had a level 3 or higher. The studies were designed optimally for the disparate locations, settings, and factors that needed to be considered.

No interventions reported decreasing the quality of clinician care or patient care. “No change” in care or an improvement in care or performance was reported in all published studies. This may be due to negative studies not being published.

The computerized studies had no change in clinician performance in 60% of the interventions; this may be due to the prompts not being integrated into the clinician’s workflow. The computerized studies were evenly split on improving patient outcomes and having no change on patient outcomes. The computer-generated studies were evenly split on having no change in practitioner performance and improving performance but had 62% of the studies report no change in patient outcomes. The paper-based studies had 69% reporting an improvement in clinician performance and a 61% improvement in the patient outcomes. There were more paper-based than computer-based studies, but paper can be an effective way to implement a protocol reminder. However, as hospitals increase their use of

computerized decision support and electronic medical records, it is likely that the efficacy of computer-based protocol implementations will also improve.

Many studies did not implement or report many success factors (25). These success factors were created for computerized decision support implementations so they may not be as valuable a scoring tool for the paper-based studies. We applied them to the paper-based and computer-generated studies as best as possible (e.g., a paper-based form with check boxes would have required minimal time to use compared to a paper-based form that required writing out entirely new orders by hand). The analysis is limited by what results were reported in the manuscripts. Although an attempt was made to contact the corresponding authors, some manuscripts were 20 years old or more and details about the exact intervention may have been lost. The outcomes varied from each study and were too disparate to combine. In conclusion, asthma guidelines generally improved patient care and practitioner performance regardless of the implementation method.

CHAPTER III

Study Design

Introduction

Asthma is the leading chronic childhood disease affecting 6.8 million children (9.4%) (1). Asthma exacerbations account for an estimated 14 million missed school days (3) and more than 1.8 million emergency department (ED) visits annually (3). Asthma disproportionately affects minority populations and adverse outcomes including ED visits are higher for black children (5). The chronic characteristic of asthma carries a considerable economic burden and accounts for >60% of asthma-related costs (10). Uncontrolled asthma can lead to exacerbations requiring the patient to seek immediate care, frequently in an ED setting.

Asthma care in the ED is complex, involving a temporal element of evaluation and reevaluation to adjust asthma medications and make disposition decisions. Standardized care is challenging to provide in a hectic, fast-paced environment like the ED. An implemented guideline can help provide this standardization. The overall goal of this study was to design and implement a computerized detection and reminder system for asthma care in the pediatric ED and embed it in the clinicians' workflow.

Background

Asthma Guidelines

Utilization of and adherence to asthma guidelines improves patients' clinical care (10, 11). Several asthma guidelines exist to support clinicians in providing adequate treatment including the guideline from the NHLBI (9). However, guideline adherence remains suboptimal. The NHLBI guidelines for asthma focus on the outpatient setting but include information about emergency management in the ED setting. The guidelines are general rules clinicians should follow for optimal care. The emergency management guidelines direct treatment through peak flow readings, forced expiratory volume, and oxygen saturation. However, the flow diagram provides general principals and requires local customization to account for individual ED variations including for medications and scoring. Peak flow measurements, for example, are not performed in all EDs or a different scoring metric may be applied.

Asthma treatment should be started quickly and its response evaluated repeatedly and adjusted to the new assessment level leading to a discharge decision within a few hours. The temporal nature of the guideline makes it more difficult to keep up with the patient's position on the flow diagram. A computerized approach could help alleviate some of these challenges.

Approaches for implementing guidelines: In the ED early identification and accurate assessment of the severity of airway obstruction and response to therapy are fundamental to the improvement of health for patients with asthma. The NHLBI guidelines emphasize early recognition and treatment of asthma exacerbations (9), as well as appropriate treatment stratified by severity. Identification of patients presenting with an asthma exacerbation is often an issue. Among studies that identified asthma patients few were intended for real-time identification and none were integrated with other information

systems. One ED-based study implemented a computerized, kiosk-like application to obtain patient information from parents (13). In a prospective study (14) the kiosk-generated care recommendations were presented on paper to the clinicians caring for the patients. The study had only marginal effects on patient care, which was primarily due to physicians' nonuse of the provided, paper-based information.

Challenges and opportunities for asthma care

When a patient presents with an asthma exacerbation in the pediatric ED, their care can take several hours. During this time, the care is driven by a team-oriented approach. Upon arrival, patients are given an initial asthma severity rating using either an asthma scoring metric (100), peak flow measurement, or oxygen saturation reading. Once treatment has begun, the patient's asthma severity should be reevaluated every 1-2 hours, but this is challenging in the ED which is fraught with delays. In the ED treatment decisions are made every 2-4 hours and the asthma medications are modified to best suit treatment. The goal is to reach a disposition decision within 4 hours.

Design Objectives

The design objectives were influenced by the team-oriented workflow of asthma care in the pediatric ED and local adaptation of the NHLBI guidelines. The design included the following steps: developing a conceptual framework, establishing guideline eligibility using a Bayesian network (BN) system (101,102), providing an electronic or paper-based flow diagram and protocol, and evaluating guideline adherence. In consideration of the workflow-embedded system, the ED management system had three main design objectives that we considered critical for a successful implementation.

Integration with clinical workflow

The approach should be embedded in the clinical workflow of the ED by making relevant patient information available when the health care provider is asked to make a decision. The system should avoid unnecessary interruptions of workflow. All data used are already collected during triage. The computer application queries the electronic medical record for any additional information including the patient's past history of asthma.

Integrated Design

The guideline management system should take full advantage of the ED information technology infrastructure, allowing for a fully computerized solution for each step in the process without prompting for additional information. In an integrated approach, the information systems should support the ED staff and facilitate following the guidelines with limited additional work required. This should provide the basis for a completely integrated, computer-based approach.

Information display and data capture

Information should be available at the right time, presented to the right individuals, and in the right format. Data entry and navigation should be minimal. Patients and providers should be able to easily opt out at any time during the process, if deemed appropriate.

Following the design objectives, a multidisciplinary team developed the system, including ED nurses, physicians, respiratory therapists, and leadership members from both the ED and the hospital.

The proposed study examines the benefits of a novel approach for reminding clinicians in an ED setting to use guideline-driven care. The overall approach will apply a workflow-embedded process taking advantage of an advanced information technology infrastructure. It will include two elements:

1) A diagnostic component consisting of a computerized, real-time reminder system, which will automatically detect guideline-eligible patients without requiring additional data entry, evaluated in phase I.

2) An asthma management component consisting of a computerized, workflow-embedded guideline implementation, evaluated in phase II.

The primary premise is that the combination of the reminder system with the guideline implementation will increase utilization and adherence of guideline-driven care, leading to improved patient outcomes. To examine separately the effects of the computerized reminder system and the computerized guideline on the utilization of and adherence to the guidelines the study will be conducted in two phases (Figure 4). The study includes two hypotheses:

1) An automatic, computerized reminder system for detecting asthma patients in the pediatric ED will increase paper-based guideline use compared to paper-based guideline without the system.

2) The creation of an integrated asthma management informatics system combining the reminder system with workflow-embedded guideline implementation will further increase guideline utilization compared to the reminder system combined with paper-based guideline delivery.

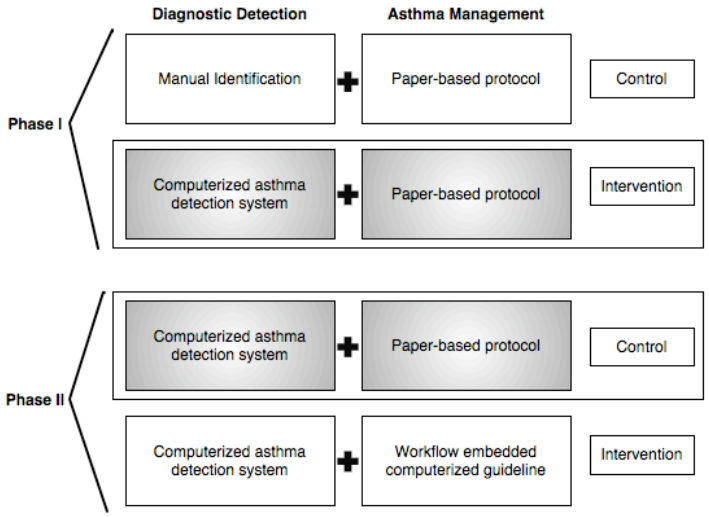


Figure 4: Study design for Phases I and II for asthma management system

The goals of the computerized asthma system are:

Phase I: Implement and evaluate a real-time, computerized asthma detection system in the ED information system.

Phase II: Implement the asthma guideline in the ED infrastructure and evaluate the effect of the detection system combined with the computerized guideline versus the asthma detection system combined with the paper-based guideline.

System Description

Setting

The Vanderbilt pediatric ED provides care for >40,000 patient visits annually. The ED has 48 physicians, 87 nurses, and 18 respiratory therapists. Approximately 10% of ED patients present with asthma exacerbations (101). A paper-based guideline including a validated asthma severity metric (8) is available for guiding asthma care including reassessment and treatment suggestions; however, the guideline is used in only 7-10% of the asthma cases presenting to the pediatric ED (101).

Informatics infrastructure

The ED information system infrastructure includes five information systems that were the basis for the computerized guideline system. The five information systems include the electronic medical record (EMR) (103), the computerized triage application (104), the computerized provider order entry system (CPOE) (105), the computerized whiteboard application (106), and the computerized respiratory therapy documentation system. The EMR and triage application provide the basis for the diagnostic detection system, phase I, and the CPOE system, whiteboard, and respiratory therapy system provide the basis for the computerized asthma management system, phase II.

Electronic Medical Record

Vanderbilt's longitudinal EMR includes patient information since 1994 (103). It represents the institution's primary repository for all patient information, including problem list, clinic notes, procedure notes, scanned documents, exam reports, and caregiver team communications.

Computerized Triage Application

The triage system (104) captures triage data in mostly coded format. In addition to capturing the usual triage information (current and past medical history, current medication, pain assessment, vital signs, acuity level, chief complaint, etc.), the triage nurse completes an initial screening for diseases, domestic violence, and cultural needs, and assigns the patient a coded chief complaint. After triage, an asthma probability is calculated using the BN diagnostic system. If the patient has findings compatible with asthma, a check-box appears on the triage exit page asking the nurse to acknowledge that there will be additional asthma documentation to print. When triage is completed, a patient summary page is displayed. The paper-based guideline will print automatically at the end of the summary page including the protocol and flow diagram.

Computerized Provider Order Entry System

Vanderbilt's CPOE system is used in all inpatient wards and the ED (105). Physicians enter more than 90% of all medication orders. The computerized asthma management system will trigger automatically using the computerized detection system. The system will be used to provide a summary page to clinicians including the patient's prior asthma scores, previous orders, and local guideline recommendations for order or discharge decisions.

Respiratory Therapy System

The respiratory therapy documentation system allows the respiratory therapists to document the asthma score (100) using a semi-structured format. The respiratory therapists can easily record the patient's asthma score as well as any notes about the patient's breathing or auscultations. The system is integrated with the EMR.

Computerized whiteboard system

The computerized whiteboard allows clinicians an overview of the ED's clinical and operational statistics (106). The whiteboard lists ED patients and relevant information about orders and labs. The whiteboard is a highly used reference for physicians accessing the patient's EMR or the CPOE system. Using the existing workflow element, the whiteboard will be used to provide an alert notification for asthma reassessment.

Applied Technology

The technology infrastructure used to connect the information systems for the application were Perl and Java programming languages, and Oracle® and MySQL® databases.

Research Design

Diagnostic Detection

Phase I addresses hypothesis 1. An existing asthma detection algorithm consisting of a BN (Figure 5) (101) has been integrated with the ED information system including the EMR and electronic triage application. The algorithm is used in real-time to determine based on the information available in triage, whether a patient has findings suggestive of an asthma exacerbation. At the end of the electronic triage, an exit screen suggests any immediate actions, reminders, or potential resources the patient may require. The effect of the detection algorithm on prompting clinicians to use the paper-based guideline is being evaluated in a currently ongoing randomized controlled trial. The control group will receive no electronic reminder. For the intervention group a prompt is displayed at the triage exit screen asking the nurse to acknowledge that she has seen the prompt and that the patient is eligible for the asthma guideline. Immediately following the triage summary page, the triage nurse prints the locally customized flow diagram and the ED's asthma protocol. The triage nurse can then easily attach the protocol to the chart. This allows the paper-based flow diagram to be available when it is needed. It also "tags" the patient as having asthma to help initiate treatment earlier.

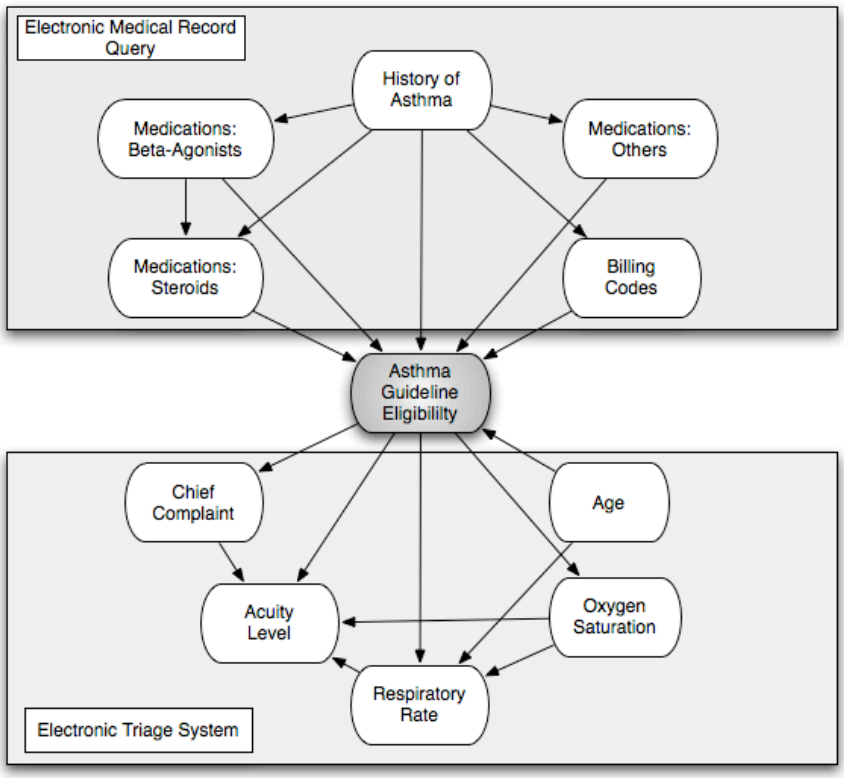


Figure 5: Bayesian Network used for determining asthma guideline eligibility.

Asthma Management

Phase II will address hypothesis 2. The asthma guideline component will be implemented and integrated with the different information systems available in the ED, including the CPOE system, the respiratory therapy system, and the ED whiteboard. Clinical workflow considerations will drive the implementation approaches and reminder methods. The effect of combining the asthma detection algorithm with the computerized guideline on guideline adherence and compliance will be examined in a second randomized clinical trial. The detection algorithm will prompt providers for all eligible patients. The control is equivalent to the intervention group in the previous study and includes the computerized asthma prompt for adding the paper-based guideline to the patient's chart. The intervention group will receive no triage prompt, but the prompt is passed on to the ED information systems, which will prompt the ED physicians to initiate the computerized guideline. In addition, the information systems will remind physicians about the repetitive assessments when they are due, which is expected to increase adherence. The computerized application will be available for use for all physicians, but will only be automatically triggered for patients in the intervention group.

Outcome measures

The outcome variables for both studies include the time to disposition decision, the frequency of guideline use and the adherence to guideline treatment recommendations. The staggered implementation will demonstrate the isolated effects of the detection system and the computerized guideline on changes in guideline compliance.

Status Report

The diagnostic asthma identification system was put into place in November 2008 to begin a comprehensive run-in period to test the informatics systems. We evaluated four weeks of data from 01/01/2009 to 01/31/2009. The pediatric ED saw 3,986 patients during the test period. Patient demographics are in table 4.

Table 4: Characteristics for patients in which an alert was triggered.

	Asthma (n=129)	Not Asthma (n=48)
Age, mean (standard deviation)	5.8 (3.9)	6.1 (4.6)
Admission	38%	21%
At least 1 asthma score	87%	33%
Respiratory Therapy Repeated Scoring	76%	33%

Patients were included in the analysis if they were between 2-18 years of age, had an ED diagnosis, and were not "fast-tracked." Fast track patients are moved quickly through the ED for care and do not get placed in the rooms for extended treatment. Patients were also excluded if they had an Emergency Severity Index of 1 (most severe) or did not undergo computerized triage documentation. The system identified 245 as asthma patients with 177 meeting inclusion criteria. A chart review of all the asthma patients identified 48 false positive and 129 true positive asthma cases. Patients were considered to have an asthma exacerbation if their primary or secondary diagnosis was "bronchiolitis," "status asthmaticus," "asthma exacerbation," or "reactive airway disease." Patients misclassified by the BN diagnostic system included respiratory complaints in 60% of the cases (Table 5).

Table 5: Diagnoses of patients misclassified by the Bayesian Network diagnostic system.

Diagnosis	(n=48)
Pneumonia	8
Upper Respiratory Infection	6
Fever	4
Cough	3
Respiratory Syncytial Virus	3
Croup	3
Tachypnea	2
Other	19

To help test the accuracy of the diagnostic detection system we queried asthma diagnosis codes (ICD9 493.*) for all patients with an ED visit during the study period. We compared the patients with at least one diagnosis code to those the diagnostic system identified. During the study period, there were 185 patients with an asthma diagnosis code. Of these, 102 were identified by our system. From the 83 patients missed 53 did not meet the inclusion criteria because of age, fast track, or had a comorbidity and unrelated asthma visit that was not ED related. The system missed 27 asthma exacerbations, and of these two patients had asthma as a secondary diagnosis. The system's real-time impact on ED asthma care is currently being examined in a randomized prospective interventional study.

Discussion

We described the design, development, and implementation of a team-oriented computerized asthma management system that used available information systems to create an informatics solution in a challenging environment. The system is embedded in the ED workflow. The detection system is currently being evaluated in a randomized prospective study. During the pre-implementation study period, the diagnostic system ran in an unobtrusive manner; the system was thoroughly evaluated and fully functional. The computerized asthma management system is currently being developed with the multidisciplinary ED team.

Limitations

The pediatric ED utilizes several information systems for patient care; this information system environment may not be typical for other EDs, limiting the generalizability of the findings. However, the project examines a new approach to increase guideline utilization and adherence, which may provide additional insights for potential approaches for delivering guideline-based care.

The system demonstrates that it is possible to leverage different information technology applications to create an integrated approach for an asthma reminder system. Having access to such an infrastructure allows the design of processes that may be easier to use, “simple,” and “do not stop clinicians,” but rather change a clinician’s direction (107). In addition, the user-driven development created a workflow-suitable approach that supported the acceptance among the busy ED clinicians.

CHAPTER IV

Phase I study

Introduction

Asthma is the leading chronic childhood disease affecting 6.8 million children (9.4%) (1). Asthma exacerbations account for >1.8 million emergency department (ED) visits annually (3). Asthma disproportionately affects minority populations and adverse outcomes, including ED visits, are higher for black children (5). The chronic characteristic of asthma carries a considerable economic burden and accounts for >60% of asthma-related costs (4). Uncontrolled asthma can lead to exacerbations requiring the patient to seek immediate care, frequently in an ED setting.

Treatment of an asthma exacerbation is complex, involving a temporal and multi-disciplinary element of evaluation and reevaluation to adjust asthma medications and make a disposition decision. It is challenging to provide standardized care in a fast-paced, interruption-driven and often overcrowded environment like the ED. An automatic, informatics-supported guideline delivery system could assist clinicians in delivering more homogeneous care for asthma patients. The goal of this study was to implement and evaluate a fully computerized asthma detection system combined with a paper-based asthma care protocol in the pediatric ED to help standardize care and reduce time to disposition decision.

Background

Guidelines

Early initiation of asthma guidelines and adherence to them improves patients' care (10, 11). The asthma guideline from the NHLBI (9) focuses on the outpatient environment but includes information on treating emergency exacerbations. The guidelines are general rules to follow for optimal care. The emergency management guidelines recommend treatment decisions be guided through peak flow readings, forced expiratory volume, and oxygen saturation. The NHLBI flow diagram provides general direction but requires local customization to account for individual ED variations including medications and asthma severity scoring. However, clinicians' adherence to guidelines remains suboptimal. Current guideline implementation approaches would benefit from an increased level of workflow integration, potentially through the application of information technology. Despite the benefits of computerized guideline implementation approaches, a major barrier exists in the daily clinic routine; clinicians need to remember to initiate the guideline process, either by retrieving paper-based guidelines or initiating the process in a computerized system.

Guideline Initiation

Guideline initiation is integral to beginning severity-adjusted treatments. The NHLBI guidelines (9) recommend that (a) asthma treatment is initiated quickly; (b) response to initial treatment is reevaluated in 1-2 hour intervals; and (c) treatments that are appropriate for the patient's severity level are readjusted within a specific time. Patient disposition decisions, e.g., whether a patient needs to be admitted to the hospital, should occur within a few hours of ED presentation. At triage an automatic reminder mechanism is implemented, which can start the evidence-based asthma protocol with nurse standing orders and mark the starting time for reevaluation intervals.

Identification of patients presenting with an asthma exacerbation is often delayed, leading to unnecessary suspension in starting treatments; furthermore, variations in timely reevaluation of a patient's treatment response can lead to further delays, followed by unduly long ED visits.

As early recognition of asthma is crucial, some studies (13, 108) have explored ways to identify asthma patients in the ED setting. One ED-based study implemented a computerized, kiosk-like application to obtain patient information from parents (13). Another used a Neural Network, but the data were from a mailed questionnaire and not the patient's visit (108). However, few were intended for real-time identification and none took advantage of an integrated information system infrastructure.

Motivation and Framework

An automatic asthma detection system could help prompt clinicians to initiate treatments earlier and remove the burden of guideline initiation from the triage nurse. Ideally the system would detect asthma patients during the triage process, which is most often the earliest time of a clinician interacting with a patient. The primary objective was that implementing a workflow-embedded, informatics-supported framework that includes automatic disease detection system combined with a locally adapted protocol based on the NHLBI guideline can decrease the time to disposition decision and improve overall care quality for asthma patients.

Methods

Setting

The Vanderbilt pediatric ED provides care for 55,000 patient visits annually. The ED has 68 attending and resident physicians, 95 nurses, and 16 respiratory therapists. Approximately 7-10% of pediatric ED patients present with an asthma exacerbation (101). For an extended time period prior to the study, an 8-page, paper-based guideline including a validated asthma severity metric (100) has been available for guiding asthma care including reassessment and treatment suggestions; however, the guideline was used in only 7-10% of asthma cases presenting to the pediatric ED (101).

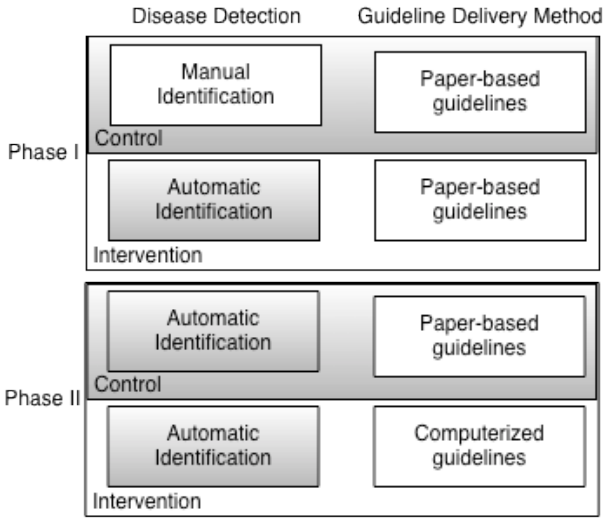


Figure 6: Two-phase study-design for evaluation of the computerized asthma management system.

Asthma system

The asthma system includes 2 components: 1) an automatic detection system, and 2) a disease management system. The two-phase study design (Figure 6) of the integrated asthma system has been reported previously (109). To examine the effects of the detection and management system, we

designed a two-phase evaluation allowing us to separately measure the effects of the automatic detection and the computerized management component.

The computerized disease detection system (101, 102) automatically screens all patients presenting to the pediatric ED for inclusion using a probabilistic algorithm (Bayesian network). The algorithm of detection system includes information from the electronic medical record for past medical history and medications, the billing system for previous asthma-related encounters, and the computerized triage application for details relating to the current visit. The detection system requires no additional data entry and operates in real-time. All patients presenting to the ED are screened for an asthma exacerbation and the Bayesian network threshold is used to distinguish between patients with and without asthma. The threshold can be adjusted and was set to reduce alert fatigue.

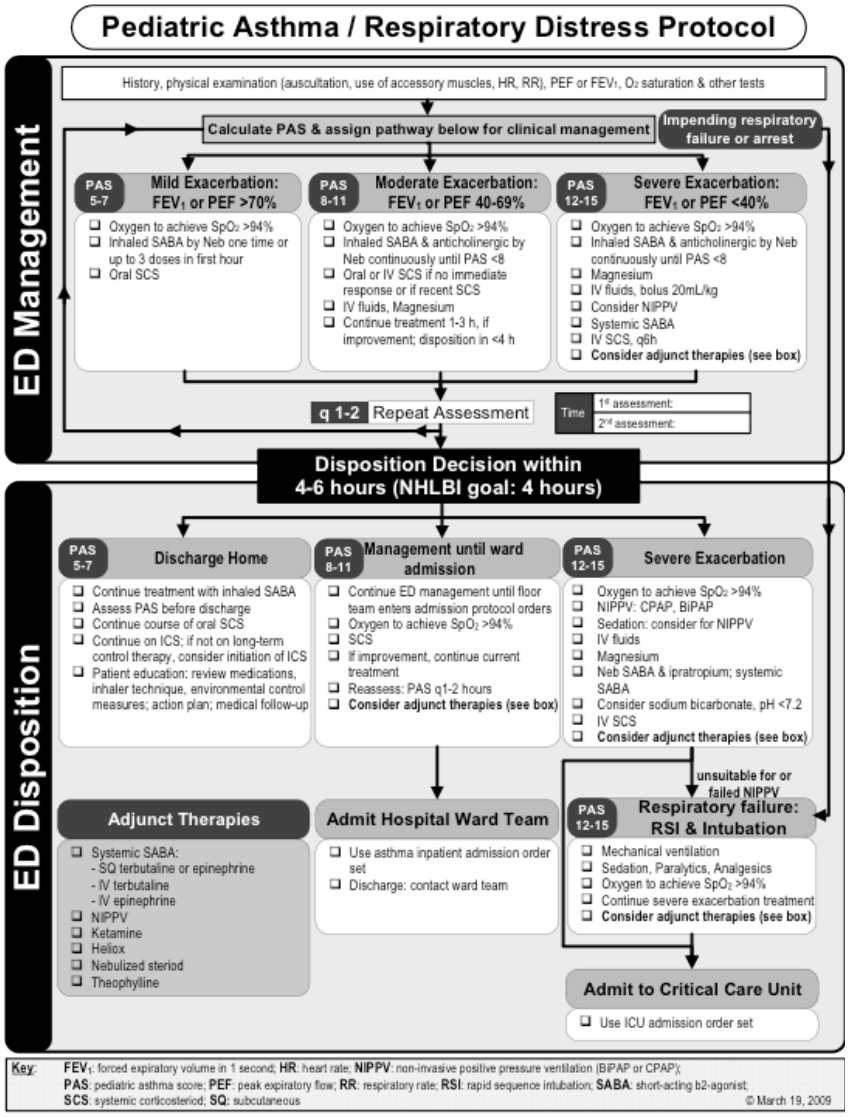


Figure 7: The locally-adapted flow sheet for emergency pediatric asthma care.

In the automatically detected patients the asthma protocol was automatically printed out and placed with the triage document in the patient's chart allowing the clinical team immediate access to the

asthma protocol at the bedside. The goal was to add asthma protocols consistently and automatically to the charts of patients who had an increased likelihood of an asthma exacerbation.

Study Design

We evaluated phase I in a prospective, randomized controlled trial. The study period was three months: July 1, 2009 – September 30, 2009, which included the H1N1 flu season. The unit of randomization was the patient with a 6-patient block randomization schema. All patients presenting to the pediatric ED during the study period were screened for inclusion using the Bayesian network system (101, 102, 109). Patients were included if they were 2-18 years of age and were identified as presenting with an asthma exacerbation by the disease detection system. Patients were randomized to either receive the paper-based guideline automatically printed and placed in their chart (intervention) or no automatic printing of records, the standard of care (control). Patients were excluded if they a) had an Emergency Severity Index = 1 (most severe, life-threatening condition), b) had no electronic triage, or c) eloped or left the ED prior to being seen by a physician. The study was approved by the institutional review board and registered on clinicaltrials.gov. A sample size of 286 patients per group was needed to detect a 10% difference with a β= 0.9 and α= 0.05.

Intervention

The pediatric ED clinical team identified optimization of asthma treatment as a high priority for quality improvement. A multidisciplinary respiratory distress committee including pediatric ED faculty and fellows, nursing staff, respiratory therapy, pharmacy, and informatics personnel iteratively developed and refined an evidence-based practice guideline, which was combined with an asthma care flow sheet. The flow sheet (Figure 7) is a best practice based adaptation of the NHLBI guidelines for acute asthma

care that also includes treatments not addressed in the national guidelines and is based on an asthma severity score. The flow sheet is a one-page, graphical algorithm which was the title page of the protocol and allowed for annotations. More detailed protocol information was available in an appended 8-page asthma protocol developed by the physicians and respiratory therapists to guide asthma care based on patient severity. The asthma protocol contains suggested drugs and dosing stratified by patient severity and includes rules and recommendations for intubation and mechanical ventilation. The asthma protocol encourages re-scoring the patient and after the additional evaluation offers disposition suggestions based on patient severity.

If the asthma detection system identified a patient presenting with signs and symptoms consistent with an asthma exacerbation (101, 102, 110), the patient was randomized to the intervention or control group. The intervention group received the flow diagram and protocol which printed automatically at the end of the triage session when the nurse printed the triage summary page. The electronic triage summary page displayed a reminder which required the nurse to acknowledge that the patient presented with symptoms compatible with an asthma exacerbation and that the protocol would print. The control group had standard care, i.e., no reminders or automatic printout was provided, while the paper-based protocol was available in the ED at triage and in the physician area.

In the two months prior to the study, a) physicians were informed about the study in the operational emergency management, faculty, and monthly resident meetings; b) an email from the ED director (division chair) describing and supporting the study was sent out to the ED staff; c) respiratory therapists were informed during their monthly management meetings; and d) for a week prior to the study the nursing leadership informed the nursing staff through the twice-daily meetings before the start of each

shift. At all of these meetings an investigator explained the study and answered any questions that arose. Posters with the one-page flow diagram were mounted as reminders in all of the triage locations and the physician work areas.

Data collection

Data on each visit were collected from the available ED information system including the electronic medical record (103), electronic triage application (104) and ED patient status board (106). A sensitivity of 85% was chosen for the Bayesian network to minimize alert fatigue but capture the maximum number of asthma patients. Based on historical data this resulted in the network having a specificity of 93.6%, positive predictive value of 65.3%, and negative predictive value of 98.7%9. To establish a reference standard for the diagnosis of an asthma exacerbation, a pediatric emergency medicine board-certified physician examined each patient visit within 3 days of the visit and determined whether asthma exacerbation was present. A pediatric ED charge nurse performed chart reviews on all patient visits. To ascertain data quality an independent pediatric emergency medicine board-certified physician reviewed and established a diagnosis for 20% of randomly selected patients' charts (k=0.89; 95% CI: 0.82, 0.95).

Outcome Measures

The primary outcome measure was the time from ED triage to disposition decision. A discharge or hospital admission order (bed request order) in the patient tracking board was considered a disposition decision. Secondary outcomes were guideline adherence measures such as asthma education ordered, protocol found on chart, any asthma scoring performed, and hospital admission rate.

Follow-up Survey

Patients: If patients were confirmed as presenting with an asthma exacerbation, a research associate contacted and consented the patient to perform a 14-item follow-up phone interview (see Appendix A). The follow-up survey addressed relapse rates, prior hospitalizations, and the impact asthma symptoms have on the patient's life. Attempts to contact the patients were made for 10 days or a maximum of 6 attempts. Patients with a primary language other than English were excluded from follow-up interviews.

Clinicians: After study completion, a one-page, 10-question follow-up survey (Appendix B) was administered to the respiratory therapists, nurses, and attending and resident physicians, and who worked shifts in the ED during the study period. The survey evaluated the use of the paper-based flow diagram and protocol during the study period.

Statistical Analysis

Primary analysis of this study focused on detecting the associations between the use of an electronic asthma management system (intervention) and time from ED triage to disposition decision, with comparison to the standard care system (control). Descriptive statistics, including means, standard deviations, and ranges for continuous variables such as time to disposition decision, length of stay, and age, as well as percentages and frequencies for categorical variables such as race, gender, insurance type, were provided to describe the study sample. Differences between group means for continuous variables were examined using ANOVA or Wilcoxon rank-sum test. Pearson chi-square tests were used to assess the categorical variables. All tests of significance were based on two-sided probabilities, at *P* values less than .05. Logistic regression was used to estimate the odds ratios (ORs) and their 95% confidence intervals (CIs) for patient's disposition status, representing the overall odds of being

admitted associated with the management system, and to adjust for potential confounding variables, including age, gender, race, insurance, language, acuity, and mode of arrival in the multivariate analysis. Kaplan-Meier curves were presented with log-rank test results to determine whether there were differences in the observed time to disposition decision as well as length of stay by management system. Cox proportional hazards models were used for time to decision and length of stay separately, to determine whether there is a significant difference in the outcome variables between the intervention and control, adjusting for the potential confounding variables. The adjusted p-values and the corresponding 95% confidence interval were reported for multivariate analyses. All data analyses were carried out using statistical software R (Version 2.12.2).

Results

Among all the 15,163 ED patients during the study period, 9,624 were within the eligible age range (2-18 years) and screened by the asthma detection system. The detection system (Bayesian Network) identified 1,100 patients having an asthma exacerbation. As determined by the reference standard, 704 had a final diagnosis of asthma, yielding a positive predictive value of 64%, 2 patients were excluded due to a registration error. Among the 394 determined not to present with asthma, 178 had a respiratory complaint, 75 had flu or flu-like symptoms, 31 had fever (101), and 110 had other complaints.

There were 54 repeat visits from 51 unique patients during the study period. The average number of days between visits was 25 (0, 79). Nine patients had repeat visits within 72 hours classified as a relapse. Of these, 5 were originally treated and released and treated and released in their second visit, 1 left against medical advice and returned to be admitted, and 3 patients were treated and released and returned to be admitted.

Table 6: Patient demographics.

	Intervention (n=358)	Control (n=346)	p-value
Age (median) (LQ, UQ)*	5 (3, 9)	5 (3, 8)	F1,702 = 1.84, P = 0.1752
Gender, female (%)	34	33	χ21 = 0.06, P = 0.8081
Acuity			χ23 = 4.14, P = 0.2461
2	43%	48%	
3	51%	44%	
4	6%	8%	
5	0%	0%	
Language English (%)	74	72	χ21 = 0.62, P = 0.4331
Race			χ2 = 1.65, P = 0.4391
Black (%)	52	57	
White (%)	37	33	
Other (%)	11	11	
Insurance			χ2 = 5.34, P = 0.0691
Tenncare (%)	55	60	
Private (%)	44	36	
Other (%)	2	3	
Arrival			χ2 = 1.24, P = 0.5391
Car (%)	79	82	
Ambulance (%)	20	17	
Unknown (%)	1	1	

* - LQ – lower quartile, UQ – upper quartile

From the 704 patients with a reference diagnosis of asthma 426 completed follow-up interviews (recall rate: 61%), 247 opted out or were not available, and 29 did not speak English as a primary language. Patients did not differ significantly in race (p=0.439, df=2) or mode of arrival (p=0.529, df=2). Patient demographics are shown in Table 6.

Intervention and control patients did not differ significantly in time to disposition; intervention patients had a median time of 289 minutes (SD: 259 minutes) and control patients a median time of 288 minutes (SD: 307 minutes; p = 0.212). Intervention patients had a median length of stay 331 minutes (SD: 517 minutes) and control of 331 minutes (SD: 565 minutes; p = 0.414). Admission rates were similar between the two groups (intervention=36.6%, control=34.4%, p=0.271). Primary findings are shown in table 7.

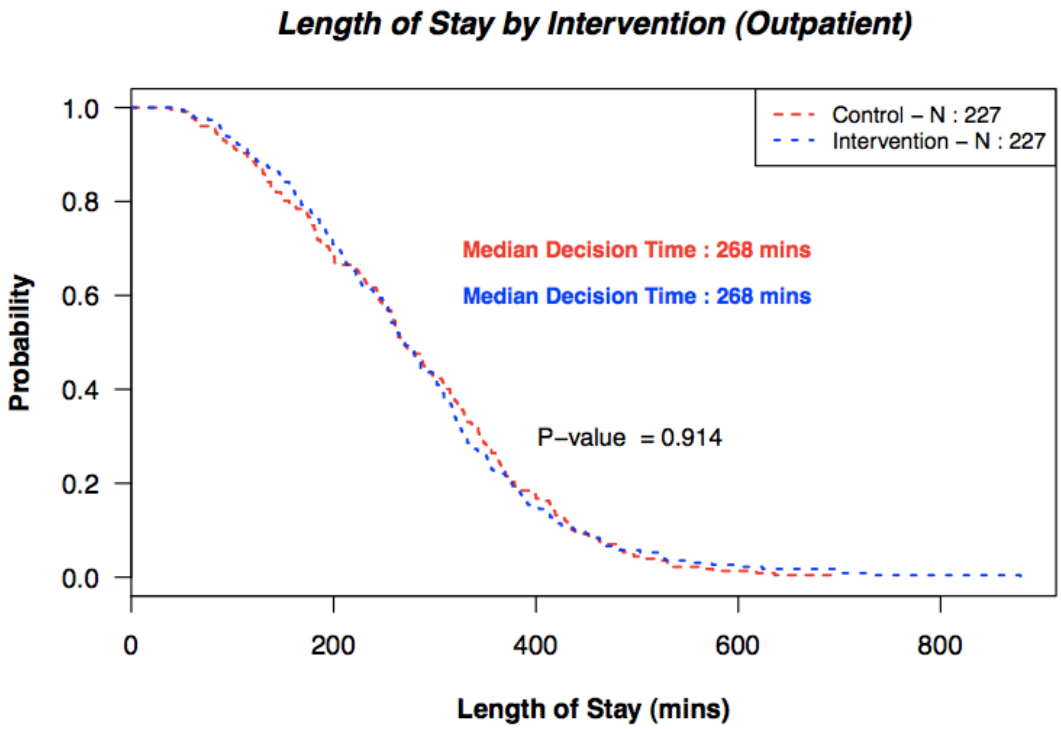


Figure 8: Time to inpatient disposition decision by intervention type.

The median time to disposition decision for inpatients was 348 minutes (figure 8) and the time to disposition decision for outpatients was 257 minutes (figure 9). The median length of stay for inpatients was 754 minutes and the median length of stay for outpatients was 268 minutes.

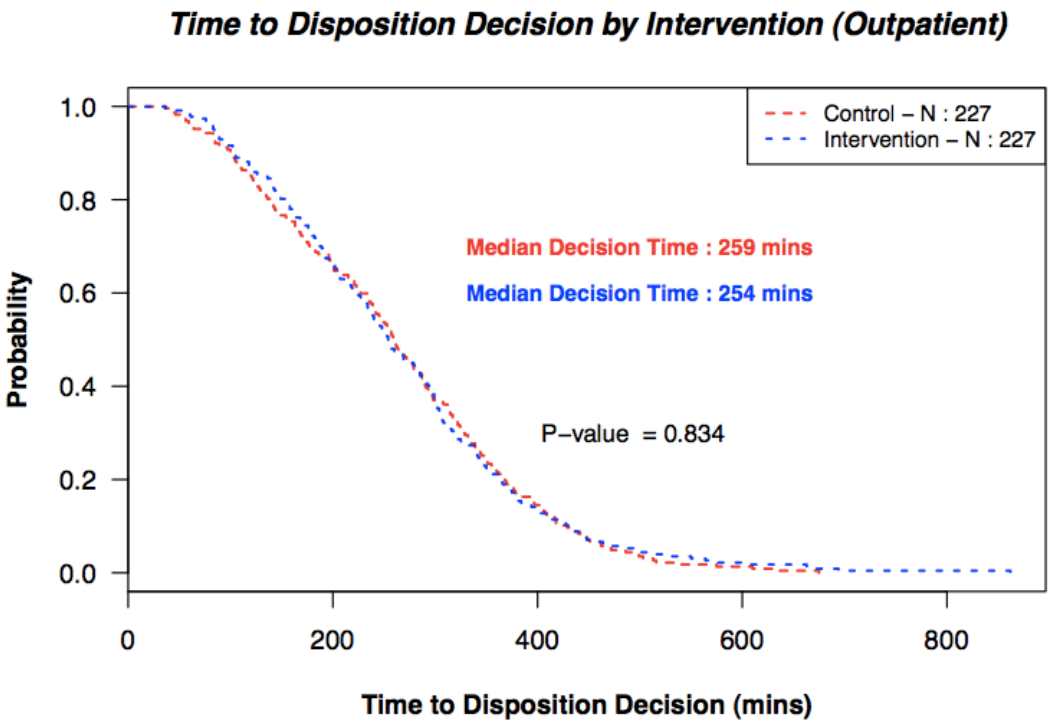


Figure 9: Time to outpatient disposition decision by intervention type.

Table 7: Primary findings.

	Intervention (n=358)	Control (n=346)	p-value
Disposition			x_1^2 = 0.37, P = 0.5451
Admit (%)	37	35	
Discharged Home (%)	63	65	
Time to disposition	288.5	288.0	
minutes (median) (LQ, UQ)	(184.0, 374.7)	(184.5, 374.7)	$F_{1,702}$ = 0.46, P = 0.4992
ED length of stay	331.0	331.0	
minutes (median) (LQ, UQ)	(225.5, 580.7)	(221.5, 515.7)	$F_{1,702}$ = 0.33, P = 0.5682
Asthma education charted (%)	92	93	x_1^2 = 0.21, P = 0.6441
Take-home asthma prescription charted (%)	84	87	x_1^2 = 1.44, P = 0.231
Follow up appointments scheduled (%)	6	7	x_1^2 = 0.07, P = 0.7851
Protocol in the chart (%)	18	1	x_1^2 = 57.52, P < 0.0011

* - LQ – lower quartile, UQ – upper quartile

Follow-up interview results are shown in Table 8; 26% of patients surveyed did not have an asthma diagnosis before their ED visit. In the previous three months, a third of the children (31%) missed school due to asthma complications and a quarter (24%) of parents reported missed workdays. Patients followed up were only statistically different in demographics compared to patients without follow up interviews with guideline placement (15% intervention had a guideline on the chart compared to 0% of the control $\chi 21 = 29.58$, $P < 0.01$).

Table 8: Results from patient follow-up interviews.

Question	Intervention (n=217)	Control (n=202)	p-value
Age (median, LQ, UQ), years	5 (3, 9)	6 (4, 9)	$F_{1,417} = 1.8$, $P = 0.181$
Gender, female (%)	31	36	$\chi^2_1 = 1.07$, $P = 0.32$
Improved per parent, yes (%)	56	52	$\chi^2_1 = 0.68$, $P = 0.4112$
Relapse to ED (%)	3	2	$\chi^2_1 = 0.63$, $P = 0.4262$
Steroid prescription filled since visit? (%)	48	50	$\chi^2_1 = 0.05$, $P = 0.8192$
Admitted to ED (%)	37	40	$\chi^2_1 = 0.29$, $P = 0.5872$
Have you ever been told your child has asthma? (%)	73	76	$\chi^2_1 = 0.34$, $P = 0.5622$
Has your child ever been hospitalized overnight for asthma? (%)	35	37	$\chi^2_1 = 0.06$, $P = 0.8062$
Have you taken your child to the ED for asthma before this visit? (%)	53	54	$\chi^2_1 = 0.04$, $P = 0.8432$
In the past three months have you missed any workdays because of your child's asthma? (%)	22	25	$\chi^2_1 = 0.57$, $P = 0.4512$
In the past three months has your child missed school because of asthma? (%)	28	35	$\chi^2_1 = 2.74$, $P = 0.0982$
Do you use a peak flow meter at home? (%)	16	27	$_1 = 7.25$, $P = 0.0072$

Response rates were (81%) for respiratory therapy, (99%) for nurses, and (75%) for physicians. Nurses who saw the protocol were not any more likely to use it than those who never reported seeing it

(p=0.094, df=3). Physicians who saw the protocol were more likely to use it (p<0.001, df=3). Clinician survey results are shown in table 9.

Table 9: Results from clinician surveys.

	Respiratory Therapist (n=13)	Nurse (n=94)	Physician (n=51)
Aware of study (%)	53.8	80.8	41.2
Saw protocol (%)	23.1	74.5	66.7
Used protocol (%)	30.8	39.4	29.4
Use an asthma score (%)	100	71.3	49.0

Discussion

This study examined the implementation of a computerized disease detection system compared to the standard of care and did not find a difference in time to disposition decision, hospital admission rate or ED length of stay between intervention and control patients. Combining the automatic detection system and printing of the paper-based protocol did not change clinician care for the patients as evidenced by similar length of stays and time to disposition decisions between both groups. Paper-based protocols were found in less than 10% of the intervention patients' charts, less than expected, though significantly greater than their presence in the control charts. Despite a high level support from all ED teams, substantial education effort, and automatic decision support, paper-based asthma protocol utilization remained at very low levels and may indicate that such multi-disciplinary protocols are difficult to implement in a busy emergency care environment that is driven by information-intense work patterns, multi-tasking, crowding, and frequent interruptions.

Patients who were identified by the system but did not present with an asthma exacerbation may have had a protocol in their chart; however, these patients were excluded from analysis. For patients in whom the protocol was identified in the chart, clinicians did not utilize the protocol for annotations (decision logic or severity assessment). Additional analysis on the patients' orders may illustrate a higher level of guideline-compliance through orders than scores alone. The time to disposition decision may be determined by the natural history of the illness; a failure to shorten this time may not be a direct result of the intervention. The low use of the paper-based protocol may bias the study towards the null hypothesis. However, the sample size analysis showed adequate power to detect a difference. In a similar prospective study (14) the kiosk-generated care recommendations were presented on paper to the clinicians treating the patients. The study had only marginal effects on patient care, which was

primarily due to physicians' non-use of the paper-based guideline. The measurements used to measure guideline compliance may not be the correct proxies or the actual guideline compliant care occurs whether or not the paper-based guideline was physically present.

The pediatric ED utilizes several information systems for patient care; this environment may not be typical, limiting the generalizability of the findings. However, the disease detection system uses only common data elements that other locations could easily obtain. Phase II will contain the disease detection system and a computer-based management system including the evidence-based order-sets will replace the paper-based protocol approach. It is expected that an integrated approach will alleviate some of the issues the paper-based protocol presented. The management system utilizing electronic and interval-driven reminders is currently being evaluated.

CHAPTER V

Phase II study

Introduction

Childhood asthma is a significant burden on the healthcare system. Asthma is a common chronic childhood disease affecting 9 million children (12.5%) (1, 2). Approximately 4 million children experience an asthma exacerbation annually leading to more than 1.8 million emergency department (ED) visits (3). The chronic characteristic of asthma carries a considerable economic burden and exacerbations account for an estimated 14 million missed school days annually (2). Asthma exacerbations leading to ED encounters and hospitalizations account for more than 60% of asthma-related costs (6). In the US asthma is the third leading cause for hospitalizations among patients <18 years of age (7). Uncontrolled asthma can lead to exacerbations requiring the patient to seek immediate care, frequently in an ED setting.

Treating asthma exacerbations is complex; it involves a temporal and multi-disciplinary evaluation element including reevaluation to adjust asthma medications and make disposition decisions. It is challenging to provide standardized multi-faceted care in a fast-paced, interruption-driven and often overcrowded environment like the ED. An automatic, informatics-supported management system could assist clinicians in delivering more homogeneous care for asthmatics. The goal of this study was to implement and evaluate a fully computerized asthma management system in the pediatric ED to help standardize care and reduce time to disposition decision.

Background

Clinical guidelines and pathways have demonstrated positive effects on patient outcomes (111). In an effort to decrease variation, providers, payors, federal agencies, healthcare institutions, and patient organizations support the development, implementation, and application of clinical guidelines. Recently the number of nationally endorsed and locally developed guidelines has grown considerably. Unfortunately considerable barriers remain that limit the implementation and integration of guidelines in the daily routine of practicing clinicians. In 1976, Clem McDonald noted the "non-perfectability of man" emphasizing the importance of continuously reminding busy clinicians about completing patient-specific or disease-specific tasks when providing care (12). Researchers have examined the benefits of paper-based and computer-based guideline implementations, but sustainable computerized approaches in a clinical environment remain infrequent.

Adherence to asthma guidelines can improve patients' care (4, 5). The asthma guideline from the NHLBI (9) focuses mainly on the outpatient environment but includes information on care for emergency exacerbations. The NHLBI flow diagram provides general direction including guiding care through a severity assessment such as peak flow readings and forced expiratory volume, but requires local customization. The temporal and disseminated nature of ED care makes it more challenging to keep up with the patient's actual health status.

When patients present with an asthma exacerbation in the pediatric ED, their treatment may take several hours. The care is complex and involves several different clinicians including nurses, respiratory therapists, and physicians. Upon arrival, patients are given an initial asthma severity rating using either an asthma scoring metric (8) or peak flow measurement. The patient's asthma severity and response to

treatment should be reevaluated every 1-2 hours. With each assessment, treatment decisions should be adjusted to the new severity level ideally leading to a disposition decision within 4-6 hours. Utilization of and adherence to asthma guidelines improves patients' clinical care (10, 11). Despite the wide dissemination of guidelines and asthma scoring systems, practice variation continues to affect adversely the treatment decisions for asthma patients.

Guideline implementation approaches benefit from an increased level of workflow integration, potentially through the application of information technology. Early guideline initiation is integral to beginning severity-adjusted treatments promptly. The NHLBI guidelines emphasize early recognition and treatment of asthma exacerbations (9), as well as appropriate treatment stratified by severity. The most frequent approach to implement asthma guidelines in a clinical environment is still paper-based (112), but computerized implementations have been shown to improved care (85).

Automating disease detection can help prompt clinicians to initiate treatments earlier and remove the burden of guideline initiation from the triage nurse. Computerizing the asthma guideline may remove some of the guideline work flow barriers and aid in use of and adherence to the asthma guideline. The goal of this project was to design and implement a computerized disease detection and reminder system for asthma care in the pediatric ED and embed the system in the clinicians' workflow.

METHODS

Setting

The Vanderbilt pediatric ED provides care for 55,000 patient visits annually. The ED has 68 attending and resident physicians, 95 nurses, and 16 respiratory therapists. Approximately 7-10% of pediatric ED patients present with an asthma exacerbation (101). For an extended time period prior to the study, an 8-page, paper-based guideline including a validated asthma severity metric (113) has been available for guiding asthma care including reassessment and treatment suggestions; however, the guideline was used in only 7-10% of asthma cases presenting to the pediatric ED (101).

Asthma system

The asthma system includes 2 components: 1) an automatic disease detection system (101), and 2) a computerized management system. The two-phase study design (Figure 10) of the integrated asthma system has been reported previously (114). To examine the effects of the detection and management system, we designed a two-phase evaluation allowing us to measure separately the effects of the automatic detection and the computerized management component.

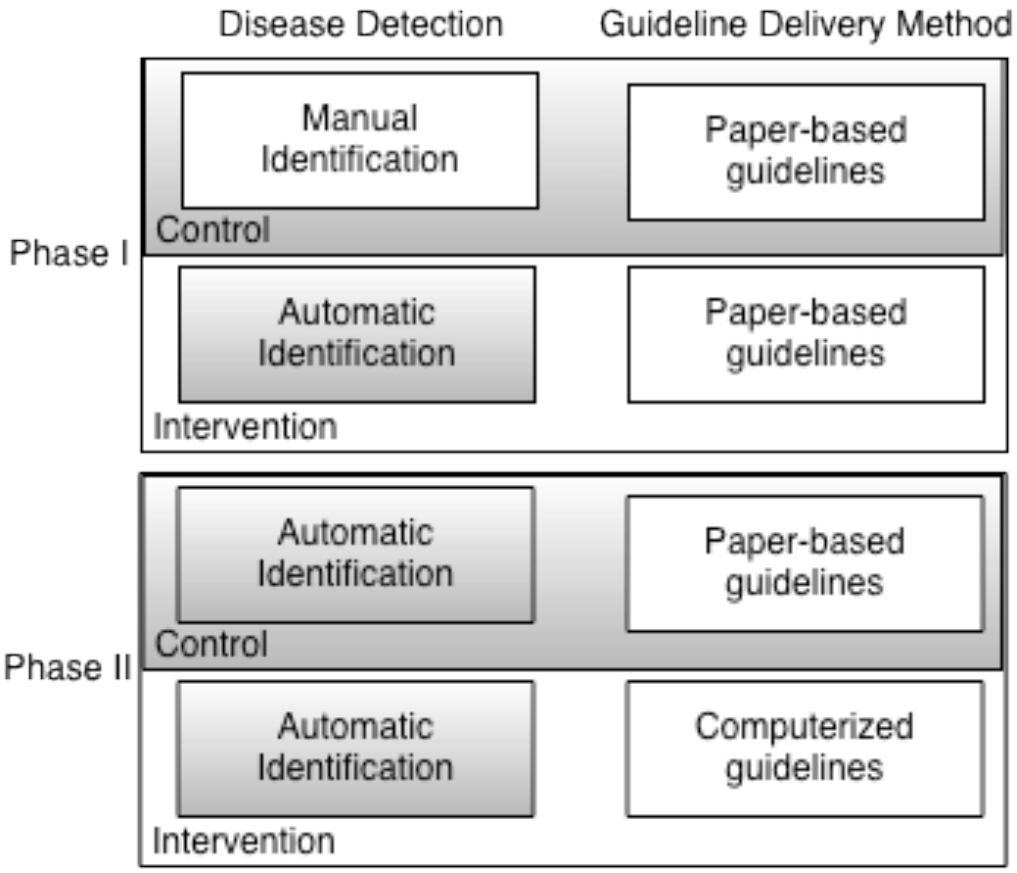


Figure 10: Two phase study design

This study describes the second phase of a two-phase study. The computerized disease detection system (101, 102) automatically screens all patients presenting to the pediatric ED for inclusion using a probabilistic algorithm (Bayesian network). The detection system's algorithm includes information from the electronic medical record for past medical history and medications, the billing system for previous asthma-related encounters, and the computerized triage application for details relating to the current visit. The detection system requires no additional data entry and operates in real-time. All patients presenting to the ED are screened for an asthma exacerbation and the Bayesian network threshold is used to distinguish between patients with and without asthma. The threshold can be adjusted and was set to reduce alert fatigue.

In the automatically detected patients the computerized management system alerts were turned on or the paper-based asthma protocol was automatically printed out and placed with the triage document in the patient's chart. A multidisciplinary respiratory distress committee created guideline-adapted severity-based order-sets. After the automatic disease detection system identifies patients, scoring reminders and the order-sets will be displayed to help maintain guideline compliance.

Study Design

We evaluated phase II in a prospective, randomized controlled trial. The study period was five months: October 1, 2010 – February 28, 2011, with 3 weeks of excluded patients. The unit of randomization was the patient, with a 6-patient block randomization schema. All patients presenting to the pediatric ED during the study period were screened for inclusion using the Bayesian network system (101, 114, 102). Patients were included if they were 2-18 years of age and were identified as presenting with an asthma exacerbation by the disease detection system. Patients were excluded if they a) had an Emergency Severity Index = 1 (most severe, life-threatening condition), b) had no electronic triage, or c) eloped or left the ED prior to being seen by a physician. The study was approved by the Institutional Review Board and registered on clinicaltrials.gov. A sample size of 313 patients per group was needed to detect a 10% difference with a β= 0.8 and α= 0.05.

Intervention

The pediatric ED clinical team identified optimization of asthma treatment as a high priority for quality improvement. A multidisciplinary respiratory distress committee including pediatric ED faculty and fellows, nursing staff, respiratory therapy, pharmacy, and informatics personnel iteratively developed and refined an evidence-based practice guideline, which was combined with an asthma care flow sheet and severity-based order sets. The flow sheet and paper-based guideline has been described previously

(phase 1). The paper-based guideline is a local adaptation of the NHLBI guidelines for the emergency treatment of asthma exacerbations. The severity-based order sets for use in the CPOE system were created using the paper-based guideline and the NHLBI guidelines. The two sets were combined to create 3 severity-based order sets (mild, moderate, and severe asthma). The computerized order sets were available as both a text-based order set that physicians can access independent of the intervention (e.g., for patients in the control group), and as an integrated, automatic prompt after the physician had scored the patient (for intervention patients).

If the asthma detection system identified a patient presenting with signs and symptoms consistent with an asthma exacerbation (101, 102, 110), at the time of triage, the patient was electronically randomized to the intervention or control group. The control group had the paper-based flow diagram and protocol which printed automatically at the end of the triage session when the nurse printed the triage summary page. The electronic triage summary page displayed a reminder which required the nurse to acknowledge that the patient presented with symptoms compatible with an asthma exacerbation and that the protocol would print. The intervention group was enrolled in the computerized management system. The electronic triage summary page required the nurse to perform an initial asthma score on the patient. When this score was complete, a page was sent to respiratory therapy containing the patient's information and asthma score and the reminders were turned on in the electronic whiteboard and CPOE systems.

The electronic whiteboard (106) acted as a communication point among all clinicians. A new column was added for displaying the asthma scores and related information. Each time a respiratory distress score was recorded electronically, the whiteboard column was updated with the new score and a trend arrow. The trend arrow looked only at the last two scores and displayed whether based on the severity score

the patient was worsening (an up arrow), improving (a down arrow), or remaining stable (an equal sign). The column displayed the latest asthma score for all of the care team to see. By mousing-over the column, a trend graph of the patient's asthma severity scores was displayed (figure 11). This graph was updated each time a new score was recorded. The electronic whiteboard also provided prompts for when a patient was due for reassessment.

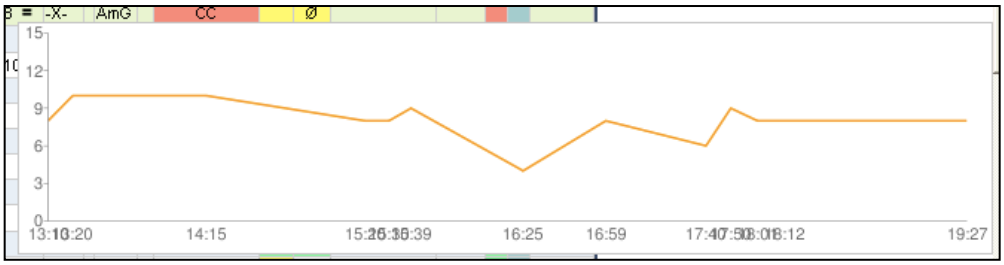


Figure 11: Asthma trend graph on the electronic whiteboard

The electronic whiteboard prompts were passive reminders for the respiratory therapist and treating physician. The respiratory therapists were given a new column to sign in for a patient. In this new column, the respiratory therapists would assign themselves to the patient so they could track the patient's movement in the ED and other clinicians could see who was the treating respiratory therapist. Respiratory therapy scoring was required hourly per protocol. If a patient was identified to be in the study, the background of this column would turn yellow when a new respiratory distress score was due within 15 minutes. The background of the column would turn red when a new respiratory distress score was due or past-due. Entering a new score into the respiratory therapy charting system would clear the column and restart the timer.

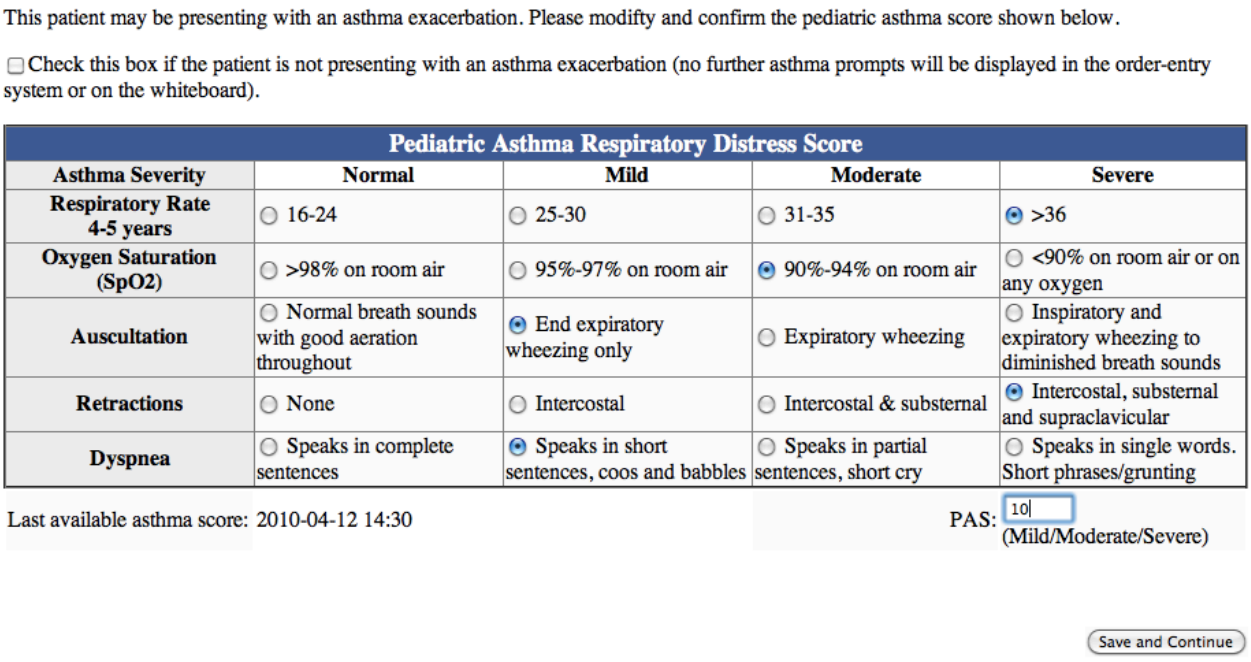
The electronic whiteboard prompts also provided passive reminders for the physicians. Physicians were

required to reassess and rescore their patients every 2 hours. If an assessment and score were due within 15 minutes, the background of the column was yellow. If an assessment was due or past due, the background of the column turned red. If the patient met the criteria for making a disposition decision, the column would flash dark blue. When the physician clicked on the column, a pop-up box would inform them that it was time to make a disposition decision on the patients. The physicians could defer this decision for 2 hours. When a discharge or bed request was entered for the patient, the column turned green indicating that a disposition decision had been made and the patient's care in the ED had reached stabilization for either admission or discharge.

When the physician opened the CPOE (105) session on an intervention patient, a pop-up required asthma scoring for the patient (figure 12). This pop-up displayed the asthma scoring matrix along with the most recent asthma score recorded and the respective time. The physician had the option of clicking a "this is not an asthma patient" button to turn off all asthma-related prompts. If the physician did not turn off the prompts and the patient was presenting with an asthma exacerbation, the physician carried through with scoring. Based upon this score, a severity-based order set was provided to the clinician. The order sets aggregated orders for mild, moderate, or severe asthma exacerbations. Each had pre-selected items that the pediatric ED recommended for asthma care. By selecting boxes, the physicians could order the asthma treatments. Once ordering was complete, a summary page was displayed to display the new orders, continuing orders, and discontinued orders. All prompts remained turned-on through the patient's stay in the ED regardless of disposition decision unless turned off in the CPOE system.

In the two months prior to the study a considerable educational effort was completed: a) physicians were informed about the study in two monthly operational emergency management meetings, faculty,

and monthly resident meetings; b) an email from the ED director (division chair) describing and supporting the study was sent out to the ED staff; c) respiratory therapists were informed during their monthly management meetings; and d) for a week prior to the study the nursing leadership informed the nursing staff through the twice-daily meetings before the start of each shift. At all of these meetings an investigator explained the study and answered any questions.



This patient may be presenting with an asthma exacerbation. Please modifty and confirm the pediatric asthma score shown below.

☐ Check this box if the patient is not presenting with an asthma exacerbation (no further asthma prompts will be displayed in the order-entry system or on the whiteboard).

Pediatric Asthma Respiratory Distress Score				
Asthma Severity	**Normal**	**Mild**	**Moderate**	**Severe**
Respiratory Rate 4-5 years	○ 16-24	○ 25-30	○ 31-35	◉ >36
Oxygen Saturation (SpO2)	○ >98% on room air	○ 95%-97% on room air	◉ 90%-94% on room air	○ <90% on room air or on any oxygen
Auscultation	○ Normal breath sounds with good aeration throughout	◉ End expiratory wheezing only	○ Expiratory wheezing	○ Inspiratory and expiratory wheezing to diminished breath sounds
Retractions	○ None	○ Intercostal	○ Intercostal & substernal	◉ Intercostal, substernal and supraclavicular
Dyspnea	○ Speaks in complete sentences	◉ Speaks in short sentences, coos and babbles	○ Speaks in partial sentences, short cry	○ Speaks in single words. Short phrases/grunting

Last available asthma score: 2010-04-12 14:30 PAS: 10 (Mild/Moderate/Severe)

Save and Continue

Figure 12: The scoring matrix in the computerized provided order entry system.

Data collection

Visit data were collected from the available ED information system including the electronic medical record (103), electronic triage application (104) and ED patient status board (105). A sensitivity of 85% was chosen for the Bayesian network to capture the maximum number of asthma patients and to limit the risk of alert fatigue. Based on historical data this resulted in the network having a specificity of 93.6%, positive predictive value of 65.3%, and negative predictive value of 98.7% (9). To establish a

reference standard for the diagnosis of an asthma exacerbation, a pediatric emergency medicine board-certified physician examined each patient visit within 7 days of the visit and determined whether asthma exacerbation was present. A pediatric ED charge nurse performed chart reviews on all patient visits. To ascertain data quality an independent pediatric emergency medicine board-certified physician established a diagnosis for 20% of randomly selected patients' charts (k=0.8837; 95% CI: 0.817, 0.9504).

Outcome Measures

The primary outcome measure was the time from ED triage to disposition decision. A discharge or hospital admission order (bed request order) in the patient tracking board was considered a disposition decision. Secondary outcomes were guideline adherence measures such as asthma education ordered, protocol found on chart, any asthma scoring performed, and hospital admission rate.

Follow-up Survey

Patients: If patients were confirmed as presenting with an asthma exacerbation, a research associate contacted and consented the patient to perform a 14-item follow-up phone interview. The follow-up survey addressed relapse rates, prior hospitalizations, and the impact asthma symptoms have on the patient's life. Attempts to contact the patients were made for 10 days or a maximum of 6 attempts. Patients with a primary language other than English were excluded from follow-up interviews.

Clinicians: After study completion a one-page, 10-question follow-up survey was administered to the respiratory therapists, nurses, and attending and resident physicians, and who worked shifts in the ED during the study period. The survey evaluated the use of the paper-based flow diagram and protocol during the study period.

Statistical Analysis

Primary analysis of this study focused on detecting the associations between the use of an electronic asthma management system (intervention) and time from ED triage to disposition decision, with comparison to the standard care system (control). Descriptive statistics, including means, standard deviations, and ranges for continuous variables such as time to disposition decision, length of stay, and age, as well as percentages and frequencies for categorical variables such as race, gender, insurance type, were provided to describe the study sample. Differences between group means for continuous variables were examined using ANOVA or Wilcoxon rank-sum test. Pearson chi-square tests were used to assess the categorical variables. All tests of significance were based on two-sided probabilities, at *P* values less than .05. Logistic regression was used to estimate the odds ratios (ORs) and their 95% confidence intervals (CIs) for patient's disposition status, representing the overall odds of being admitted associated with the management system, and to adjust for potential confounding variables, including age, gender, race, insurance, language, acuity, and mode of arrival in the multivariate analysis. Kaplan-Meier curves were presented with log-rank test results to determine whether there were differences in the observed time to disposition decision as well as length of stay by management system. Cox proportional hazards models were used for time to decision and length of stay separately, to determine whether there is a significant difference in the outcome variables between the intervention and control, adjusting for the potential confounding variables. The adjusted p-values and the corresponding 95% confidence interval were reported for multivariate analyses. All data analyses were carried out using statistical software R (Version 2.12.2).

RESULTS

Among all the 12,077 ED patients during the 18-week study period in 2010-2011, all patients within the eligible age range (2-18 years) were screened by the asthma detection system. The detection system (Bayesian Network) identified 839 patients having an asthma exacerbation. As determined by the reference standard, 534 had a final diagnosis of asthma, yielding a positive predictive value of 64%. Among the 305 not presenting with asthma, 216 had a respiratory complaint, 12 had flu or flu like symptoms, 15 with fever (9), and 62 other complaints.

Table 10: Phase II patient demographics.

	Intervention (n=268)	Control (n=266)	p-value
Age (median) (LQ, UQ)*	6 (3,9)	6 (3,10)	$F_{1,532} = 0.02$, P = 0.886
Gender, female (%)	40	36	$x_1^2 = 1.19$, P = 0.275
Acuity (%)			$x_3^2 = 4.28$, P = 0.232
2	37	36	
3	47	52	
4	16	12	
5	0	1	
Language English (%)			
Race			$x^2 = 2.36$, P = 0.307
Black (%)	57	58	
White (%)	34	30	
Other (%)	8	12	
Insurance			$x^2 = 1.81$, P = 0.404
Tenncare (%)	65	61	
Private (%)	30	35	
Other (%)	4	3	
Arrival			$x^2 = 0.53$, P = 0.767
Car (%)	81	80	
Ambulance (%)	18	18	
Unknown (%)	1	2	

* - LQ – lower quartile, UQ – upper quartile

From the 534 patients with a reference diagnosis of asthma x completed follow-up interviews (recall rate: 53%), 236 opted out or were not available, and 17 did not speak English as a primary language. Patients did not differ significantly in race (p=0.307, x^2 = 2.36) or mode of arrival (p=0.767, x^2 = 0.53). Patient demographics are shown in Table 10.

Intervention and control patients did not differ significantly in time to disposition; intervention patients had a median time of 239 minutes and control patients a median time of 233 minutes (p = 0.592). Intervention patients had a median length of stay 261 minutes and control of 237 minutes (p = 0.794). Admission rates were similar between the two groups (intervention=25%, control=26%, p=0.881). Primary findings are shown in Table 11.

The time to disposition decision for inpatients was 211 minutes (figure 13) and the time to disposition decision for outpatients was 330 minutes (Figure 14).

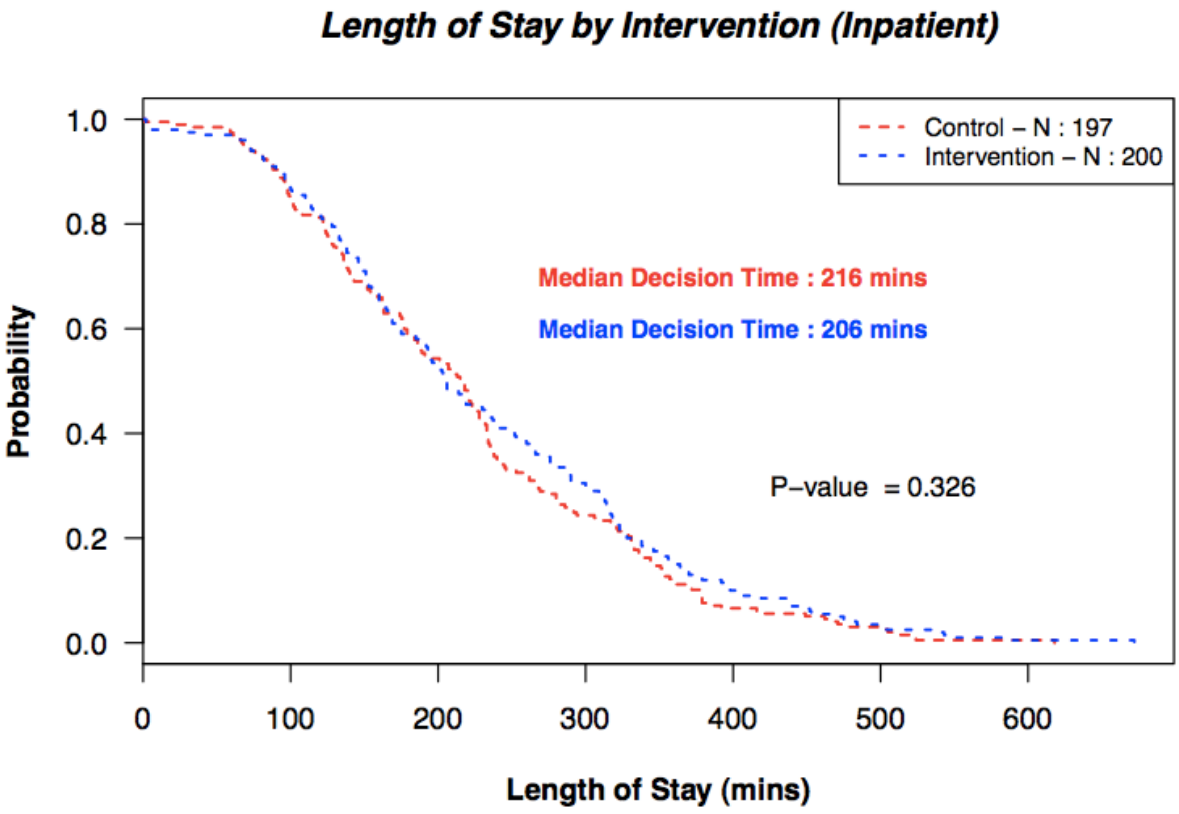


Figure 13: Time to disposition decision by intervention (inpatient).

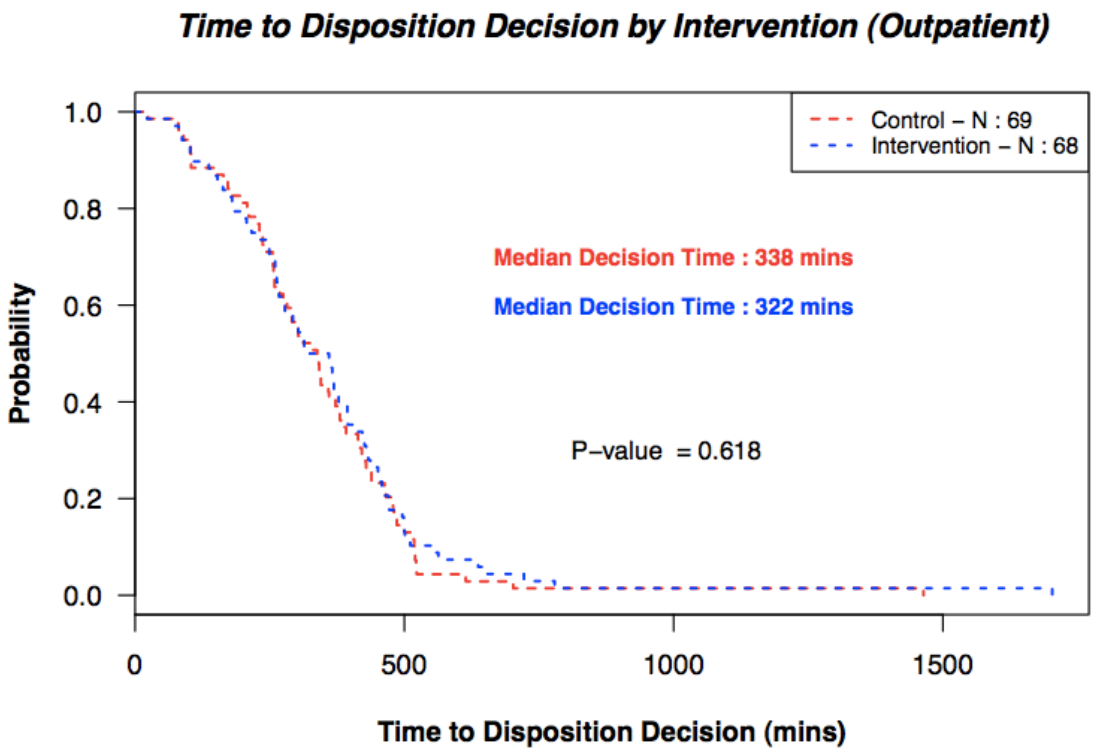


Figure 5: Time to Disposition Decision by Intervention

Figure 14: Time to disposition decision by intervention type. (outpatient)

Table 11: Phase II, primary findings.

	Intervention (n=268)	Control (n=266)	p-value
Disposition			x_1^2 = 0.02, P = 0.881
Admit (%)	25	26	
Discharged Home (%)	75	74	
Time to disposition minutes (median) (LQ, UQ)	239 (150, 354)	233 (141, 34)	$F_{1,532}$ = 0.29, P = 0.592
ED length of stay minutes (median) (LQ, UQ)	261 (156, 399)	237 (155, 379)	$F_{1,532}$ = 0.07, P = 0.794
Asthma education charted (%)	97	96	x_1^2 = 0.15, P = 0.694
Take-home asthma prescription charted (%)	88	84	x_1^2 = 1.05, P = 0.305
Follow up appointments scheduled (%)	6	6	x_1^2 = 0, P = 0.954
Protocol in the chart (%)	0	7	x_1^2 = 10.93, P < 0.001

* - LQ – lower quartile, UQ – upper quartile

Follow-up interview results are shown in table 12; 16% of patients surveyed did not have an asthma diagnosis before their ED visit. In the previous three months, a third of the children (31%) missed school due to asthma complications and 41% of parents reported missed workdays.

Table 12: Results from patient follow-up interviews.

Question	(n=281)
Age (mean), years	7.1
Gender, female (%)	40.6
Improved per parent (%)	68
Relapse to ED (%)	3
Steroid prescription filled since visit? (%)	64
Admitted to ED (%)	25
Have you ever been told your child has asthma? (%)	84
Has your child ever been hospitalized overnight for asthma? (%)	49
Have you taken your child to the ED for asthma before this visit? (%)	68
In the past three months have you missed any workdays because of your child's asthma? (%)	41
In the past three months has your child missed school because of asthma? (%)	31
Do you use a peak flow meter at home? (%)	24

DISCUSSION

This study examined the implementation of a fully computerized asthma management system compared to printing out a paper-based asthma protocol. The study did not find a significant difference between the computerized management system and time to disposition decision, length of stay, or the rate of hospital admission. Despite a thorough educational element and support from the ED clinicians, the management system did not show a significant effect.

The patient's time to disposition decision may be determined by the disease progression and response to treatment. It is possible that even with earlier scoring and treatment initiation, the disease progress would not be significantly changed. When a patient needs to be admitted but there are no beds open, it is possible that a bed request would not be placed. Therefore, these patients would benefit from an "intent to admit" option indicating the clinician has made a disposition decision but is unable to act on it yet.

The pediatric ED is highly integrated with using several information systems for patient care, and this environment may limit the generalizability of the findings. However, the system uses common data elements to determine patient eligibility and makes use of the clinicians' existing workflow. The BN only detected two-thirds of eligible patients and we do not have information about patients not detected by the BN. The pediatric ED treats a large number of asthma exacerbations, small changes in outcomes may be detected in EDs where clinicians are less familiar with diagnosis and treatment of asthma. The applicability of the asthma management system may be beneficial in smaller and less-experienced EDs.

The management system seamlessly integrated several different information systems to aid in communication. The clinical team was able to determine the patient's trajectory in a more efficient manner.

Although the time to disposition decision was not statistically significant, we believe this management system to be a sustainable computerized management system to help standardize asthma care. The system integrated patient and clinician data to help the care team communicate more effectively. Everyone could easily follow the patient's visit based on the graph of scores displayed. The computerized asthma management system represents a work-flow oriented, sustainable approach in a challenging environment.

CHAPTER VI

Discussion

This thesis described the design, development, and prospective evaluation of a computerized asthma management system in the pediatric ED.

The systematic literature review looked at 73 unique asthma protocol implementations (1966-2007) and examined their impact on patient care and graded their design. The literature review differentiated between paper-based, computer-generated, and fully computerized protocol and guideline reminder systems. The review found that paper-based systems are the most common implementation method, however computer-generated and computerized protocol and prompting systems are increasing in number. The review found that although 60% of the computerized studies had no change in clinician performance; this could be due to the prompts not being integrated into the clinician's workflow. The computerized studies were evenly split on improving patient outcomes and having no change on patient outcomes. The computer-generated studies were evenly split on having no change in practitioner performance and improving performance but had 62% of the studies report no change in patient outcomes. And the paper-based studies had 69% reporting an improvement in clinician performance and a 61% improvement in the patient outcomes. There were more paper-based studies than computer-based but paper can be effective way to implement a protocol reminder. However, as hospitals increase their use of computerized decision support and electronic medical records, it is likely that the efficacy of

computer-based protocol implementations will also improve. Asthma guidelines generally improved patient care and practitioner performance regardless of the implementation method.

The system and study design focused heavily on implementation into the clinicians' workflow. The computerized system utilized the electronic triage application, the electronic medical record, the computerized provider order entry system, the respiratory therapy system, and the electronic whiteboard. Patient eligibility was determined using a Bayesian network. For purposes of the study, a board-certified physician in pediatric emergency medicine checked the eligibility. The management system was studied in two separate clinical trials. The first trial, phase I, assessed the effectiveness of the automatic disease detection system. The second trial, phase II, evaluated the computerized asthma management system.

The first phase of the study identified 1,100 potential asthma patients of which 704 were presenting with an asthma exacerbation. Intervention and control patients did not differ significantly in time to disposition; intervention patients had a median time of 289 minutes (SD: 259 minutes) and control patients a median time of 288 minutes (SD: 307 minutes; $p = 0.212$). Intervention patients had a median length of stay 331 minutes (SD: 517 minutes) and control of 331 minutes (SD: 565 minutes; $p = 0.414$). Admission rates were similar between the two groups (intervention=36.6%, control=34.4%, $p=0.271$). The phase I trial did not find a difference in time to disposition decision, hospital admission rate or ED length of stay between intervention and control patients. Combining the automatic detection system and printing of the paper-based protocol did not change clinician care for the patients. The time to disposition decision may be determined by the natural history of the illness; a failure to shorten this time may not be a direct result of the intervention.

The phase II trial examined the implementation of the fully computerized asthma management system. Despite a thorough educational element and support from the ED clinicians, the management system did not show a significant effect.

The patient's time to disposition decision may be determined by the disease progression and response to treatment. It is possible that even with earlier scoring and treatment initiation, the disease progress would not be significantly changed. When a patient needs to be admitted but there are no beds open, it is possible that a bed request would not be placed. Therefore, these patients would benefit from an "intent to admit" option indicating the clinician has made a disposition decision but is unable to act on it yet. Additional analysis on orders may help reveal guideline compliance in both the Phase I and Phase II interventions.

We designed, evaluated and implemented a fully-computerized asthma management system. By using an automatic disease detection method, we removed one of barriers to initiating a guideline. No additional data entry was required to identify an asthma patient and triage nurses were only asked to score intervention patients. The respiratory therapists kept their established method of severity scoring and treatment charting with the only change being passive reminders on the electronic whiteboard. The largest work-flow change was with the physicians. They were asked to score asthma patients every two hours and then order sets were provided based on that score. These prompts appeared at the beginning of an order-entry session and could be turned off if the patient was not presenting with an asthma exacerbation. All of the prompts and reminders were automatically launched and integrated into the work-flow to help make using the system seamless.

In summary, we believe this management system to be a sustainable computerized management system to help standardize asthma care. The system integrated patient and clinician data to help the care team communicate more effectively. Everyone could easily follow the patient's visit based on the graph of scores displayed. The computerized asthma management system represents a work-flow oriented, sustainable approach in a challenging environment.

APPENDIX

Appendix A

Patient follow-up survey.

Follow-up Interview for Asthma/Respiratory Distress Patients

Last Visit Review			
ED Visit Date (mm/dd/yy)	__/__/____	ED Triage Time (hh:mm)	___:___
MRN:		Case Number:	
Birthday (mm/dd/yy)	__/__/____	Sex	[ ] Male [ ] Female

Call Log			
Date (mm/dd/yy)	Time (hh:mm)	Caller Initials	Comments
___/___/___	___:___		
___/___/___	___:___		
___/___/___	___:___		
___/___/___	___:___		
___/___/___	___:___		
___/___/___	___:___		

Interview Status			
[ ] Agreed to Participate	[ ] Refused f/u interview	[ ] Unreachable x 6 (over at least 10 days)	[ ] Other:

APPENDIX A

Phone Number I: _____

Phone Number II: _____

Hello. May I speak with _____? My name is _____ and I work for the Vanderbilt Children's Hospital Emergency Department. On _____ (date) you took _____(child) to the emergency department for an asthma attack. I'm calling to learn how _____(child) is doing. Is this a good time to talk for a few minutes?

[ ] No: When would be a better time to contact you?_____ Patient

[ ] No: (or) Would you prefer not to participate in the study? follow-up phone

[ ] Yes: Great. Please remember that all of your answers will be kept confidential, and will be used for asthma research only. Upon completion of this interview we will send you a $5 gift-card.

What is your relationship to the child? interview.

Date Interviewed (mm/dd/yy)	__/__/____			
Who was interviewed?	[ ] Mother	[ ] Father	[ ] Grandparent	[ ] Other:
Name:				

Discharged to Home	F/U information Source: Date: Time:	
Subject improved per parent	Yes	No
Recheck:*		
Physician request	Yes	
Parent request	Yes	
Unscheduled recheck**		
Not improved	Yes	
Worse	Yes	
Relapse to ED***	Yes	
Compliance with steroid tx		
Rx filled	Yes	No
Pt is taking steroid Rx	Yes	No

*Recheck: Planned, scheduled visit for asthma with PCP within 48hr of discharge from ED decided by PCP, ED physician, or parent.
**Unscheduled recheck: Unplanned, unscheduled visit to PCP within 48hr of discharge from ED because pt not improved or worse.
***Return to an ED for asthma care within 48hr of discharge from ED.

Section A: Demographics

Disposition: [ ] Admit [ ] Discharge

1. Has a doctor ever told you that your child has asthma? [ ]Yes [ ] No
   If yes, how old was your child when a doctor first diagnosed him/her with asthma
   [ ] <2 years old
   [ ] 2-5 years old
   [ ] 5-9 years old
   [ ] 10-14 years old
   [ ] 15-18 years old

Section B: Emergency Asthma Care History

The following questions do not apply to [child]'s most recent ED visit. Please answer them for any previous visits.

2. Has your child ever been hospitalized overnight for treatment of asthma symptoms (i.e., wheezing, dry cough, shortness of breath, and/or chest tightness)?
   [ ] No

[ ] Yes

If yes, how many times in the last 12 months? _____

3. Excluding the most recent visit, has your child ever previously gone to an emergency room for urgent treatment of asthma symptoms?

   [ ] No

   [ ] Yes

   If yes, how many times in the last 12 months, did your child visit an emergency room for urgent treatment of asthma symptoms? _____

   Which emergency room(s) did your child visit? _____

   How long ago was the visit? _____ (day/weeks/months)

Section C: Current Symptoms and control

4. In the past 3 months (excluding this ED visit), has [child] missed any school because of asthma symptoms?

   [ ] No

   [ ] Yes

   If yes, how many _____ (number)

5. In the past 3 months (excluding this ED visit),, has [child]'s primary caregiver missed any days of work because of [child]'s asthma symptoms?

   [ ] No

   [ ] Yes

   If yes, how many _____ (number)

6. Over the past 2 weeks how many days has your child had to use his/her quick relief medicine (i.e., short acting bronchodilator or rescue medicine)?

   _____ (times)

7. Does your child use a peak flow meter at home?

   [ ] No

   [ ] Yes

That's it! Do you have any questions or comments? Thank you for your help with this asthma study.

I need to verify your mailing address so we know where to send the gift-card.

Comments:

_____

_____

Appendix B

Clinician follow-up surveys.

Asthma/Respiratory Distress Protocol Survey

The purpose of this survey is to evaluate use of the respiratory distress protocol in the Vanderbilt Pediatric Emergency Department. Participation in this survey is anonymous and voluntary. Thank you.

Demographics

1. Which best describes your role in the ED?

☐ Full-time Nursing staff ☐ Part-time Nursing staff ☐ Other:_____

Asthma/Respiratory Distress Protocol

1. Did you know a protocol-based asthma study was taking place in the fall? ☐ Yes ☐ No

2. Did you see the asthma protocol printed from triage on the patient's chart? ☐ Yes ☐ No

If yes →

How many times:
- ☐ 1-3
- ☐ 4-6
- ☐ 7 or more
- ☐ Other: _____

3. Did you use the protocol? ☐ Yes ☐ No

If yes →

Which section (check all that apply):
- ☐ the flow diagram (first page)
- ☐ the scoring algorithm
- ☐ to base treatment decisions
- ☐ to make a disposition decision
- ☐ other: _____

CONTINUE ↓

Did you write on the protocol sheet? ☐ Yes ☐ No

If yes ←

If no ↓

Why not (check all that apply):
- ☐ Inadequate space to write
- ☐ I didn't need to
- ☐ I prefer to do everything electronically
- ☐ Other:_____

CONTINUE ↑

If no ↓

4. Do you use an asthma score to determine or change treatments? ☐ Yes ☐ No

If no → END

If yes ↓

5. Check all that apply:
- ☐ I scored the patient myself
- ☐ Respiratory Therapy paper score sheet
- ☐ Respiratory Therapy notes in StarPanel
- ☐ Respiratory Therapist treating the patient (verbal)
- ☐ Nursing paper score sheet
- ☐ Nurse treating the patient (verbal)
- ☐ Other:_____

Comments: _____

Date of IRB Approval: 1/05/2010

Asthma/Respiratory Distress Protocol Survey

The purpose of this survey is to evaluate use of the respiratory distress protocol in the Vanderbilt Pediatric Emergency Department. Participation in this survey is anonymous and voluntary. Thank you.

Demographics

1. Which best describes your role in the ED?

☐ Full-time Respiratory Therapist ☐ Part-time Respiratory Therapist ☐ Other:_____

Asthma/Respiratory Distress Protocol

1. Did you know a protocol-based asthma study was taking place in the fall? ☐ Yes ☐ No

2. Did you see the asthma protocol printed from triage on the patient's chart? ☐ Yes ☐ No

If yes →

How many times:
- ☐ 1-3
- ☐ 4-6
- ☐ 7 or more
- ☐ Other: _____

3. Did you use the protocol? ☐ Yes ☐ No

If yes →

Which section (check all that apply):
- ☐ the flow diagram (first page)
- ☐ the scoring algorithm
- ☐ to base treatment decisions
- ☐ to make a disposition decision
- ☐ other: _____

CONTINUE ↓

If no ↓

Did you write on the protocol sheet? ☐ Yes ☐ No

If yes ←

If no ↓

CONTINUE ↑

4. Do you use an asthma score to determine or change treatments? ☐ Yes ☐ No

If yes ↓

If no → END

5. Check all that apply:
- ☐ I scored the patient myself
- ☐ Respiratory Therapy paper score sheet
- ☐ Respiratory Therapy notes in StarPanel
- ☐ Respiratory Therapist treating the patient (verbal)
- ☐ Nursing paper score sheet
- ☐ Nurse treating the patient (verbal)
- ☐ Other:_____

Why not (check all that apply):
- ☐ Inadequate space to write
- ☐ I didn't need to
- ☐ I prefer to do everything electronically
- ☐ Other:_____

Comments: _____

Date of IRB Approval: 1/05/2010

Asthma/Respiratory Distress Protocol Survey

The purpose of this survey is to evaluate use of the respiratory distress protocol in the Vanderbilt Pediatric Emergency Department. Participation in this survey is anonymous and voluntary. Thank you.

Demographics

1. Which best describes your role in the ED?

☐ PED EM Fellow ☐ Attending Physician ☐ PED EM Attending ☐ Resident Physician

Asthma/Respiratory Distress Protocol

1. Did you know a protocol-based asthma study was taking place in the fall? ☐ Yes ☐ No

2. Did you see the asthma protocol printed from triage on the patient's chart? ☐ Yes ☐ No

If yes →

How many times:
- ☐ 1-3
- ☐ 4-6
- ☐ 7 or more
- ☐ Other: _____

3. Did you use the protocol? ☐ Yes ☐ No

If yes →

Which section (check all that apply):
- ☐ the flow diagram (first page)
- ☐ the scoring algorithm
- ☐ to base treatment decisions
- ☐ to make a disposition decision
- ☐ other: _____

CONTINUE →

If no ↓

Did you write on the protocol sheet? ☐ Yes ☐ No

If yes ←

If no ↓

4. Do you use an asthma score to determine or change treatments? ☐ Yes ☐ No

If no ↓ END

CONTINUE ←

If yes ↓

Why not (check all that apply):
- ☐ Inadequate space to write
- ☐ I didn't need to
- ☐ I prefer to do everything electronically
- ☐ Other:_____

5. Check all that apply:
- ☐ I scored the patient myself
- ☐ Respiratory Therapy paper score sheet
- ☐ Respiratory Therapy notes in StarPanel
- ☐ Respiratory Therapist treating the patient (verbal)
- ☐ Nursing paper score sheet
- ☐ Nurse treating the patient (verbal)
- ☐ Other:_____

Comments: _____
_____
_____
_____
_____

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