



Reducing pediatric asthma hospital length of stay through evidence-based quality improvement and deployment of computerized provider order entry

George A. Gellert, Crystal M. Davenport, Charles G. Minard, Claudia Castano, Kylynn Bruner & Deon Hobbs

To cite this article: George A. Gellert, Crystal M. Davenport, Charles G. Minard, Claudia Castano, Kylynn Bruner & Deon Hobbs (2019): Reducing pediatric asthma hospital length of stay through evidence-based quality improvement and deployment of computerized provider order entry, Journal of Asthma, DOI: [10.1080/02770903.2018.1553053](https://doi.org/10.1080/02770903.2018.1553053)

To link to this article: <https://doi.org/10.1080/02770903.2018.1553053>



Published online: 25 Jan 2019.



Submit your article to this journal [↗](#)



Article views: 21



View Crossmark data [↗](#)



Reducing pediatric asthma hospital length of stay through evidence-based quality improvement and deployment of computerized provider order entry

George A. Gellert, MD, MPH, MPA^a, Crystal M. Davenport, MD^b, Charles G. Minard, PhD^c, Claudia Castano, BS^b, Kylynn Bruner, BS, MBA^a, and Deon Hobbs, RN^b

^aDepartment of Health Informatics, CHRISTUS Health Santa Rosa, San Antonio, TX, USA; ^bCHRISTUS Health Santa Rosa and Baylor College of Medicine, Department of Pediatrics, Children's Hospital of San Antonio, San Antonio, TX, USA; ^cBaylor College of Medicine, Dan L. Duncan Institute for Clinical and Translational Research, Houston, TX, USA

ABSTRACT

Objective: Evaluate the impact of multi-component quality improvement for pediatric asthma care focusing on serial use of an evidence-based clinical pathway via paper order sets, pathway integration into computerized provider order entry (CPOE), use of a clinical respiratory score (CRS) and a discharge checklist. **Methods:** Outcomes were assessed over three intervention periods and 50 months on: time to beta-agonist and steroid first administration, frequency of readmissions and hospital length of stay. A general linear model estimated mean log(LOS) over time and between study periods. Time to discharge was transformed using the natural logarithm. **Results:** No improvements in time to first beta-agonist or steroid administration were observed. There was a reduction in 100-day readmissions ($p=0.008$): decreasing from 7.4 to 2.1% after introduction of paper order sets and CRS (adjusted $p=0.04$); to 3.9% after CPOE implementation (adjusted $p=0.53$) and to 2.2% when a discharge checklist was added (adjusted $p=0.01$). There was a statistically significant reduction in LOS between study periods ($p=0.015$). The geometric mean LOS in hours during study periods 1–4 were: 34.8 (95% CI: 32.2, 37.6), 29.3 (95% CI: 27.5, 31.3), 29.0 (95% CI: 27.0, 31.3) and 23.1 (95% CI: 22.1, 24.2). Pair-wise comparisons between periods were statistically significant (adjusted $p\leq 0.003$), except for Periods 2 and 3 (adjusted $p=0.83$). **Conclusions:** Hospital length of stay and 100-day readmissions rate in a predominantly Hispanic, Medicaid patient population were reduced by utilization of an evidence-based best practices asthma management pathway and CRS within CPOE, combined with a checklist to expedite discharge.

Abbreviations: CPOE: Computerized Provider Order Entry; CHAT: Children's Hospital Association of Texas; ED: Emergency Department; LOS: Length of Stay

ARTICLE HISTORY

Received 15 August 2018
Revised 18 October 2018
Accepted 24 November 2018

KEYWORDS

Asthma length of stay; quality improvement; CPOE asthma pathway

Introduction

Pediatric asthma is one of the most common chronic diseases of childhood, affecting more than 6 million children and causing more than 679,000 hospitalizations annually in the US [1,2]. It is the most common reason for preventable pediatric emergency department (ED) and hospital admissions [1,2], and affects 8.6% of US children [1,2]. High readmission rates for pediatric asthma are associated with substantial health care costs, estimated as high as \$50 billion annually, as well as school absenteeism [1–3].

There has been substantial research on quality improvement in asthma care. An integrative review of the literature on the impact of inpatient asthma

clinical pathways found that clinical pathways appear to be effective in reducing inpatient asthma length of stay (LOS) and costs [4]. Chen et al. [5] focused on seven randomized controlled trials involving 2600 participants and found that use of asthma clinical pathways may decrease hospital length of stay, but did not reduce asthma readmissions or hospital costs. However, a systematic review completed by Okelo et al. [6] found that a minority of studies dealt with pediatrics, and few focused specifically on pediatric clinical outcomes. More recent studies have demonstrated improvement in clinical outcomes [7–10], and those focused on improving inpatient asthma care showed reductions in hospital readmission rates and

CONTACT George A. Gellert, MD, MPH, MPA  ggellert33@gmail.com  Department of Health Informatics, CHRISTUS Health Santa Rosa, 703 Sentry Hill, San Antonio, TX 78260, USA.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ijias.

© 2018 Taylor & Francis Group, LLC

length of stay [11]. Nkoy et al. [11] assessed the impact of an evidence-based care process model 5 years after implementation within a tertiary care facility and community hospitals focusing on eight quality measures. Sustained reductions in asthma readmissions, length of stay and cost were reported among the community hospitals. However, populations studied were largely white and covered by private insurance [11,12].

A majority of patients at our urban children's hospital are Hispanic and have Medicaid insurance. Our literature review found no studies demonstrating improvement in clinical outcomes in this particular population. Beginning in 2013, hospitalists in our children's hospital sought to standardize asthma care at our facility from ED triage through inpatient admission to discharge home, leveraging computerized provider order entry (CPOE) to effectively and efficiently distribute and ensure evidence-based care practices throughout the institution [13–20]. CPOE created new opportunities to distribute evidence-based best clinical practice guidelines, and to expand use of disease severity scores [21,22]. CPOE enables sustained diffusion of standardized clinical best practices by ensuring utilization of evidence-based workflows and clinical care order sets, and clinical decision support prevents order duplications, adverse drug events and other risks to patient safety [13–20].

A study by Dexheimer et al. [23] showed that a computerized asthma management system did not significantly improve time to disposition, and Kazley and Teufel [24] found no evidence of a significant difference in outcomes based on stage of EHR meaningful use, suggesting this may indicate a lack of EHR products designed to serve children. However, Chisolm et al. [25] found that asthmatic children were more likely to receive pulse oximetry and systemic corticosteroid treatment when CPOE order sets were used in care. Bartlett et al. [26] showed that integration of a standardized asthma pathway with their EHR was associated with a reduction in average asthma LOS from 2.9 days to 2.3 days among pediatric patients, but no reduction in readmission rates. In this report, we describe the implementation of a pediatric asthma management pathway by a consortium of free-standing children's hospitals in Texas, and evaluate the clinical impact of the integration of this pathway with CPOE in one participating hospital.

The Children's Hospital Association of Texas Safety and Quality Collaborative is a partnership of seven free-standing children's hospitals whose mission is to ensure Texas children have access to effective, high

quality and funded health care [27]. The Association's asthma initiative was established in 2012 to improve asthma care in the ED and inpatient units by developing and facilitating adoption of evidence-based care pathways and use of best practices [28,29].

Methods

Study setting

CHRISTUS Health is an independent delivery network comprised of 49 hospitals with over 15,000 physicians. The Children's Hospital of San Antonio is a free-standing academic medical center with 200 currently staffed beds and 5200 admissions annually, including about 400 asthma cases. It contributed actively to the formulation of the CHAT Asthma Management Pathway. The electronic health record deployed by CHRISTUS Health was MEDITECH Client Server, Version 5.66. Children's Hospital of San Antonio adopted CPOE in December 2014.

Interventions: The CHAT asthma management pathway

The CHAT Asthma Management Pathway ("the Asthma Pathway") is evidence-based, commences in the ED and follows the patient through admission and discharge (Figure 1). The Asthma Pathway focuses on children age 2 through 17 with no other chronic respiratory disease and standardizes assessment of severity and management of asthma. Excluded conditions included bronchiolitis, cystic fibrosis, tracheostomy patients, neuromuscular diseases, cardiac patients, immunodeficiencies, bronchiectasis, bronchopulmonary dysplasia, restrictive lung diseases, autoimmune diseases that affect the lungs, etc. It was developed through a multidisciplinary process involving pediatric hospitalists, ED physicians, nurses, respiratory therapists and pharmacists.

Children's Hospital of San Antonio standardized care delivery by implementing the CHAT Asthma Pathway and its quality improvement measures and best practices [27]. Interventions in the ED included calculating a standardized clinical respiratory score (CRS) (Figure 2) and workflow changes designed to decrease time to first beta-agonist treatment and time to first steroid treatment [27]. Interventions in the inpatient setting included calculating the CRS (Figure 3); spacing beta-agonist treatment aggressively via a respiratory therapist driven protocol; use of a valve holding chamber for beta agonist delivery; starting controller medicine if indicated; delivering a single

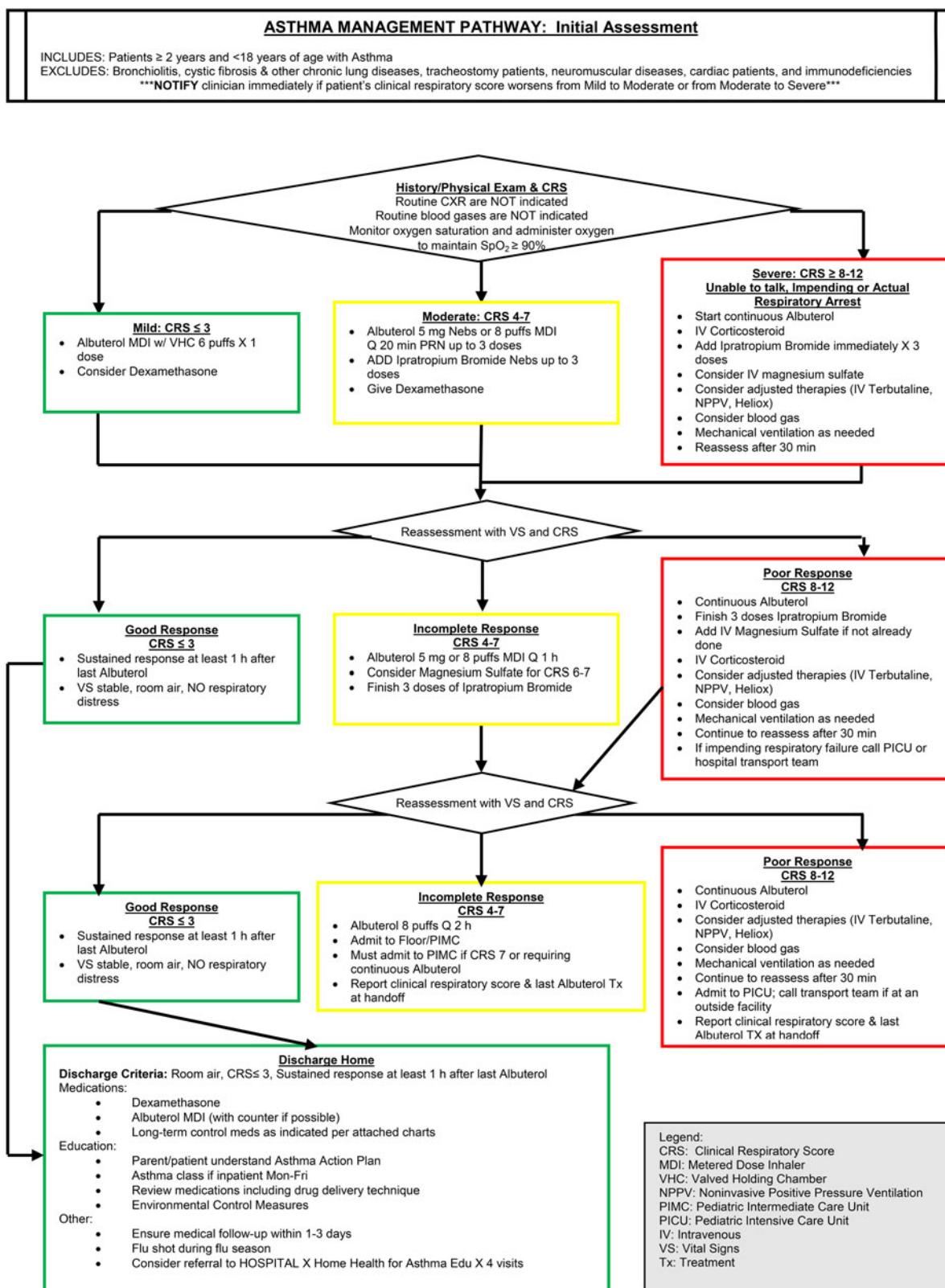


Figure 1. CHAT inpatient pediatric asthma management pathway.

daily dose of dexamethasone for 2 days instead of multi-dose prednisone or prednisolone; referral for pulmonary follow-up; confirmation of primary care provider follow-up; asthma education; use of

standardized discharge criteria and implementation of an evidence-based 16-point discharge checklist of interventions and education to improve asthma management (Figure 4) [27]. The goal was to standardize

Assess	Score 0	Score 1	Score 2
Respiratory Rate	< 2 months: < 50 2- 12 months: < 40 1- 5 years: < 30 > 5 years: < 20	< 2 months: 50-60 2-12 months: 40-50 1-5 years: 30-40 > 5 years: 20-30	< 2 months: > 60 2-12 months: > 50 1-5 years: > 40 > 5 years: > 30
Auscultation	Good air movement, expiratory scattered wheezing or loose rales /crackles	Depressed air movement, inspiratory and expiratory wheezes or rales/crackles	Diminished or absent breath sounds, severe wheezing or rales/ crackles, or marked prolonged expiration
Use of Accessory Muscles	Mild to no use of accessory muscles, mild to no retractions or nasal flaring on inspiration	Moderate intercostal retractions, mild to moderate use of accessory muscles, nasal flaring	Severe intercostal and sub sternal retractions, nasal flaring
Mental Status	Normal to mildly irritable	Irritable, agitated, restless	Lethargic
Room Air SpO2	> 95%	90-95%	< 90%
Color	Normal	Pale to normal	Cyanotic, dusky

Figure 2. Electronic health record screenshot of CHAT pediatric asthma clinical respiratory score embedded in ordering process. ED: emergency department; PED: pediatric; SDO: standard delegated order.

and start the discharge process early so critical components were not delayed or forgotten.

Clinical respiratory score

Clinical decisions in the Asthma Pathway are driven by an objective score assessing clinical severity based on the CRS at specified timed intervals, starting from ED triage and following one of several contingencies through discharge (Figure 2) [27]. The Asthma Pathway is respiratory therapist driven; enabling respiratory therapists to evaluate clinical severity at each stage and determine/modify treatment. This allows physicians and nurses to provide needed care elsewhere, enhancing clinical productivity and efficiency while enabling each to operate at the top of their clinical license. It also expedites weaning of albuterol because the respiratory therapist can titrate multiple times daily based on severity score without calling the physician.

The CRS is determined based on the child's vitals and other clinical parameters, with three levels stratified by acuity of the clinical presentation (from 0 to 2) within six domains (Figure 2). The CRS is evaluated at each stage of the pathway to determine the most appropriate and effective therapy. The maximum score possible is 12. Children with a score greater

than 3 following ED interventions are admitted to the floor for continued treatment and observation. A child scoring greater than 7 is typically admitted to the intensive care unit.

Diffusion of the asthma management pathway and CRS via CPOE

Children's Hospital of San Antonio and the CHRISTUS Health Department of Health Informatics adapted the Asthma Pathway and CRS for use within our MEDITECH CPOE module (Figure 3). With the Asthma Pathway integrated into CPOE, we were able to diffuse this best clinical practice and the CRS most effectively across the facility, and subsequently the enterprise at large.

To expedite care delivery during triage in the ED, we developed a standing delegated order set for nurses so that they could deliver beta agonist treatment immediately based on the CRS when triaging patients (Figure 5). We ensured that all component orders within the set fall fully within and did not exceed the licensed capabilities of registered nurses. While these measures were instituted before CPOE implementation, all were integrated into CPOE to ensure strong clinician uptake and full integration into clinical workflows.

Step 1 - Standardized clinical severity scoring embedded within CPOE order sets:

☐	☐	☐	PED: CRS Score 3 or less
☐	☐	☐	PED: CRS Score 4-7
☐	☐	☐	PED: CRS Score 8 or greater

Step 2 - User selects the appropriate module (e.g., clinical respiratory score 3 or less)

☐	☐	☐	PED: CRS Score 3 or less
Status			
CRS (Clinical Respiratory Score) in order set overview.			
Vital Signs			
☒	Vital Signs	Frequency (NUR)	
	Today Now		Edit
	DEFAULT: With Pulse Ox & each CRS score		
	Frequency With Pulse Ox & each CRS score		
Medications: Albuterol			
	Albuterol 90 Mcg/Act Hfa Inh (Ventolin Hfa Inh)		
	8 PUFF INH ronce STAT		
	Edit		
	DOSE INSTRUCTIONS:		
	With spacer		
Medications: Systemic Steroids			
	Dexamethasone Conc Liq (Decadron Intensol Liq)		
	7.08 MG PO once ONE		
	0.6 MG/KG/DOSE; ONCE PEDI		
	Calculate		
	COMMENTS:		
	BKC **HAZARDOUS WASTE DISPOSAL REQUIREMENT**		
	Please dispose of any waste of this product in the		
	BLACK disposal containers in the designated area.		
	Take with food OR milk to minimize stomach upset		
	Dexamethasone (Decadron)		
	MG PO once ONE		
	Edit		
	DOSE INSTRUCTIONS:		
	0.6 mg/kg/dose; Max dose 12 mg		
	Dexamethasone Sod Phos Inj (Decadron Inj)		
	7.08 MG IM once ONE		
	0.6 MG/KG/DOSE IM; ONCE PEDI		
	Calculate		
	Prednisolone Sod Phos Odt (Orapred Odt)		
	15 MG PO once STAT		
	Edit		
	COMMENTS:		
	2 mg/kg/dose; Max 60 mg/dose		
	Prednisolone Sod Phos Odt (Orapred Odt)		
	30 MG PO once STAT		
	Edit		
	COMMENTS:		
	2 mg/kg/dose; Max 60 mg/dose		
	Prednisolone Sod Phos Odt (Orapred Odt)		
	45 MG PO once STAT		
	Edit		
	COMMENTS:		
	2 mg/kg/dose; Max 60 mg/dose		
	Prednisolone Sod Phos Odt (Orapred Odt)		
	60 MG PO once STAT		
	Edit		
	COMMENTS:		
	2 mg/kg/dose; Max 60 mg/dose		
	Prednisolone Sod Phos Liq (Prednisolone Sod Phos Liquid)		
	23.59 MG PO once ONE		
	2 MG/KG/DOSE; ONCE PEDI		
	Calculate		
Reference			

Figure 3. Standardization of pediatric asthma management using clinical respiratory score and CPOE order sets. *PED: pediatric; CRS: Clinical Respiratory Score.

Adoption of an evidence-based asthma discharge checklist

A key component of the Asthma Pathway was utilization of a 16-point asthma discharge checklist (Figure 4) whose objective was to start the discharge process early and to standardize it so that critical care and education components were not

overlooked [27]. Initially, physicians, nurses and respiratory therapists were responsible for completing the checklist. However, due to inadequate completion the discharge nurse was made fully responsible for ensuring the team performed all checklist tasks, and completion rates increased substantially.

Children's Hospital Association of Texas
Asthma Multidisciplinary Inpatient Discharge Checklist
ASTHMA EDUCATION ON ARRIVAL to EMERGENCY DEPARTMENT/FLOOR
****Initiate on arrival; must be completed in order to discharge patient****

1. **Asthma Action Plan/Education** (Physician fills out. Checked by nurse, respiratory therapist, or asthma educator)

Last name, Initial and Date/Time on Completion

Green Zone:

- Control Medicine – name, dose, method & frequency

Yellow Zone:

- Control Medicine – name, dose, method & frequency
- Quick Reliever – name, dose, method & frequency
- Educate on when to call primary care provider

Red Zone:

- Control Medicine – name, dose, method & frequency
- Quick Reliever – name, dose, method & frequency
- Educate patient in their preferred language
- Educate on when to call 911
- Educate patient on inhaler techniques, specific triggers, co-morbid conditions, — zones above, and general care
- Educate patient on medications including medication reconciliation and new medication availability, cost, and compliance
- Primary Care Provider/Clinic follow up appointment arranged
- Primary Care Provider/Clinic follow up name and phone number
- Date & time of follow-up appointment or when to follow-up with physician

2. Discharge Planning

Last name, Initial and Date/Time on Completion

- Asthma Action Plan completed and in chart
- Asthma Education ordered
- Patient meets discharge criteria à physician, nurse, respiratory therapist notified
- Asthma Action Plan completed by respiratory therapist/asthma educator
- Asthma Education completed
- Primary Care Provider/Clinic follow up appointment arranged
- Family education completed in their preferred language and family signs plan
- Flu shot administered during flu season
- Discharging nurse verifies asthma discharge checklist is complete prior to discharge

Figure 4. Asthma inpatient discharge checklist.

Interventions employed and outcomes of interest

We evaluated the impact of utilization of the Asthma Pathway and CRS before and after implementation of CPOE on four outcomes:

1. Time to first beta-agonist administration from ED check in (percentage of patients receiving beta-agonist therapy within 1 hour of arrival).
2. Time to first steroid administration from ED check in (percentage of patients receiving steroid therapy within 1 hour of arrival).
3. Frequency of ED revisits or readmissions for asthma 30 days and 100 days after discharge.

4. Inpatient and observation length of stay in hospital.

Data from a 50-month study period were analyzed from 27 May 2013 to 27 July 2017. A paper-based version of the Asthma Pathway was implemented in the Children's Hospital of San Antonio ED and inpatient units starting in January 2014. Prior to this date, multiple or no pathways, and diverse paper orders sets were utilized, but were not standardized or evaluated for the extent to which they were evidence-based.

Implementation of CPOE began at Children's Hospital of San Antonio in November 2014, and the

ED PED SDO: Asthma	
ED PED Standing Delegated Orders	
Orders may be initiated in the Emergency Department by an RN/RT before medical staff evaluation	
Patient care is directed by Clinical Respiratory Score (CRS)	
Criteria to initiate this order set are: > Patients 2 years or greater and less than 18 years of age with asthma > Complaint of wheezing, difficulty breathing, or chest pain	
Contraindications: > Bronchiolitis, cystic fibrosis & other chronic lung disease, tracheostomy patients, neuromuscular diseases, cardiac patients, and immune-deficiencies	
Respiratory	
☒ RC Oxygen Therapy (RCPCI) Today Now AS DIRECTED	Edit
☒ RC / NUR Clinical Respiratory (RCPCI) Today Now AS DIRECTED	Edit
SUPPLEMENTAL TEXT: Obtain CRS Score. Notify Provider if CRS is 8 or greater	
Medications	
☐ Albuterol Neb Soln (Proventil Neb Soln, Ventolin Neb Soln) 5 MG NEB ronce ONE	Edit
COMMENTS: As indicated for CRS score of 4-7 if a provider is not available to evaluate patient within 30 minutes	
☐ Ipratropium 0.02% Neb Soln (Atrovent Neb) 0.5 MG NEB ronce ONE	Edit
COMMENTS: As indicated for CRS score of 4-7 if a provider is not available to evaluate patient within 30 minutes	
☐ Albuterol 90 Mcg/Act Hfa Inh (Ventolin Hfa Inh) 8 PUFF INH ronce ONE	Edit
DOSE INSTRUCTIONS: With spacer	
COMMENTS: As indicated for CRS score of 4-7 if a provider is not available to evaluate patient within 30 minutes	

Figure 5. Emergency department pediatric asthma standard delegated order set. *RN: registered nurse; RT: respiratory therapist; Neb: nebulized; Soln: solution.

Asthma Pathway and CRS became electronically integrated with standardized clinical workflows, making it essentially a forced function as electronic order entry became the expected standard of practice in the hospital. Very strong CPOE adoption combined with other process improvements enabled observation of the impact of the use of:

1. Multiple provider-selected non-standardized asthma care order sets pre-CPOE.

2. Paper-based use of the standardized evidence-based CHAT Asthma Pathway and CRS pre-CPOE.
3. Standardized electronic CHAT Asthma Pathway and CRS use with CPOE integration and required CPOE use.
4. Revised discharge checklist employed.

We can thus examine the impact of the CHAT Asthma Pathway and CRS on outcomes of interest

pre- versus post-CPOE implementation, and of the Asthma Pathway using paper-based standardization versus non-standard use of order sets self-selected by providers before the standard pathway was deployed across the facility.

LOS was computed in hours as the date/time of discharge minus the date/time of admission. Only the first visit for each patient was included in the length of stay analysis. Study periods were defined by admission dates as follows:

Period 1, 27 May 2013 to 31 December 2013: Hospitalists usual practice before the quality improvement program commenced and associated interventions were implemented. Usual practice involved use of non-standard, variable paper order sets for the care of asthma as determined by physician preference.

Period 2, 1 January 2014 to 31 October 2014: Use of paper-based, standardized evidence-based order sets plus a CRS throughout the hospital.

Period 3, 1 November 2014 to 31 July 2015: As above, but with evidence-based order sets now integrated into the CPOE module of the EHR, with hospitalists completing all orders within CPOE and the associated clinical decision support.

Period 4, 1 August 2015 to 27 July 2017: All of the above interventions plus introduction and systematic use of a discharge checklist.

Statistical methods

To assess the primary outcome of interest of patient length of stay, a general linear model was used to compare the mean LOS between study periods and to estimate the changes in LOS over time. The model included fixed effects for study time (years), study period (discrete) and the time-period interaction term. Study time was measured in years since 27 May 2013. Study period was an ordinal variable indicating the intervention type. LOS was log transformed for the analysis using the natural logarithm. This was based on residual plots and fit statistics for the regression model, which indicated a poor fit without the data transformation. Model contrasts were specified to estimate the change in LOS over time within each study period, and to compare the mean LOS between study periods. All means reported represent the geometric mean due to the data transformation used for the analysis. The model was used to estimate geometric means with 95% confidence intervals, and statistical significance was assessed at the two-sided 0.05 level.

The percentage of patients who were readmitted within 30 days and 100 days were also estimated by

study period. Fisher's exact test was used to compare the percent of patients readmitted between study periods. If the overall test for differences was significant at the 0.05 level, then all pairwise comparisons between the four study periods were assessed using Fisher's exact test, and *p* values were adjusted for multiple comparisons using the Holm's step-down Bonferroni correction.

Study population

All interventions were monitored by the Quality Department via chart abstraction over a 50-month period. All children presenting with asthma to the ED during the study period were included in the evolving QI treatment regime. The number of charts abstracted was 1494 of initial and repeat visits for 1223 unique patients. ED charts were abstracted for: date/time of triage, CRS, date/time of discharge, date/time to first beta-agonist treatment and date/time to first steroid treatment. Inpatient/observation charts were reviewed to abstract date/time of admission, CRS, date/time of discharge, date/time to beta-agonist, date/time to controller medicine, primary care provider follow up information and completion of discharge checklist. The discharge checklist was used consistently only on inpatient units. Length of stay was used as an indicator of intervention impact.

Demographic data were collected, and insurance data on this specific cohort of patients reflected the overall distribution of insurance type for the general patient population served by this hospital located in the urban core of a major US city. The patients were disproportionately Hispanic (77%) or African American (16%) and of low SES. Insurance type was Medicaid for 79%, commercial insurance 8%, with 5% covered by a preferred-provider organization (PPO), 4% self-pay, 2% Tricare 2% and 2% other. The age breakdown was: 56% of children were 2–6 years old, 33% were 7–11 years old and 11% were 12–17 years old. There were more male (60%) than female (40%) children in our sample.

Results

Shortly after go-live providers at Children's Hospital of San Antonio achieved sustained month over month facility-wide CPOE use rates of 83–89% to present day, with an average monthly use rate of 85%. We present analyses on the outcomes of interest on 1223 unique patients seen during the study period.

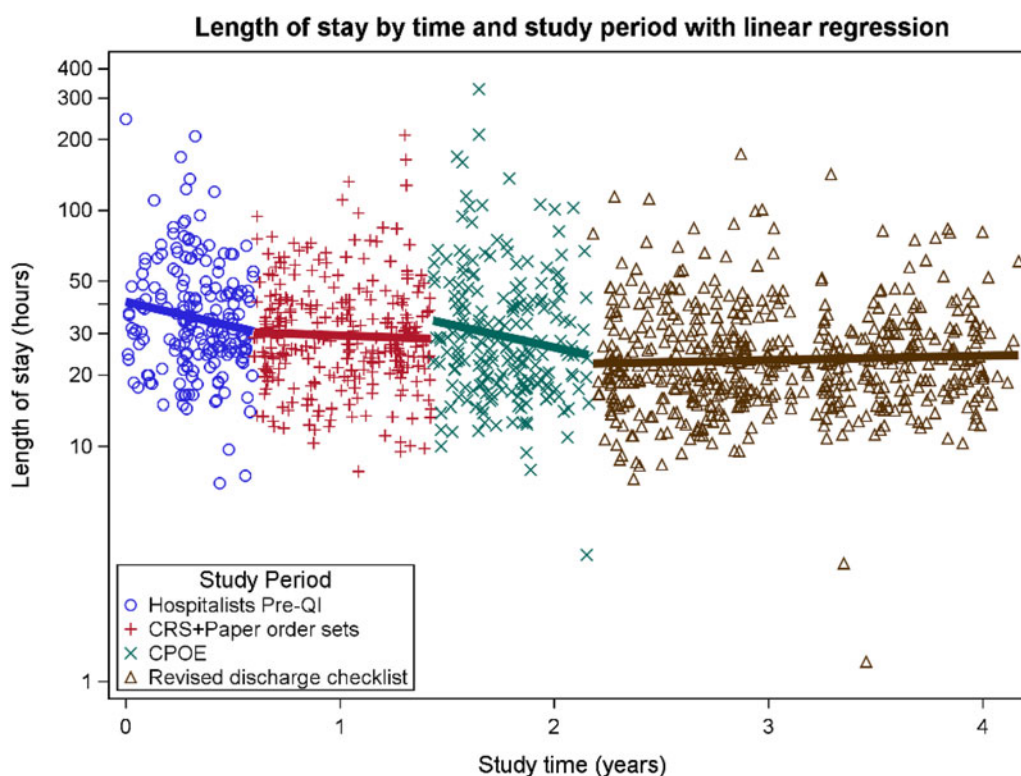


Figure 6. Hospital length of stay reduction associated with quality improvement program and CPOE implementation.

Impact on time to first administration of a beta-agonist or steroid therapy

Analyses demonstrated no statistically significant improvements in time to first beta-agonist or first steroid administration over the observation period. However, integrating the Asthma Pathway into CPOE did not impede time to delivery of therapeutics, as some clinicians had feared before CPOE implementation.

Impact on length of stay

The effect of study time on $\log(\text{LOS})$ significantly depends on the study period ($p=0.015$). That is, the change in LOS over time, i.e. slope, significantly depends on the study period. Therefore, the model was used to estimate the change in $\log(\text{LOS})$ over time (the slopes) for each study period as well as the geometric mean LOS within each study period.

Figure 6 illustrates the impact of the introduction of new elements of the QI program on hospital length of stay. The figure ranges from 10 to 100 h, and excludes 21 observations that are less than 10 and 28 observations that are greater than 100 h. Length of stay tended to decrease within each process improvement period (Figure 6). Overall, there was a statistically significant difference in LOS

between study periods ($p=0.015$). The (geometric) mean LOS in hours during Periods 1–4 were 34.8 (95% CI: 32.2, 37.6), 29.3 (95% CI: 27.5, 31.3), 29.0 (95% CI: 27.0, 31.3) and 23.1 (95% CI: 22.1, 24.2). All pair-wise comparisons between study periods were statistically significant (adjusted $p \leq 0.003$) except for Periods 2 and 3 (adjusted $p=0.83$). During the first period prior to QI intervention, a 1-year increase in time was associated with a 38% decrease in LOS ($p=0.054$). During the second period, when paper evidence-based order sets and use of a CRS were introduced, a 1-year increase in time was associated with a 7.2% decrease in LOS ($p=0.56$). In the third period, when evidence-based order sets and the respiratory score were utilized through CPOE, a 1-year increase in time was associated with a 37% decrease in LOS ($p=0.02$). In the fourth and last period, when a discharge checklist was utilized systematically, a 1-year increase in time was associated with a 4% increase in LOS ($p=0.33$).

The geometric mean LOS decreased from 40.8 h in May 2013 to 30.7 h in December 2013 (24.8%). Similarly, the geometric mean LOS decreased from 30.2 h in January 2014 to 28.4 h in October 2014. During Period 3, the geometric mean LOS declined from 33.8 h in November 2014 to 24.3 h in July 2015 (28.1%). The geometric mean LOS increased 4% per year ($p=0.33$) during Period 4.

The reductions in length of stay observed were not attributable to any large systematic decrease in CRS, which remained relatively stable year over year. The mean CRSs from early implementation and for comparable periods 2 and 3 years later varied little. Completion of the discharge checklist rose sharply from 18% to 72% of patients admitted over the course of the study period.

Impact on hospital readmission rates

The percentage of patients who were readmitted within 30 days of the index or initial hospital visit was compared across study periods. The proportion of patients readmitted within 30 days tended to decrease throughout the course of the study and was 1.06%, 1.06%, 0.48% and 0.74% during study periods 1, 2, 3 and 4, respectively (usual practice, evidence-based paper order sets plus CRS, the latter used via CPOE and lastly the introduction of a discharge checklist). There was, however, no statistically significant difference in the proportion of patients readmitted within 30 days ($p = 0.83$).

The percentage of patients readmitted within 100 days of the index hospital visit also decreased by the end of the study period, with a statistically significant reduction in the proportion of patients who were readmitted within 100 days of the initial, index visit ($p = 0.008$). During the first period without any standardization of evidence-based care (Period 1), 7.4% (14/189) of the patients were readmitted within 100 days. Compared with Period 1, the proportion of 100-day readmissions was reduced to 2.1% (6/284) during Period 2 after introduction of a standardized, evidence-based care pathway using paper order sets and a CRS (adjusted $p = 0.04$). It was reduced to 3.9% (8/207) during Period 3 when CPOE was implemented (adjusted $p = 0.53$), and to 2.2% (12/543) during the deployment of a revised discharge checklist in Period 4 (adjusted $p = 0.01$). There were no significant differences in the 100-day readmission rates between periods 2, 3, or 4 (adjusted $p \geq 0.64$).

These findings demonstrate that as the multidisciplinary care team was able to decrease the length of stay for patients treated for asthma in the facility, these efforts did not cause a concomitant increase in readmission rates by discharging patients too soon with respect to their clinical status and readiness to go home.

Discussion

The primary positive outcomes of this multi-component clinical care improvement effort were meaningful

reductions in LOS and rate of acute hospital readmissions occurring in a predominantly Hispanic and African American cohort of children. This comprehensive approach to standardizing asthma care throughout our facility, and a leveraging CPOE as vehicle to deliver QI interventions, was highly successful. No improvements were achieved with regard to decreasing the time to first administration of a beta-agonist and first administration of steroid therapy. Children's Hospital of San Antonio is located in the urban core or center of one of the 10 largest cities in the US, and we suspect from discussions with the ED physicians that efforts to accelerate first administration of these agents were hampered by competing urgent and emergent care imperatives faced in an extremely busy downtown emergency department. Achieving clinically important reductions in time to first administration of these therapeutics remains a priority for continuing asthma care QI efforts within the hospital.

As this study demonstrates, continuous improvement in care delivery for asthma in children can reduce hospital length of stay, which indirectly reduces exposure to risk of harm during hospitalization, as well as associated care costs (which account for a majority of the \$50 billion in annual US asthma spend). To our knowledge, this study is one of the first hospital-based quality improvement projects to demonstrate significant improvement in clinical outcomes within a predominately Hispanic, underserved, and Medicaid-insured population, and to sustain this improvement year over year.

We were surprised to observe the LOS improvement during the first period of analysis prior to implementation of specific QI measures, and suspect that this may be due to a change in hospital academic affiliation and the discontinuation of residents providing patient care. All patients admitted during this period were cared for directly by attending physicians, which could have involved less delays in patient throughput due to pre-rounds, rounds and noon conferences that are integral to care delivery in a teaching facility. These attending physicians were able to rapidly improve their own care delivery as they adapted to their new hospital environment, learned how to use the CPOE module of the EHR, and became familiar with hospital staff. In addition, a significant Hawthorne effect may be operative in that the care team was well aware of the CHAT and QI Initiative prior to its implementation, and further this facility was the last in the region to go live with CPOE but aware of the timeline for their engagement of evidence-based practices in the upcoming adoption.

A significant limitation of this study is our inability to assign specific attribution to each component of the asthma care quality improvement initiative. However, we suspect that institution of the evidence-based CHAT Asthma Pathway and CRS achieved the large length of stay reductions observed, initially via paper orders and then amplified through their build into CPOE, which enabled rapid and full distribution of the evolving practice standards throughout the facility. Unfortunately, we are unable to quantitatively differentiate the impact of paper versus electronic adoption of the Asthma Pathway, respiratory score and other tools deployed. Further research on this question would be valuable and is warranted.

Other study limitations include our inability to identify, evaluate systematically and control for the impact of other interventions patients may have received as outpatients or inpatients at other facilities, including use of additional therapeutics, patient/familial education and post-discharge follow up or asthma preventive care. However, we note that this challenge exists for other QI efforts delivered in clinical context and in vivo. It is conceivable that environmental factors and stimuli that typically precipitate asthma exacerbations varied from year to year over our study period. However such fluctuations were not widely perceived in the clinical community where the hospital is located. Adoption of the discharge checklist likely also contributed to length of stay reduction, but we are unable to distinguish its' effect from that of CPOE implementation or use of a standardized evidence-based clinical care pathway. Without a randomized clinical trial exerting precise control on the deployment of various interventions, quality improvement efforts of this kind may remain unable to assign specific attribution of effect to cause. These results may not, as a result, be generalizable to other institutions, and adaptation to the specific clinical, patient demography and institutional setting is imperative. Furthermore, the interventions deployed were not randomized, and the reported impact of each of the subsequent interventions in the evolving QI regime described was cumulative in nature.

The results of this evaluation align with those of Banasiak and Meadows-Oliver [4] showing the effectiveness of clinical pathways in reducing inpatient length of stay for pediatric asthma. Our findings also parallel those of Chen et al., which showed that clinical pathways can reduce asthma LOS but had less impact on hospital readmissions [5]. Our patient population differed from most reported studies in the literature in having evaluated and demonstrated the

clinical impact of QI interventions within a predominantly Hispanic, lower SES and publicly insured population.

Conclusions

We observed a substantial reduction in hospital length of stay associated with utilization of an evidence-based, best practice asthma management pathway incorporating a CRS, first via paper order sets and then within CPOE, combined with a tool to expedite appropriate discharge. In addition, there was a significant reduction in the proportion of patients who were readmitted within 100 days of the initial hospital visit. To our knowledge, this is one of the first studies to demonstrate improved, reduced LOS and 100-day hospital readmissions within a predominantly Hispanic, lower SES and publicly insured patient population. The time to first administration of a beta-agonist and first administration of a steroid did not decrease during the study period, and remain critical objectives for further quality improvement efforts to improve our asthma outcomes.

CPOE conveys clinical value by eliminating handwriting illegibility as a source of care related errors and delays, by reducing variations in care not supported by evidence, and by preventing harm events through clinical decision support alerts. Because utilization of the Asthma Pathway was also high during the pre-CPOE use of standardized paper order sets, we suspect that the observed reduction in length of stay is due to a combination of the evidence-based standardization of care, first through paper orders sets and then much augmented by adoption of CPOE with clinical decision support. The systematic use of a discharge checklist likely also contributed by expediting hospital release through improved care team coordination and reduction of preventable discharge delays. CPOE appeared to improve the impact of a best practice pathway to reduce asthma length of stay. Increasing pressure exists for hospitals to improve care quality and decrease cost of care, and this study of multi-component quality improvement exemplifies how this can be achieved and sustained in even the most challenging of patient populations.

Acknowledgements

The authors are grateful to the physicians, nurses, respiratory therapists and other caregivers of the Children's Hospital of San Antonio for their engagement and pursuit of clinical excellence; to the clinical and administrative leaders of Children's Hospital of San Antonio; and to the

clinical informaticists of CHRISTUS Health Department of Health Informatics that supported physician adoption of CPOE across the facility. We are also thankful for the support system, activities and structure of CHAT, which were central to initiating and driving this asthma quality improvement process.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

No funding was used in the completion of this evaluative research.

References

1. NHIS. National health interview survey (NHIS 2014). Hyattsville, MD: National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention; 2015. Available from: https://www.cdc.gov/asthma/most_recent_data.htm.
2. Akinbami LJ, Moorman JE, Liu X. Asthma prevalence, health care use, and mortality: United States, 2005–2009. *Natl Health Stat Rep* 2011;12:1–14.
3. Chung HS, Hathaway DK, Lew DB. Risk factors associated with hospital readmission in pediatric asthma. *J Pediatr Nurs* 2015;30:364–384.
4. Banasiak NC, Meadows-Oliver M. Inpatient asthma clinical pathways for the pediatric patient: an integrative review of the literature. *Pediatric Nursing* 2004;30:447–450.
5. Chen KH, Chen C, Liu HE, Tzeng PC, Glasziou PP. Effectiveness of paediatric asthma clinical pathways: a narrative systematic review. *J Asthma* 2014;51:480–492.
6. Okelo SO, Butz AM, Sharma R, Diette GB, Pitts SI, King TM, Linn ST. Interventions to modify health care provider adherence to asthma guidelines: a systematic review. *Pediatrics* 2013;132:517–534.
7. Bergert L, Patel SJ, Kimata C, Zhang G, Matthews WJ. Linking patient-centered medical home and asthma measures reduces hospital readmission rates. *Pediatrics* 2014;134:e249–e256.
8. Meyer H. Targeted care improvements show promising results for treating children with asthma. *Health Aff (Millwood)* 2011;30:404–407.
9. Billett AL, Colletti RB, Mandel KE, Miller M, Muething SE, Sharek PJ, Lannon CM. Exemplar pediatric collaborative improvement networks: achieving results. *Pediatrics* 2013;131:S196–S203.
10. Britto MT, Vockell A-LB, Munafo JK, Schoettker PJ, Wimberg JA, Pruett R, Yi MS, Byczkowski TL. Improving outcomes for underserved adolescents with asthma. *Pediatrics* 2014;133:e418–e427.
11. Nkoy F, Bernhard Fassel B, Stone B, Uchida DA, Johnson J, Reynolds C. Improving pediatric asthma care and outcomes across multiple hospitals. *Pediatrics* 2015;130:e1602–e1610.
12. Fassel BA, Nkoy FL, Stone BL, Srivastava R, Simon TD, Uchida DA, Koopmeiners K, et al. The Joint Commission children's asthma care quality measures and asthma readmissions. *Pediatrics* 2012;130:482–491.
13. Charles K, Cannon M, Hall R, Coustasse A. Can utilizing a computerized provider order entry (CPOE) system prevent hospital medical errors and adverse drug events? *Perspect Health Inf Manage* 2014;11:1b.
14. Nuckols TK, Smith-Spangler C, Morton SC, Asch SM, Patel VM, Anderson LJ, Deichsel EL, Shekelle PG. The effectiveness of computerized order entry at reducing preventable adverse drug events and medication errors in hospital settings: A systematic review and meta-analysis. *Syst Rev* 2014;3:56. doi:10.1186/2046-4053-3-56
15. Yu FB, Menachemi N, Berner ES, Allison JJ, Weissman NW, Houston TK. Full implementation of computerized physician order entry and medication-related quality outcomes: a study of 3364 hospitals. *Am J Med Qual* 2009;24:278–286. doi:10.1177/1062860609333626
16. Georgiou A, Prgomet M, Paoloni R, Creswick N, Hordern A, Walter S, Westbrook J, et al. The effect of computerized provider order entry systems on clinical care and work processes in emergency departments: a systematic review of the quantitative literature. *Ann Emerg Med* 2013;61:644–653.
17. Georgiou A, Prgomet M, Markewycz A, Adam E, Westbrook JI. The impact of computerized provider order entry systems on medical-imaging services: a systematic review. *JAMIA* 2011;18:335–340.
18. Lyons AM, Sward KA, Deshmukh VG, Pett MA, Donaldson GW, Turnbull J. Impact of computerized provider order entry (CPOE) on length of stay and mortality. *JAMIA* 2016;ocw091. doi:10.1093/jamia/ocw091.
19. Schreiber R, Peters K, Shaha SH. Computerized provider order entry reduces length of stay in a community hospital. *Appl Clin Inf* 2014;685–698.
20. Amarasingham R, Plantinga L, Diener-West M, Gaskin DJ, Powe NR. Clinical information technologies and inpatient outcomes: a multiple hospital study. *Arch Intern Med* 2009;169:108–114.
21. Ducharme FM, Chalut D, Plotnick L, Savdie C, Kudirka D, Zhang X, Meng L, et al. The pediatric respiratory assessment measure: a valid clinical score for assessing acute asthma severity from toddlers to teenagers. *J Pediatr* 2008;152:476–480. <http://www.ncbi.nlm.nih.gov/pubmed/18346499>.
22. Smith SR, Baty JD, Hodge D. Validation of the pulmonary score: an asthma severity score for children. *Acad Emerg Med* 2002;9:99–104. <http://www.ncbi.nlm.nih.gov/pubmed/11825832>.
23. Dexheimer JW, Abramo TJ, Arnold DH, Johnson K, Shyr Y, Ye F, Fan K-H, et al. Implementation and evaluation of an integrated computerized asthma management system in a pediatric emergency department: A randomized clinical trial. *Int J Med Inf* 2014;83:805–813.

24. Kazley AS, Teufel RJ. Advanced electronic health record use and quality of asthma care in hospitals that care for children. *Int J Healthcare Technol Manage* 2015;15:22–30.
25. Chisolm DJ, Scheck McAlearney A, Veneris S, Fisher D, Holtzlander M, McCoy KD. The role of computerized order sets in pediatric inpatient asthma. *Pediatr Allerg Immunol* 2006;17:199–206.
26. Bartlett KW, Parente VM, Morales V, Hauser J, McLean HS. Improving the efficiency of care for pediatric patients hospitalized with asthma. *Hosp Pediatr* 2017;7:31–38.
27. Children’s Hospital Association of Texas, All children need children’s hospitals. Available from: <http://cha-texas.com/> [last accessed 12 April 2018].
28. Children’s Hospital Association of Texas, The pediatric asthma collaborative. Available from: <http://cha-texas.com/the-pediatric-asthma-collaborative/> [last accessed 12 April 2018].
29. Children’s Hospital Association of Texas, CHAT Asthma Quality and Safety Collaborative Comprehensive Site Workbook. Available from: <http://chatexas.com/wp-content/uploads/2014/11/CHAT-Asthma-comprehensive-site-workbook.pdf> [last accessed 12 April 2018].