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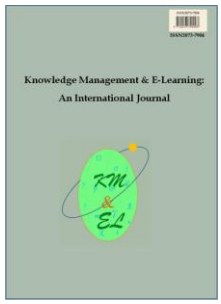

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Design and implementation of the asthma treat smart system in a pediatric institution

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Abstract: Asthma is one of the most common chronic diseases of childhood, affecting an estimated 7 million children (9.4%) in the United States. Asthma care is complex and dynamic requiring temporal, multi-faceted, and coordinated care. The purpose of the Asthma Treat Smart (ATS) application was to help providers provide evidence-based, guideline-compliant care to patients presenting to the pulmonary clinic for treatment of asthma. The application guides the providers through collecting the necessary information to classify the patient's severity and control and suggests appropriate medications according to the classification, age, and guidelines. The application helps to improve patient safety, healthcare provider training, and improves the quality of care patients receive by helping to align their chronic asthma care with national guidelines.

Keywords: Asthma; Medical informatics; Pediatrics; Education; Medical; Guideline; Guideline adherence

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1. Introduction

The purpose of this paper is to outline a methodology for designing, implementing and maintaining an Asthma Treatment Smart System web-based application for the management of pediatric patients with chronic asthma.

1.1. Asthma

Asthma is one of the most common chronic diseases of childhood, affecting an estimated 7 million children (9.4%) in the United States (American Lung Association, 2014; Asthma and Allergy Foundation of America, 2015; Mannino et al., 2002). The chronic characteristic of the disease carries a significant economic burden accounting for more

than 60% of the associated costs (Wang, Zhong, & Wheeler, 2005; Weiss, Sullivan, & Lyttle, 2000). The incidence of asthma is increasing, necessitating adherence to national guidelines and improved education (Loftus & Wise, 2015). Asthma care is complex and dynamic, requiring temporal, multi-faceted, and coordinated care within the clinic setting.

1.2. Asthma guidelines

Asthmatic patients need frequent follow-up and are often referred for subspecialty care due to the complex and refractory nature of the disease. National guidelines exist to help guide care, including asthma control categorization and associated step-wise treatment with long-term controller medications and written asthma action plans. The National Heart, Lung, and Blood Institute (NHLBI) guidelines (National Heart, Lung, and Blood Institute, 2007) recommend categorization of asthma control level and associated stepwise treatment for daily non-rescue management, including suggested controller medications and a written asthma action plan.

Providing evidence-based care for patients with asthma involves determining the patient's current asthma control level, which can be complex and is based on recent symptoms and current medications within the patient's recent past medical history. Integration of a decision support tool into the electronic health record which classifies an asthma patient's level of control can result in more standardized and reliable care for the outpatient treatment of this disease, with the goal of improving quality of life and decreasing emergency visits for these patients.

Evidence-based guidelines use improves patient safety and outcomes (Garg et al., 2005; Sirajuddin et al., 2009; Zemek, Bhogal, & Ducharme, 2008). Provider adherence to evidence-based guidelines (including asthma severity classification, written asthma action plan, and when applicable, prescription of controller medications) in an urban pediatric clinic setting of more than 3500 patients resulted in decreased hospitalization rates and ED visits for asthma (Cloutier, Hall, Wakefield, & Bailit, 2005). Identified barriers to lack of adherence to clinical practice guidelines include physician knowledge (such as familiarity and awareness), physician attitudes (including lack of agreement, lack of outcome expectancy), and behaviors (including external barriers such as patient factors or environmental factors) (Cabana et al., 1999). Health information technology, including the use of decision support systems, has been shown to have quality and efficiency benefits, especially in increasing adherence to guideline-based care (Chaudhry et al., 2006).

1.3. Challenges and opportunities for care

Patients with asthma should be managed with close follow-up outpatient visits; their level of control is assessed and evaluated at each visit. Patients frequently need to be followed closely and monitored to ensure effective care and well-controlled symptoms. The NHLBI guidelines offer both severity and control classifications and corresponding treatment recommendations. Patients are initially classified by severity as mild, intermittent, or persistent with exact criteria varying by age. Asthma control is assessed by monitoring patient symptoms and medical histories.

Patient education is vital in achieving asthma control, including written asthma action plans. These action plans include individualized instructions for both daily management and worsening symptoms, including recognizing and responding to symptoms and delineating when to seek medical care. Asthma control includes

identifying and reducing exposures that may trigger a patient's asthma such as allergens. All of these steps together help to improve the patient's asthma symptoms and control level. The guidelines are complex and require time and consistency to ensure that the patient is prescribed and compliant with correctly categorized medications, necessary follow-up visits, and has a current asthma action plan to help guide home care.

1.4. Electronic health record

An electronic health record (EHR) encompasses orders, patient visit information, and history. EHRs chronicle information about the patient's medical history, including but not limited to immunizations, orders, visits to the healthcare system, and laboratory results. They replace the traditional paper-based record and are becoming more universal (Jamoom et al., 2012). In comparison to paper-based records, EHRs are able to offer real-time clinical decision support to help aid providers in making care decisions. Clinical decision support systems (CDS) can provide medication alerts, guideline-based care recommendations, and other reminders or alerts to aid the providers. The CDS systems are designed to help leverage the EHR as a tool to improve care instead of just a data repository for medical information.

1.5. Decision support

CDS can provide evidence-based, point-of-care support for clinicians using EHR. CDS can improve clinician performance (Garg et al., 2005; Hunt, Haynes, Hanna, & Smith, 1998). However, successful integration of CDS into the clinical workflow is complex and requires many factors, including local user involvement in the development process, integration with the existing charting system, and speed (Bates et al., 2003; Kawamoto, Houlihan, Balas, & Lobach, 2005).

Implementation and adherence to guidelines is challenging in the clinical environment. Integration of guidelines with the clinical workflow can be accomplished through CDS. Asthma guideline-based decision support systems are commonly used (Hoeksema et al., 2011; Lomotan et al., 2012; Porter, Forbes, Feldman, & Goldmann, 2006; Tierney et al., 2005). The CDS systems provide accuracy in suggestions and guiding care (Hoeksema et al., 2011). While the CDS have shown to improve documentation (Lomotan et al., 2012), most of the interactions with the system were performed after the conclusion of the patient visit.

The Asthma Treat Smart (ATS) program combines six components of historical patient data to produce individualized asthma treatment compliant with the NHLBI recommendations. The goal of this project was to develop a workflow-integrated, evidence-based asthma management system to be used in the outpatient pulmonary clinic to increase guideline-compliant treatment and improve care for patients with asthma.

1.6. Objectives

The creation of a multidisciplinary team ensured successful CDS development. The team involved leaders from pulmonary clinicians and nurses, informatics development and information services personnel. Team members included two pulmonologists, one advance practice nurse, a project manager, two developers, two nurses, two biomedical informatics support staff, and two individuals from the hospital information services team. The goal of the system design was to be intuitive and easy to use by the providers and

patients to help collect the necessary information in order to be adherent to NHLBI guidelines.

The primary purpose of the ATS application was to help providers provide evidence-based, guideline-compliant care to patients presenting to the pulmonary clinic for treatment of asthma. The system guides the providers through collecting the necessary information to classify the patient's severity and control and also recommends appropriate medications according to the classification, age, and guidelines.

2. Design

2.1. Setting

The Cincinnati Children's Hospital Medical Center (CCHMC) is an academic level 1 trauma center with 628 beds and more than 1.2 million patient encounters annually. The outpatient pulmonary clinic is a teaching facility and has 23 attending and resident physicians, 43 nurses, and 38 respiratory therapists. There are approximately 9,000 clinic visits annually, 30% of which are asthma- related. Prior to implementation of the ATS, written action plans were created by the providers and medication suggestions were based solely upon clinical knowledge and expertise.

2.2. Informatics infrastructure

CCHMC has been using the Epic® (Verona, WI) EHR in the pulmonary clinic since 2008. The Epic longitudinal EHR includes patient history, medications, order entry, scanned documents, exam reports, and all institution-related visit information. The EHR is fully integrated and all orders and notes are electronic. The application integrates with the Epic EHR through an embedded link out to the ATS.

2.3. Logic development

To develop the logic within the application, we performed an extensive analysis of the NHLBI guidelines for the Diagnosis and Management of Asthma 2007 (National Heart, Lung, and Blood Institute, 2007), including an evaluation of how to transform the guidelines into computational algorithm. Considerations included items such as: Is the guideline feasible for a computational decision tool? Does the tool evaluate and reach our clinical goals such as guideline recommendations, conditions, reason, logic, action and components that can be coded. Once the logic creation was complete, a review and evaluation of other available asthma tools was performed. No existing tool fit the unique needs of the pulmonary clinic.

2.4. Design considerations

The ATS iterative design began in 2009. The design objectives included a multidisciplinary design team, intuitive user interface, and adherence to national guidelines. The multidisciplinary team helped design the treatment algorithm and user interfaces. Using paper-mockups and workflow trials, the interfaces were iteratively tested. The system was trialed in the clinic to ensure workflow integration and necessary modifications made.

We obtained support from the clinic team leader and division director Dr. Kercsmar, who provided content expertise with the medications and treatment modalities as well as expertise with the design elements, including the treatment algorithm and user interface. The next focus was to design the asthma patient visit form based on the national guideline and existing asthma visit form used in the clinic. Paper mock ups of the interface were trialed in the clinic and adjusting to the appropriate reading level for patient comprehension. Based on the work flow observed in the clinic, the user interface was designed in two parts: the first is the patient asthma form that allows patients enter asthma treatment related information (Fig. 1) and the second part is for the physicians (Fig. 2) so they can review the answers with patients and start the treatment program.

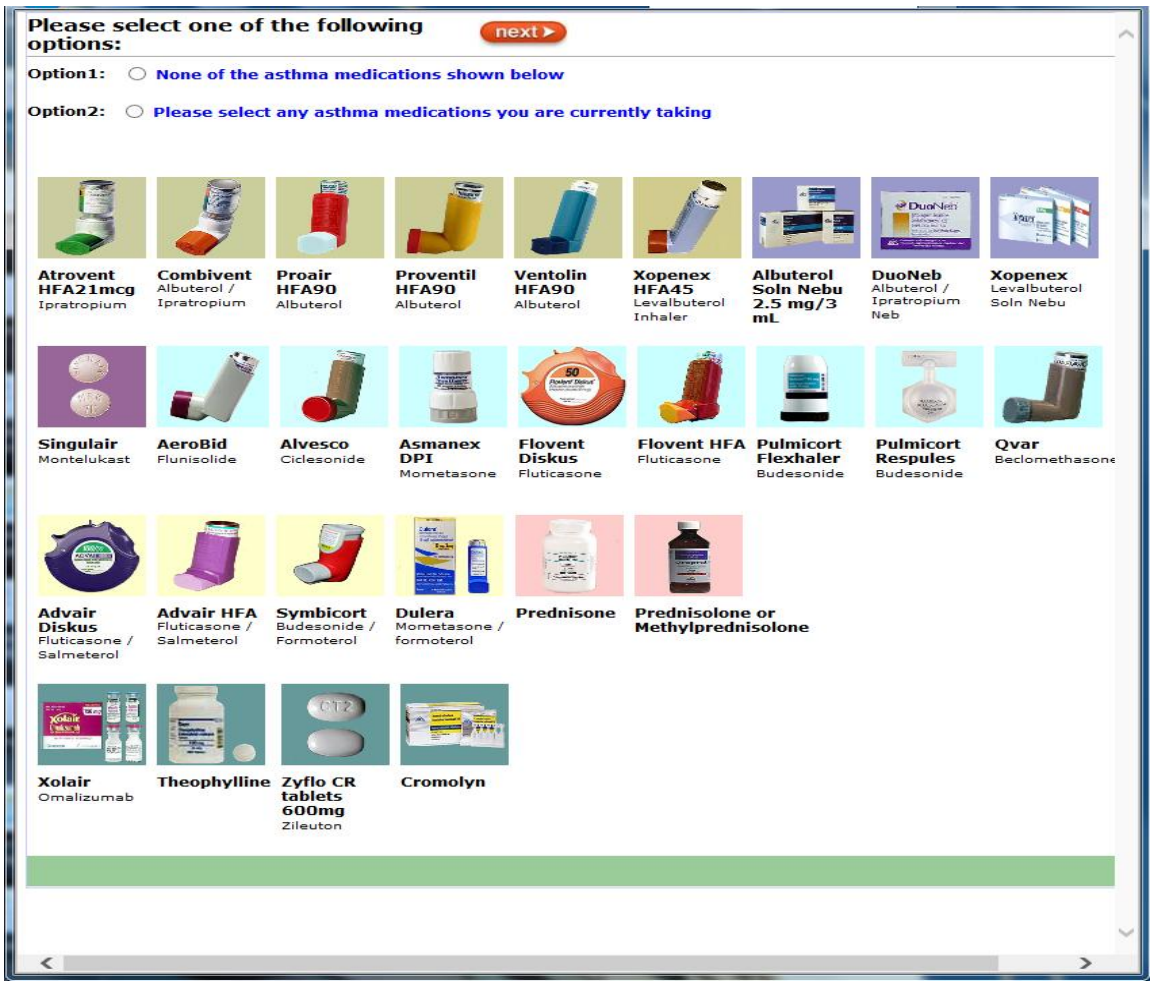


Fig. 1. Common asthma medication images for patient entry into the ATS application

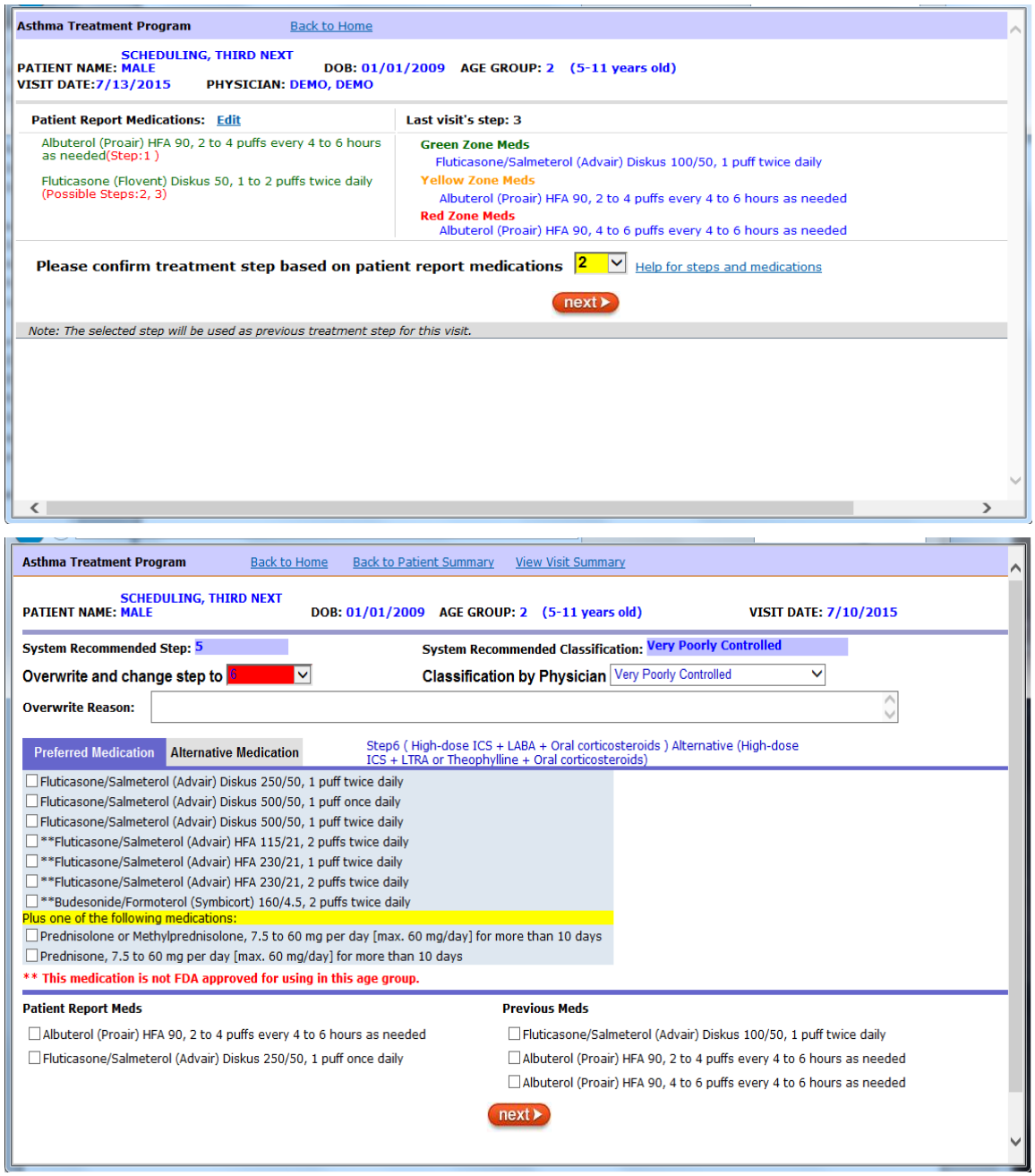


Fig. 2. Provider summary and recommendations based on national guidelines

After the initial design, the application was based on above analysis and trialed in the pulmonary clinics to ensure fit into clinic flow. We made iterative adjustments and enhancements to the interface and algorithm based on user feedback. After collecting the initial data, we analyzed the algorithm with the help of our statisticians to make sure the algorithm follows the guideline and abides by the asthma treatment practice in pulmonary

clinic. After the system had been in place for a year, we undertook a larger version updated in 2011. The new version allows the patients to select the asthma medication by picture, and calculates the patient's initial step based on the patient-reported medications. This improved the accuracy and user-friendliness of the treatment program.

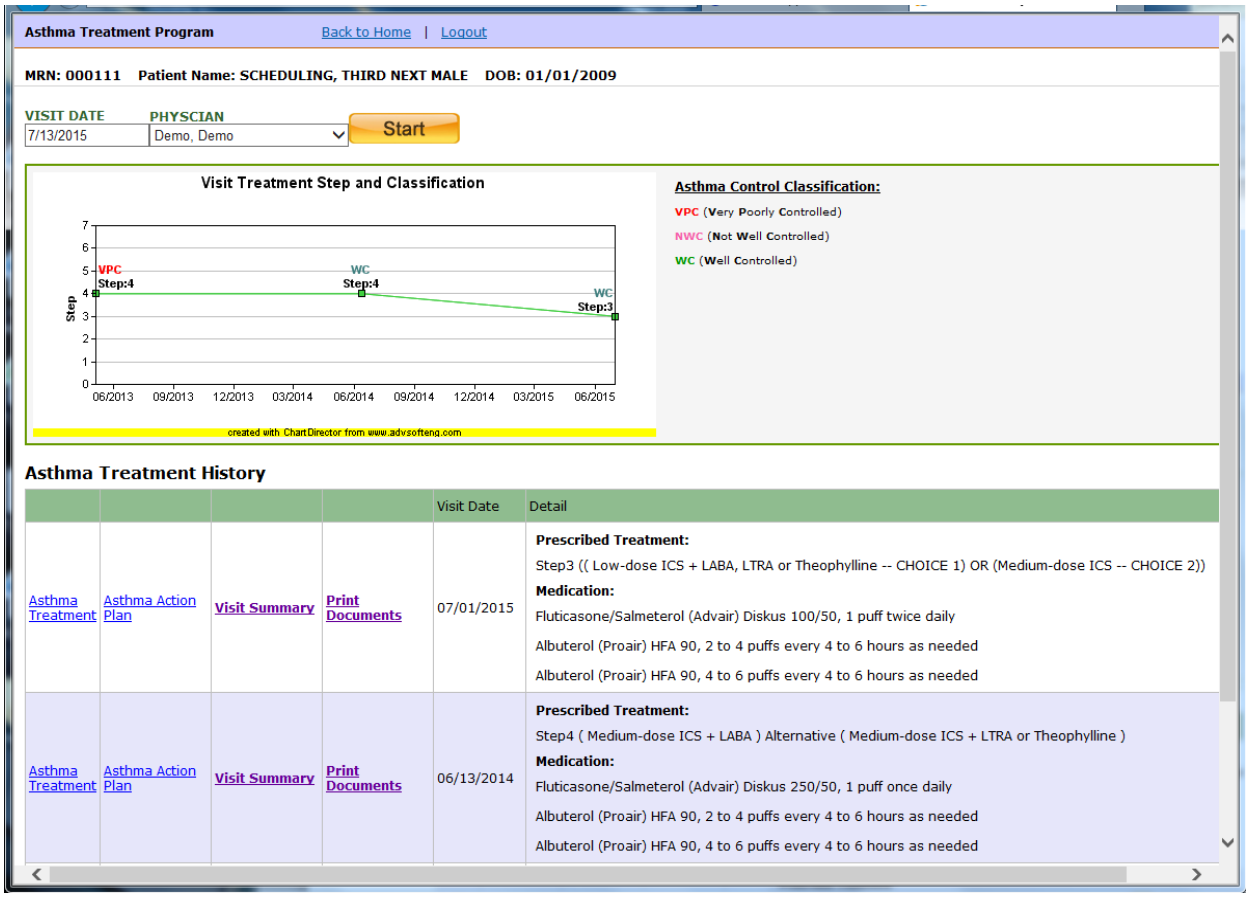
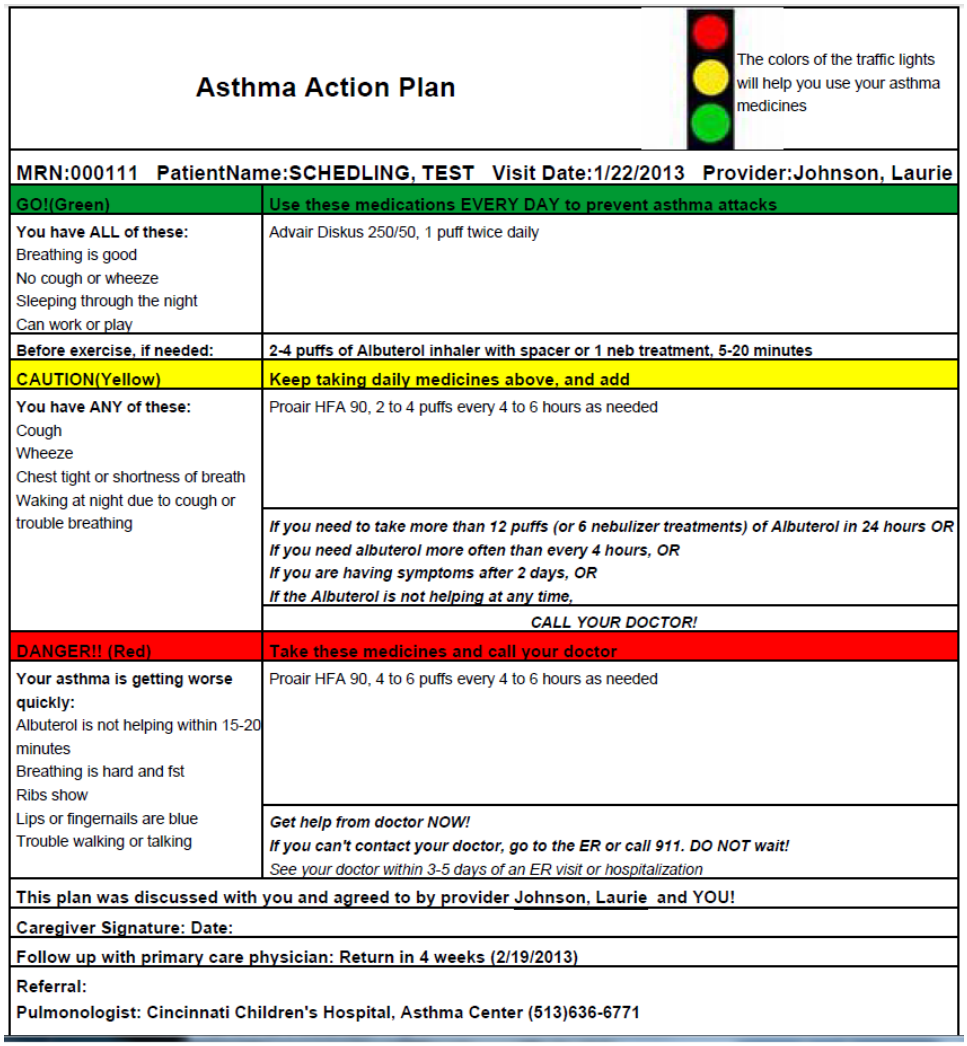


Fig. 3. Summary screenshot of ATS application to view past asthma history

2.5. System walkthrough

The ATS opening screen shows patient history, previous severity/control levels, treatment steps and assessment dates (Fig. 3). Providers can see all past recommendations, patient-reported medications, written asthma action plans, and can choose to reprint previous documentation. When creating a new visit, providers are first taken to the patient medication entry screen (Fig. 1); this screen was designed to allow patients to quickly and easily enter all their current asthma-related medications. Next, patients answer symptom-related questions for the past month including night-wakenings, how often asthma has interrupted their daily life, and prior hospitalizations and ED visits. This ends the patient-driven section of the application. When providers log in to the system, they are able review the patient-reported answers for symptoms and then are provided with NHLBI-compliant recommendations for patient step classification and medications (Fig. 2). Providers are able to select recommended medications while viewing the

patient's current medications. Finally, providers create a new written asthma action plan (Fig. 4) based on the information provided by the patient and medications selected. This is created as a printer-friendly PDF to hand to the patient for home use and is stored in the system for future reference.



Asthma Action Plan

The colors of the traffic lights will help you use your asthma medicines

MRN:000111 PatientName:SCHEDLING, TEST Visit Date:1/22/2013 Provider:Johnson, Laurie

GO!(Green)	**Use these medications EVERY DAY to prevent asthma attacks**
You have ALL of these: Breathing is good No cough or wheeze Sleeping through the night Can work or play	Advair Diskus 250/50, 1 puff twice daily
Before exercise, if needed:	**2-4 puffs of Albuterol inhaler with spacer or 1 neb treatment, 5-20 minutes**
CAUTION(Yellow)	**Keep taking daily medicines above, and add**
You have ANY of these: Cough Wheeze Chest tight or shortness of breath Waking at night due to cough or trouble breathing	Proair HFA 90, 2 to 4 puffs every 4 to 6 hours as needed
	If you need to take more than 12 puffs (or 6 nebulizer treatments) of Albuterol in 24 hours OR ***If you need albuterol more often than every 4 hours, OR*** ***If you are having symptoms after 2 days, OR*** ***If the Albuterol is not helping at any time,***
	CALL YOUR DOCTOR!
DANGER!! (Red)	**Take these medicines and call your doctor**
Your asthma is getting worse quickly: Albuterol is not helping within 15-20 minutes Breathing is hard and fst Ribs show Lips or fingernails are blue Trouble walking or talking	Proair HFA 90, 4 to 6 puffs every 4 to 6 hours as needed
	Get help from doctor NOW! ***If you can't contact your doctor, go to the ER or call 911. DO NOT wait!*** *See your doctor within 3-5 days of an ER visit or hospitalization*
This plan was discussed with you and agreed to by provider Johnson, Laurie and YOU!	
Caregiver Signature: Date:	
Follow up with primary care physician: Return in 4 weeks (2/19/2013)	
Referral: **Pulmonologist: Cincinnati Children's Hospital, Asthma Center (513)636-6771**	

Fig. 4. Personalized asthma action plan

2.6. Expansion

After successful implementation and integration in the pulmonary clinic, we expanded the ATS to the other clinic practices. A site visit was performed for each practice and clinic flow was discussed with the nurses and physicians; an independent observer also evaluated the clinic flow. Based on the initial analysis, we designed a new outpatient version and presented it in a focus group meeting. We made additional iterative changes based on the feedback. For example, we prepared paper patient forms and electronic version since some of the practice were still using paper forms for patients. The patient

does not initiate the program in the practice, so for the outpatient practices, the medication section was combined with the physician section. We trialed the outpatient version for 6 month and gradually expand to additional practices.

To continue expansion, we started an emergency department (ED) specific design, initially meeting with the ED team to discuss the design elements and necessary requirements in the unique environment. The ED version will only including the most common asthma medications, the asthma action plan and a new additional section for ED discharge instructions.

3. Results

3.1. Preliminary data

The ATS application has been in use in the clinic for 5 years. The algorithm was analyzed to evaluate guideline adherence in the clinic. Patient demographics for pulmonary clinic use are in Table 1. From 561 asthma visits made to pediatric pulmonologists, 489 visits had accepted ATS-recommended treatment (accuracy 87.2%) and control categorization suggestions. A small number of visits (72 total) included a change such as: "symptoms are NOT due to asthma; infection and immune deficiency and increased symptoms as a result of allergies."

Table 1
Patient demographics

Patient demographics	(n=374)
Age (median), range	9, (0,21)
Sex (Female)	45%
Race	
Black	38.2%
Caucasian	50.2%
Other	11.5%
Ethnicity	
Non-Hispanic	94%

3.2. Design history

The design of the ATS began in 2009 and improvements and updates are continually made. The ATS was first designed for use in the outpatient pulmonary clinic setting. The system is currently in use in the CCHMC pulmonary clinic and is being trialed in the pediatric ED. On the ambulatory side, the system is successfully used in the following six clinics: Landen Lake Pediatrics, The Whole Child Pediatrics, Children's Healthcare, ESD Pediatrics, Pediatric Associates, and Anderson Hills Pediatrics.

Starting in 3/15/2011, the ATS application was modified and updated to be trialed in additional ambulatory clinics. In 5/10/2011, focus groups were held with the ambulatory practices to demonstrate the ATS application and to get feedback and suggestions for what would be most helpful. Six site visits were conducted from 5/16/2011-6/30/2011. And on 7/1/2011-12/31/2011, the system was piloted in three selected practices. Current efforts are focused on expanding the system into an additional three clinics.

From 9/30/2011-12/7/2011, the system was developed and tested in the pulmonary clinics. Starting 12/8/2011, a new version was implemented in the pulmonary clinics, which included changing the asthma visit form from long form to short form, addition of medication pictures, and modification of the algorithm to identify the initial step based on patient report medications.

The system is also being adapted for use in the pediatric emergency department. On 8/24/2011, a static CCHMC website was created for the introduction and demonstration of the application in the ED. From 8/24/2011-5/2012, focus group meetings were held to discuss ED-specific design considerations and needs. Current work focuses on developing a new ATS version that is entirely ED-specific, including the modification of follow-up requests, the total number of medications offered, and workflow considerations for completing the tool.

3.3. Implementation with the EHR

The ATS tool is a standalone web application; to integrate the tool with hospital-wide EHR system; we worked with the vendor team to find the best solution so that our users can seamlessly access the tool from within the EHR. The asthma link will open the ATS tool from the visit navigator and pass the patient encounter parameters into ATS. We are in the stage of initial testing of this function. Currently the provider needs to copy and paste the visit summary generated by ATS back into the EHR.

4. Conclusion

The ATS is a successful stand-alone web-based application based on national guidelines with site-specific modifications. The real-time decision support tool provides a recommended treatment plan, treatment steps, asthma control level classification, and generates a personalized asthma action plan and a visit summary that can be copied into the EHR. The ATS design is based on NHLBI Guidelines for the Diagnosis and Management of Asthma 2007 (National Heart, Lung, and Blood Institute, 2007). We made site-specific adjustments and modifications to the algorithm based on our asthma practice in the pulmonary clinic. The tool generates a personalized Asthma Action Plan (Fig. 4) for the patients and a visit summary that can be copied to the EHR system as a permanent part of the medical record, thereby facilitating communication across systems for asthma patients.

The application helps guide healthcare providers to use national asthma guidelines to improve the quality of patient care. Guideline compliance has shown to improve patient outcomes (Garg et al., 2005; Sirajuddin et al., 2009; Zemek, Bhogal, & Ducharme, 2008) and safety (Gurses, Murphy, Martinez, Berenholtz, & Pronovost, 2009). And this application reinforces the NHLBI asthma guidelines for providers with each use. The asthma-related medications (Fig. 1) are those recommended as important for guideline severity classification and asthma action plan creation. Although the application only

offers patient education through a written asthma action plan, providers have a continual reminder of severity classification sets and associated recommended treatments. In this way, provider education is passively improved and using guidelines and provider education can help the quality of asthma care and prescribing (Feder et al., 1995).

Identified barriers to lack of adherence to clinical practice guidelines include physician knowledge (such as familiarity and awareness), physician attitudes (including lack of agreement, lack of outcome expectancy), and behaviors (including external barriers such as patient factors and environmental factors) (Cabana et al., 1999). The goal of clinical decision support tools is to "ensure optimal, usable, and effective" patient-specific knowledge to providers at the point-of-care in order "to improve the quality of health care services" (Osheroff et al., 2007). The ATS application accomplishes this goal by providing real-time decision support and provider education in the outpatient clinics. The application helps providers seamlessly provide this care and this can be accomplished through CDS (Jones, Rudin, Perry, & Shekelle, 2014).

CDS has also been used to provide education to providers (Denny et al., 2015). The ATS application functions as both an online decision support tool to improve patient care and an educational system. Use of the system in the pulmonary clinics is optional, as it is both an educational and decision support tool. The ATS application is being modified for use in the busy ED setting, where providers may not be as familiar with all the details of asthma controller medication recommendations based on national guidelines. Providers are efficiently guided through the NHLBI guidelines during the patient encounter as they access the application and guideline-compliant care is recommended. This allows them to familiarize themselves with the guidelines in a continual fashion during each patient visit.

At the core of this application is the integration of the NHLBI asthma treatment algorithm and the asthma medications. While the guideline is the base of the algorithm, the ATS tool also incorporates expertise from our pulmonary and allergy physicians that have many years of clinical experience with asthma. The tool not only translates the guideline into use, but also transfers it into a very practical clinical tool. Future efforts include continued incorporation of the ATS application into the ED and urgent care environment. Utilization of the tool for each asthma patient encounter within these fast-paced workflows transforms the emergency visit into a comprehensive evaluation and treatment of the patient's current asthma status and provides optimum asthma care at discharge.

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References

American Lung Association. (2014). *Asthma & children fact sheet*. Retrieved from http://www.lung.org/lung-disease/asthma/resources/facts-and-figures/asthma-children-fact-sheet.html

Asthma and Allergy Foundation of America. (2015). *Allergy facts and figures*. Retrieved from https://www.aafa.org/display.cfm?sub=42&id=8

Bates, D. W., Kuperman, G. J., Wang, S., Gandhi, T., Kittler, A., Volk, L., Spurr, C.,

Khorasani, R., Tanasijevic, M., & Middleton, B. (2003). Ten commandments for effective clinical decision support: Making the practice of evidence-based medicine a reality. *Journal of the American Medical Informatics Association, 10*(6), 523– 530.

Cabana, M. D., Rand, C. S., Powe, N. R., Wu, A. W., Wilson, M. H., Abboud, P. A., & Rubin, H. R. (1999). Why don't physicians follow clinical practice guidelines? A framework for improvement. *JAMA: The Journal of the American Medical Association, 282*(15), 1458–1465.

Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., Roth, E., Morton, S. C., & Shekelle, P. G. (2006). Systematic review: Impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine, 144*(10), 742–752.

Cloutier, M. M., Hall, C. B., Wakefield, D. B., & Bailit, H. (2005). Use of asthma guidelines by primary care providers to reduce hospitalizations and emergency department visits in poor, minority, urban children. *The Journal of Pediatrics, 146*(5), 591–597. doi: 10.1016/j.jpeds.2004.12.017

Denny, J. C., Spickard, A., 3rd, Speltz, P. J., Poirier, R., Rosenstiel, D. E., & Powers, J. S. (2015). Using natural language processing to provide personalized learning opportunities from trainee clinical notes. *Journal of Biomedical Informatics*. doi: 10.1016/j.jbi.2015.06.004

Feder, G., Griffiths, C., Highton, C., Eldridge, S., Spence, M., & Southgate, L. (1995). Do clinical guidelines introduced with practice based education improve care of asthmatic and diabetic patients? A randomised controlled trial in general practices in east London. *BMJ: British Medical Journal, 311*(7018), 1473–1478.

Garg, A. X., Adhikari, N. K., McDonald, H., Rosas-Arellano, M. P., Devereaux, P. J., Beyene, J., Sam, J., & Haynes, R. B. (2005). Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: A systematic review. *JAMA: The Journal of the American Medical Association, 293*(10), 1223–1238. doi: 10.1001/jama.293.10.1223

Gurses, A. P., Murphy, D. J., Martinez, E. A., Berenholtz, S. M., & Pronovost, P. J. (2009). A practical tool to identify and eliminate barriers to compliance with evidence-based guidelines. *The Joint Commission Journal on Quality and Patient Safety, 35*(10), 526–532, 485.

Hoeksema, L. J., Bazzy-Asaad, A., Lomotan, E. A., Edmonds, D. E., Ramirez-Garnica, G., Shiffman, R. N., & Horwitz, L. I. (2011). Accuracy of a computerized clinical decision-support system for asthma assessment and management. *Journal of the American Medical Informatics Association, 18*(3), 243–250. doi: 10.1136/amiajnl-2010-000063

Hunt, D. L., Haynes, R. B., Hanna, S. E., & Smith, K. (1998). Effects of computer-based clinical decision support systems on physician performance and patient outcomes: A systematic review. *JAMA: The Journal of the American Medical Association, 280*(15), 1339–1346.

Jamoom, E., Beatty, P., Bercovitz, A., Woodwell, D., Palso, K., & Rechtsteiner, E. (2012). Physician adoption of electronic health record systems: United States, 2011. *NCHS Data Brief, 98*, 1–8. Retrieved from http://www.cdc.gov/nchs/data/databriefs/db98.htm

Jones, S. S., Rudin, R. S., Perry, T., & Shekelle, P. G. (2014). Health information technology: An updated systematic review with a focus on meaningful use. *Annals of Internal Medicine, 160*(1), 48–54. doi: 10.7326/m13-1531

Kawamoto, K., Houlihan, C. A., Balas, E. A., & Lobach, D. F. (2005). Improving clinical practice using clinical decision support systems: A systematic review of trials to identify features critical to success. *BMJ: British Medical Journal, 330*(7494), 765–

768. doi: 10.1136/bmj.38398.500764.8F

Loftus, P. A., & Wise, S. K. (2015). AAOA asthma primer: Epidemiology and economic burden of asthma. *International Forum of Allergy & Rhinology, 5*(s1), s7–s10. doi: 10.1002/alr.21547

Lomotan, E. A., Hoeksema, L. J., Edmonds, D. E., Ramirez-Garnica, G., Shiffman, R. N., & Horwitz, L. I. (2012). Evaluating the use of a computerized clinical decision support system for asthma by pediatric pulmonologists. *International Journal of Medical Informatics, 81*(3), 157–165. doi: 10.1016/j.ijmedinf.2011.11.004

Mannino, D. M., Homa, D. M., Akinbami, L. J., Moorman, J. E., Gwynn, C., & Redd, S. C. (2002). Surveillance for asthma--United States, 1980-1999. *Morbidity and Mortality Weekly Report: Surveillance Summaries, 51*(1), 1–13.

National Heart, Lung, and Blood Institute. (2007). *Guidelines for the diagnosis and management of asthma (EPR-3)*. Retrieved from http://www.nhlbi.nih.gov/health-pro/guidelines/current/asthma-guidelines

Osheroff, J. A., Teich, J. M., Middleton, B., Steen, E. B., Wright, A., & Detmer, D. E. (2007). A roadmap for national action on clinical decision support. *Journal of the American Medical Informatics Association, 14*(2), 141–145.

Porter, S. C., Forbes, P., Feldman, H. A., & Goldmann, D. A. (2006). Impact of patient-centered decision support on quality of asthma care in the emergency department. *Pediatrics, 117*(1), e33–e42. doi: 10.1542/peds.2005-0906

Sirajuddin, A. M., Osheroff, J. A., Sittig, D. F., Chuo, J., Velasco, F., & Collins, D. A. (2009). Implementation pearls from a new guidebook on improving medication use and outcomes with clinical decision support: Effective CDS is essential for addressing healthcare performance improvement imperatives. *Journal of Healthcare Information Management, 23*(4), 38–45.

Tierney, W. M., Overhage, J. M., Murray, M. D., Harris, L. E., Zhou, X. H., Eckert, G. J., Smith, F. E., Nienaber, N., McDonald, C. J., & Wolinsky, F. D. (2005). Can computer-generated evidence-based care suggestions enhance evidence-based management of asthma and chronic obstructive pulmonary disease? A randomized, controlled trial. *Health Services Research, 40*(2), 477–498. doi: 10.1111/j.1475-6773.2005.00368.x

Wang, L. Y., Zhong, Y., & Wheeler, L. (2005). Direct and indirect costs of asthma in school-age children. *Preventing Chronic Disease, 2*(1). Retrieved from http://www.cdc.gov/pcd/issueS/2005/jan/04_0053.htm

Weiss, K. B., Sullivan, S. D., & Lyttle, C. S. (2000). Trends in the cost of illness for asthma in the United States, 1985-1994. *Journal of Allergy and Clinical Immunology, 106*(3), 493–499. doi: 10.1067/mai.2000.109426

Zemek, R. L., Bhogal, S. K., & Ducharme, F. M. (2008). Systematic review of randomized controlled trials examining written action plans in children: What is the plan? *Archives of Pediatrics and Adolescent Medicine, 162*(2), 157–163. doi: 10.1001/archpediatrics.2007.34