Journal of Nursing & Interprofessional Leadership in Quality & Safety

Volume 5 | Issue 1 Article 3

January 2022

Nurse-Initiated Treatment Reduces Costs for Acute Asthma in a Pediatric Emergency Department

Michael D. Johnson MD, MS
University of Utah Department of Pediatrics, mike.johnson@hsc.utah.edu

Minkyoung Yoo PhD
University of Utah Division of Epidemiology, minkyoung.yoo@pharm.utah.edu

Richard E. Nelson PhD
University of Utah Division of Epidemiology, richard.nelson@utah.edu

Amanda K. Nielson MD
University of Utah School of Medicine, amanda.nielson@hsc.utah.edu

Lauren Allen MAS
Intermountain Healthcare Primary Children's Hospital, lauren.allen@imail.org

See next page for additional authors

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Abstract

Standardized emergency department (ED) pathways can improve care delivery to children with acute asthma, though their impact on hospitalization and costs is unclear. An Acute Asthma Care Pathway (AACP) that facilitates nurse initiation of treatment was implemented at a tertiary care pediatric ED using standard quality improvement methodology. The impact of implementation was assessed using process control methodology and multivariable time series analyses between pre- and post-implementation periods. Provision of a steroid within 30 minutes and 60 minutes of arrival increased by 21 and 22 percentage points respectively, IV magnesium sulfate administration increased by 30 percentage points, the proportion hospitalized decreased from 44.8% to 32.2%, and mean direct costs per patient decreased from $2,663 to $2,303 (13.5%). In multivariable analysis, these improvements remained significant. Implementation of the AACP improved timeliness of treatment, hospitalization, and direct costs of children receiving ED treatment for acute asthma.

Keywords

pediatric asthma, acute asthma care pathway, pediatric emergency department, acute asthma, cost of care, quality improvement

Authors

Michael D. Johnson MD, MS; Minkyoung Yoo PhD; Richard E. Nelson PhD; Amanda K. Nielson MD; Lauren Allen MAS; Nanette Dudley MD; Brandon Andersen RRT; Amanda Orme DNP, CPNP-AC; Cameron McFarland NP-C; and Michael Mundorff MBA, MHSA

Introduction

Asthma is the most common chronic illness of childhood (Bloom et al., 2012). Hospitalization is a primary driver of direct costs of asthma in children (Bahadori et al., 2009), contributing $3.9 billion of the $5.9 billion in total pediatric asthma costs estimated in 2017 (Sullivan et al., 2017). Implementation of a standardized pathway for emergency department (ED) treatment can reduce hospitalization of children with asthma (Gray et al., 2016) but may not reduce costs. Prior implementations of standardized pathways either demonstrated reduced costs using pre-post comparison (Johnson et al., 2018), or showed no effect using interrupted time series (ITS) analysis (Rutman et al., 2016).

The ED described in this paper, at a tertiary care pediatric hospital serving the Intermountain West, has used an asthma order set since 2002, based on and updated in alignment with national guidelines (National Asthma Education and Prevention Program, 2007). In 2014, 45% of 985 children with a primary diagnosis of asthma (ICD-9 493.xx) were hospitalized after treatment in this ED, almost double the median proportion among other U.S. children's hospitals that same year (24%) (Bourgeois et al., 2014). Hospital leadership prioritized reduction of asthma admissions from the ED in alignment with the organizational goals of the healthcare system (James & Savitz, 2011). In 2014, the hospital prioritized development and implementation of a new Acute Asthma Clinical Pathway (AACP), with a goal to safely reduce the proportion of children hospitalized after treatment for acute asthma in the ED.

The objective of this paper is to describe the implementation of an ED clinical pathway for children with acute asthma and investigate the impact on care delivery and outcomes including direct costs.

Methods

Setting

This study was conducted at an urban tertiary care freestanding children's hospital with 34 ED beds and approximately 42,000 ED visits and 13,000 hospitalizations annually. The ED is staffed by pediatricians, pediatric emergency medicine physicians, fellows, residents, nurse practitioners, nurses, and respiratory therapists (RTs). Patients are seen according to nurse-assigned triage acuity by the next available provider, and clinicians are not assigned to specific conditions or severities.

Planning the Intervention

In January 2015, the physician champion (MJ) and senior data analyst (MM) conducted an initial investigation of ED asthma care quality including an evidence review, retrospective chart review of baseline care delivery, interview of asthma quality directors at five other pediatric EDs with published pediatric asthma pathways, and statistical analysis comparing this hospital's ED performance to other pediatric EDs. They found an opportunity for improvement in the timing of medication delivery and proportion of children hospitalized after ED treatment.

Implementation Team

A multidisciplinary development team was formed including the ED Quality Improvement (QI) director (ND) (Dudley et al., 2015), an ED nurse practitioner (AO), a QI project coordinator (LA), the nursing quality director, an administrative sponsor familiar with prior improvements in asthma care delivery (Miescier et al., 2005), a pediatric hospitalist experienced in inpatient asthma QI (Nkoy et al., 2015), and a data analyst. This team developed the AACP beginning in March 2015 with input from ED clinicians, a hospital QI oversight committee, pharmacists, and ICU and hospitalist physicians. The AACP addresses specific gaps in care delivery including slow initiation of albuterol and steroid treatments, mismatch of care delivery timeliness with patient severity, and underuse of intravenous magnesium sulfate (IVMg).

Project Goal

The overall goal of the project was to reduce hospitalization without increasing returns after ED discharge, while minimizing the adverse effects of cognitive bias (Russ et al., 2013) through development and implementation of minimally complex clinical decision support, essential to overcome barriers to successful guideline implementation (Cabana et al., 1999).

The Intervention

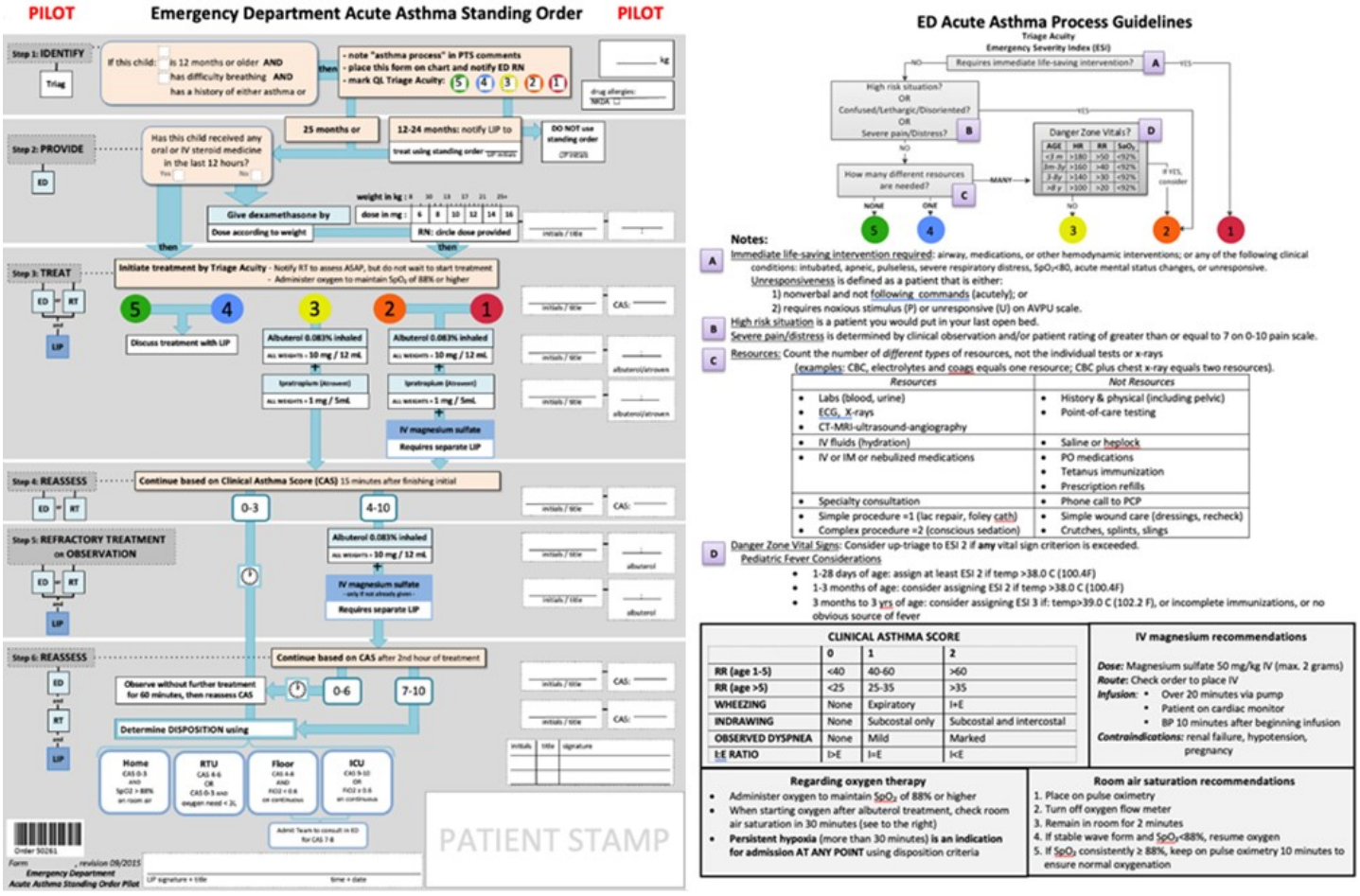
Description of the Acute Asthma Clinical Pathway

The AACP follows the structure of the Acute Care Model (Iyer et al., 2011) for ED care, by addressing *therapeutic reliability* of interventions, *diagnostic accuracy*, *segmentation* of patients by risk, and *accurate disposition*. The team compiled elements of the AACP into a single-page decision support tool for care delivery. The AACP, outlined in **Figure 1**, includes the following elements:

1. **Severity-based guidance for standardized medication delivery**, based on previously published pathways with significant reductions in hospitalization (Norton et al., 2007; Gildenhuys et al., 2009).
2. A **multi-stage nurse-initiated standing order**, previously shown to decrease time to treatment in asthma (Zemek et al., 2012; Qazi et al., 2010), improving therapeutic reliability by ensuring timely treatment regardless of ED crowding (Bekmezian et al., 2013). The AACP outlines an expanded role for nurses and RTs to deliver medications by standing order using validated standardized assessments (Johnson et al., 2017; see #6).
3. **A standing order nested in a treatment algorithm** that structures care delivery and patient disposition in a clear graphical format. The AACP is integrated into workflow using a single form that can be initiated by a triage nurse, delivering decision support at the time and location of decision-making by persisting on the patient's chart once selected by the triage nurse.
4. **Simple screening questions used by nurses to identify patients for treatment** (Sanders et al., 2007), a diagnostic strategy at least as accurate as clinician judgment (Zemek et al., 2012).
5. **Oral dexamethasone** for any child with acute asthma and visible difficulty breathing. **Timely administration of steroids** reduces hospitalization and ED length of stay (Rowe et al., 2001).
6. **Treatment stratification according to patients' hospitalization risk**, a measure of validity used in the development of clinical asthma scoring instruments (Bekhof et al., 2014). Local comparative data showed that nurses' application of the Emergency Severity Index (ESI) produced better segmentation by hospitalization risk than any clinical asthma score obtained prior to ED treatment (Johnson et al., 2017).
7. **Use of a standardized initial inhaled dose of albuterol and ipratropium** for patients with hospitalization risk of 40% or greater (ESI 1-3). Continuous dosing has improved efficacy over intermittent dosing in severe asthma (Camargo et al., 2003) and minimizes delays. The efficacy of ipratropium in decreasing hospitalization is well established (Griffiths & Ducharme, 2013).
8. **Use of IVMg** for any patient with hospitalization risk >80% (ESI of 1 or 2 on arrival [Parkin et al., 1996] or clinical asthma score ≥4 after initial treatment), similar to inclusion criteria in trials that demonstrated effect of IVMg on hospitalization (Shan et al., 2013).
9. **All children with lower hospitalization risk** (ESI 4-5) **receive treatment beyond dexamethasone at physician discretion**, allowing flexibility in the choice and duration of treatment for children with low hospitalization risk.
10. **Standardized criteria for disposition after ED treatment** allows time for ED treatment to improve asthma symptoms prior to a disposition decision.

Figure 1

One-Page AACP Decision Support Tool Used in Clinical Care



Implementation of the Acute Asthma Clinical Pathway

Implementation of the AACP was based on The Model for Improvement (Langley et al., 2009), a QI methodology with proven utility in efforts to improve ED care delivery to children (Mahajan, 2011; Gray et al., 2016). Following hospital approval, implementation began in March 2015 by presenting baseline data and planned changes separately to ED, ICU, and Hospitalist physicians and staff. This data included graphical comparisons of hospitalization for asthma at the hospital's ED compared to other pediatric EDs (patient outcome), timing of medication delivery according to patient severity (process measures), and variation in asthma hospitalization by ED physician. Feedback from these meetings was used to refine the AACP. Baseline data was used to set entry (one statistical deviation above the mean), target (80% within 60 minutes), and stretch (80% within 30 minutes) goals for process measures.

Using clinicians' suggestions, the data feedback plan focused on the proportion of eligible patients included in the new process. Distribution of statistical process control (SPC) charts on process and control measures was limited to the implementation team. The AACP recommends higher initial albuterol doses than was prior practice for most patients, so strategies for consistent coding and billing were implemented so as to not interpret higher dosing as higher acuity.

Outcome Measures and Data Collection

The institution's enterprise data warehouse (EDW) was used to identify cases, defined as any ED visit in a child 1-18 years old with a primary diagnosis of asthma (ICD-9 493.xx or ICD-10 J45.xx).

The primary outcome measure included hospitalization from the ED and direct costs. Process measures included timing of steroid delivery, timing of albuterol delivery, and use of IVMg. Patient severity was controlled for in the analysis using baseline clinical characteristics including patient severity of illness (ESI), triage vital signs, and history of ED, ICU, or hospital admission 12 months prior to the index visit. Balancing measures included ED length of stay (LOS) and ED returns, defined as a visit with a diagnosis of asthma in any billed field to any facility in the same healthcare network within 50 miles of the hospital for 7 days following discharge from the ED.

Three trained abstractors (MJ, AN, and CM) obtained patient-level data for secondary outcomes from retrospective review of paper and electronic ED records, combining manually abstracted data with EDW data in a secure REDCap database (Harris et al., 2009). All other data was obtained by electronic query from the EDW. Direct costs include both variable and fixed costs and were adjusted for inflation using the Consumer Price Index for Hospital Services in 2016 dollars.

Analyses

SPC charts and rules for special cause variation were used to assess change during process implementation. SPC charts were generated using JMP Pro 14.0 (SAS Institute) with 3 sigma limits and centerlines adjusted at major implementation timepoints.

For statistical analysis, all outcomes were compared between pre-implementation (June 2013-February 2015) and post-implementation (June 2015-May 2016 for medication delivery and June 2015-May 2017 for hospitalization) periods, excluding the implementation period (March 2015-May 2015). Timing of steroid and albuterol were considered only in cases receiving those medicines during their ED treatment. The proportion of cases receiving IVMg included all cases as the denominator. Finally, ED LOS was evaluated similarly to primary outcomes. All outcomes were analyzed at the patient level except descriptive statistics on visit characteristics, which were analyzed at the visit level.

Summary descriptive statistics of patient demographics and outcomes included mean and standard deviation for continuous variables (assessed by Student's t test) and counts and percentages for categorical variables (assessed by Chi-square test). The intervention effect of AACP implementation was then assessed using an interrupted time series (ITS) approach with multivariable generalized estimating equations (GEE). An ITS approach is helpful in this situation because it can correct for overall time trends in outcomes while also controlling for patient-level covariates. In GEE models, a logit link and binomial variance function was used for hospitalization and clinical outcomes and a log link and gamma variance function for the cost outcome. Similarly, GEE with square root link and Gaussian variance function was used for the hospital LOS. A p-value of 0.05 or less was used for statistical significance. All analyses were performed using SAS 9.4 and STATA 12.1. Systolic hypotension was defined according to age-based guidelines (Kleinman et al., 2010).

Ethical Considerations

A review by the institutional review board of the university affiliated with the children's hospital approved the project as a quality improvement initiative. All data was de-identified and there were no conflicts of interest for any authors.

Results

Process Implementation

The clinical workflow for the AACP was refined using a one-week trial period in a small group of providers and patients just prior to launch. The AACP was launched in June 2015 by stocking the single-page decision support tool at the triage desk and sending an email notification to all providers. Brief role-specific descriptions of the process change were attached to computer workstations for the first month following launch. Launch of

the AACP was followed by a series of four Plan-Do-Study-Act (PDSA) cycles to embed the AACP into usual clinical workflow.

The first PDSA cycle addressed a lack of familiarity among nursing staff with clinical asthma scoring, offering a "scoring card" that each nurse submitted after simultaneously completing asthma scoring with an RT to receive a chocolate bar (September 2015; **Figure 2**). The second PDSA cycle followed feedback that 20 mg albuterol dosing caused unexpectedly long administration times, prompting simplification of drug choices (October 2015; Figure 2). The third PDSA cycle followed nonattainment (69%) of the goal for steroid delivery within 60 minutes (80%) in the first four months following launch. Frontline nurses identified lack of awareness of the AACP as a possible cause, so the study team began a weekly system of recognition and reward (December 2015; Figure 2). The ED team delivering steroid to a patient the fastest the preceding week was recognized in a group email and received chocolate bars. This accompanied a sharp rise in the attainment of this goal from 77% to 90% within two months (**Figure 3**). A fourth PDSA followed feedback from RTs that system-wide pharmacy policies did not allow them to administer oral dexamethasone. The study team helped develop a policy in coordination with supportive hospital leadership allowing RTs to administer oral dexamethasone in line with applicable state professional code (April 2016; Figure 3). Over a 7-month period of intensive inclusion monitoring of all respiratory patients, 86% of all intended patients were treated using the AACP.

Figure 2

Annotated P Chart of Proportion Hospitalized; Implementation of PDSA Cycles

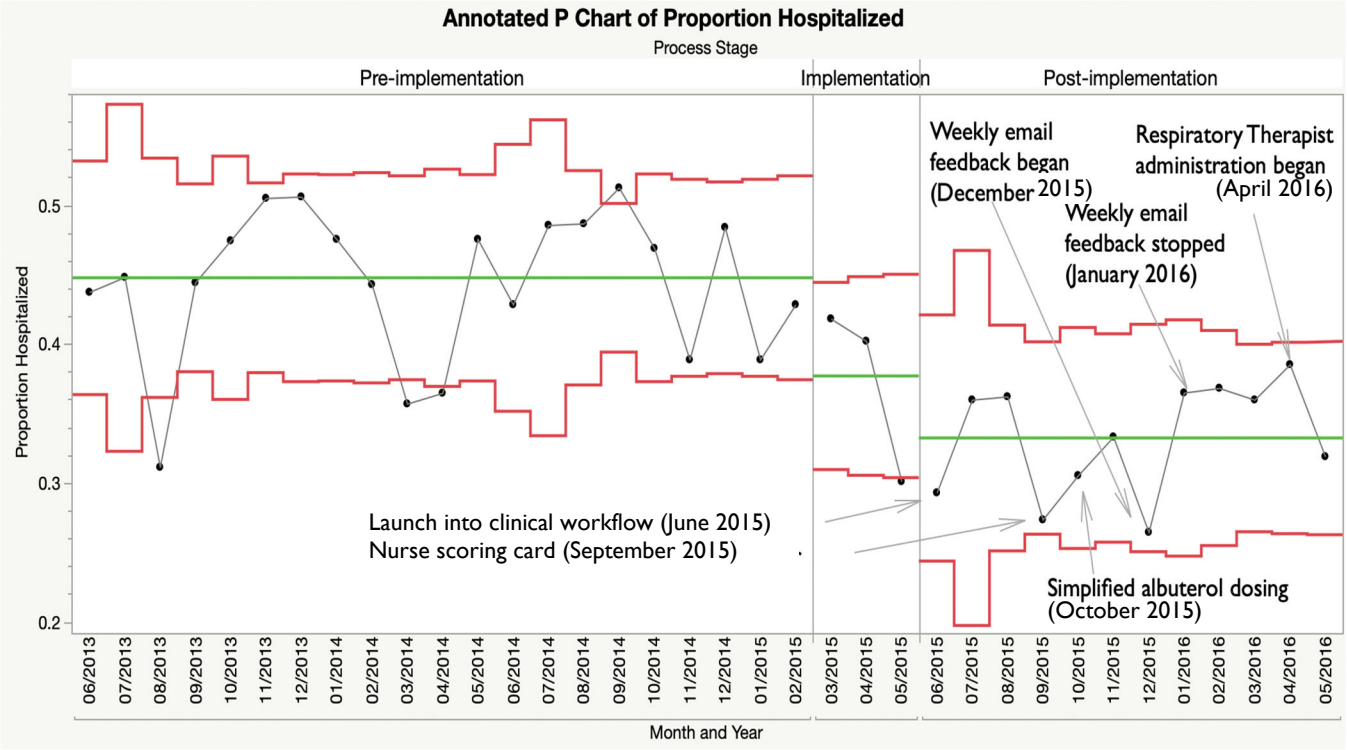
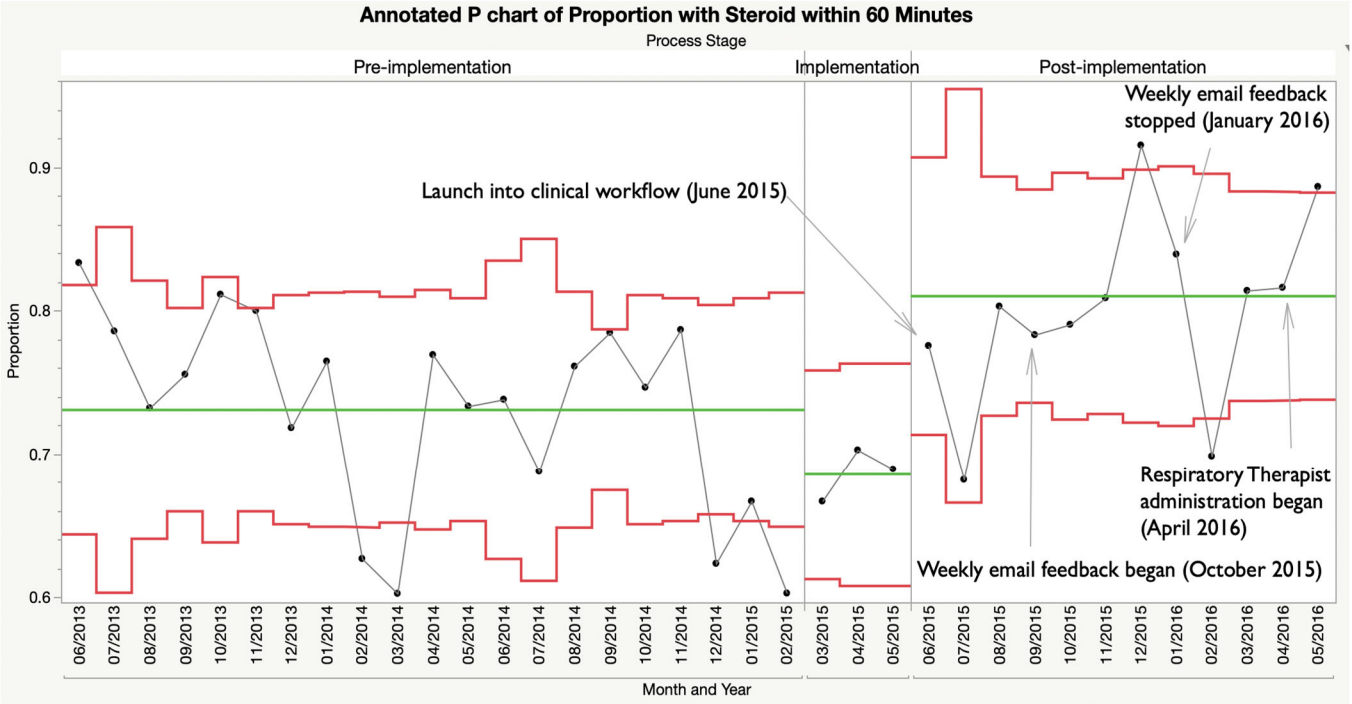


Figure 3

Annotated P Chart of Proportion with Steroid in 60 Minutes; Implementation of PDSA Cycles



Outcomes

For statistical analysis of all outcomes, the pre-implementation period from June 2013-February 2015 included a total of 1,648 visits from 1,290 unique patients. The post-implementation period included 1,833 visits from 1,350 unique patients. Patient-level and visit-level characteristics are outlined in **Table 1**. Age, gender, and payer types were comparable between pre- and post-implementation periods.

Primary Outcomes

The average uncontrolled proportion hospitalized was 44.8% pre-implementation and 32.2% in the post-implementation period (**Table 2**). In multivariable analysis this decrease in hospitalization was statistically significant (risk difference -0.09, 95% CI -0.15 to -0.04, p=0.001; **Table 3**).

Direct Costs

The mean direct cost decreased from a baseline of $2,663 (SD $979; median $3,691) pre-implementation to $2,303 (SD $950; median $3,825) in the post-implementation period (p=0.005; Table 2). These relationships persisted in multivariable analysis, with the predicted direct cost of $517 less post-implementation (CI $61-$974; p=0.026) compared to the pre-implementation period (Table 3).

Process and Balancing Measures

In unadjusted models, implementation of the AACP significantly increased the chance of children receiving steroids and albuterol both within 30 and 60 minutes of arrival in the ED (Table 2). Delivery of IVMg also increased by 30 percentage points. After controlling for patient characteristics, timely delivery of steroids improved within 30 minutes (risk difference 0.08, 95% CI 0.03-0.14, p=0.003) and 60 minutes (risk difference 0.11, 95% CI 0.01-0.22, p=0.035), while the influence of implementation of the AACP on timely delivery of albuterol was not statistically significant (30-minute risk difference 0.02, p=0.65; 60-minute risk difference 0.05,

p=0.388; Table 3). Delivery of IVMg was also increased in multivariable analysis (risk difference 0.15, 95% CI 0.07-0.23, p<0.001; Table 3).

Uncontrolled mean ED LOS increased from 3.5 hours (SD 3.4 hours) to 3.8 hours (SD 3.6 hours), and median ED LOS from 1.3 hours to 1.4 hours during the study period (Table 2), but this difference was not significant in multivariable analysis (0.01 hours or 0.6 minutes increase, p=0.915 [Table 3]).

Table 1

Patient-Level and Visit-Level Characteristics Before and After AACP Implementation

Patient level (N=2640)	**Pre n = 1,290**	**Post n = 1,350**	**p-value**
Age (months) (Mean;SD)	74 (47.6)	76 (49.9)	0.445
Gender (N;%)			0.246
Female	463 (35.9)	514 (38.1)	
Male	827 (64.1)	836 (61.9)	
Language preference (N;%)			0.146
English	1152 (89.3)	1216 (90.1)	
Spanish	7 (0.5)	15 (1.1)	
Others	131 (10.2)	119 (8.8)	
Race (N;%)			<.0001
White	881 (68.3)	1029 (76.2)	
Black	72 (5.6)	83 (6.2)	
Native American/Pacific Islander	88 (6.8)	125 (9.3)	
Asian	27 (2.1)	34 (2.5)	
Unknown	222 (17.2)	79 (5.9)	
Payer class (N;%)			0.137
Commercial	620 (48.1)	656 (48.6)	
Government	587 (45.5)	631 (46.7)	
Others (S)	83 (6.4)	63 (4.7)	
Visit history (Mean;SD)			
ED last 12 mo	358 (27.8)	349 (25.9)	0.270
Hospitalization last 12 mo	320 (24.8)	292 (21.6)	0.053
ICU last 12 mo	77 (6)	75 (5.6)	0.649
Visit level (N=3481)	**Pre n = 1,648**	**Post n = 1,833**	**p-value**
Triage clinical values (Mean;SD)			
HR (n=1503;1631)	131 (25)	131 (27.1)	0.987
RR (n=1498;1629)	36 (13.2)	37 (13.8)	0.193
SYSTOLIC (n=765;1482)	111 (11.5)	113 (12)	0.002
DIASTOLIC (n=762;1477)	68 (10.4)	73 (10.8)	<.0001
SPO2 (n=1275;1417)	93 (4.6)	93 (4.4)	0.955
ESI (N;%)			0.066
1	85 (5.2)	72 (3.9)	
2	495 (30)	487 (26.6)	
3	894 (54.3)	1070 (58.4)	
4	167 (10.1)	199 (10.9)	
5	5 (0.3)	4 (0.2)	
Unknown	2 (0.1)	1 (0.1)	
Triage SPO2 (N;%)			0.146
50-87	168 (10.2)	152 (8.3)	
88-100	1107 (67.2)	1265 (69)	
Unknown	373 (22.6)	416 (22.7)	

Table 2

Descriptive Statistics on Outcome Variables Before and After AACP Implementation

	Pre-period N = 1,648		Post-period N = 1,833		Diff	p-value*
Primary Outcomes						
Hospitalization (N;%)	738	44.8%	590	32.2%	-12.59	<.0001
Adjusted total cost in 2017$ (Mean[SD];Median)	2,663 (979)	3,691	2,303 (950)	3,825	-360	0.005; 0.083+
Process and Balancing Measures						
ED LOS in hours (Mean[SD];Median)	3.5 (3.4)	1.3	3.8 (3.6)	1.4	0.28	<.0001
Returns after ED discharge (N;%)	50	3.0%	70	3.8%	0.01	0.205
Steroid (N;%)(N=1,648; 899)	1,240	75.2%	700	77.9%	0.03	0.138
Steroid in 60 min (N;%)(N=1,648; 899)	609	37.0%	530	59.0%	0.22	<.0001
Steroid in 30 min (N;%)(N=1,648; 899)	234	14.2%	317	35.3%	0.21	<.0001
Albuterol (N;%)(N=1,648; 899)	1,461	88.7%	799	88.9%	0.00	0.865
Albuterol in 60 min (N;%)(N=1,648; 899)	1,063	64.5%	640	71.2%	0.07	<.0001
Albuterol in 30 min (N;%)(N=1,648; 899)	562	34.1%	349	38.8%	0.05	0.018
IVMG (N;%)(N=1,648; 899)	89	5.4%	349	38.8%	0.33	<.0001

*p-values are from Chi-square test for categorical variables; t-test for continuous variables

+From Wilcoxon-Mann-Whitney test

Table 3

Summary Table of Multivariable Analyses (N = 3,481)

	ME/OR (CI)	p-value
Primary Outcomes		
Hospitalization Rate		
(Risk Diff, 95% CI)	-0.09 (-0.15, -0.04)	0.001
Total Cost		
(Cost Diff, 95% CI)	-517 (-974, -61)	0.026
Process and Balancing Measures		
ED LOS (hrs)		
(LOS Diff, 95% CI)	0.01 (-0.18, 0.2)	0.915
Return (N=3,447)		
(Risk Diff, 95% CI)	0 (-0.02, 0.02)	0.874
Steroid (N=2,547)		
(Risk Diff, 95% CI)	-0.02 (-0.12, 0.09)	0.718
Steroid in 60 min (N=1,925)		
(Risk Diff, 95% CI)	0.11 (0.01, 0.22)	0.035
Steroid in 30 min (N=1,925)		
(Risk Diff, 95% CI)	0.08 (0.03, 0.14)	0.003
Beta (N=2,547)		
(Risk Diff, 95% CI)	0.02 (-0.04, 0.08)	0.458
Beta in 60 min (N=2,547)		
(Risk Diff, 95% CI)	0.05 (-0.06, 0.16)	0.388
Beta in 30 min (N=2,547)		
(Risk Diff, 95% CI)	0.02 (-0.06, 0.1)	0.650
IVMg (N=2,547)		
(Risk Diff, 95% CI)	0.15 (0.07, 0.23)	<0.001

Discussion

A nurse-initiated ED care process improved delivery of albuterol, steroid, and IVMg, though only steroid and IVMg improvements were statistically significant in multivariable analysis. Using process control methodology, implementation of the AACP produced a sustained reduction in hospitalization within 4 months of implementation (See Figure 2), and this was statistically significant in time series analysis. Direct healthcare costs for children presenting to the hospital's ED with acute asthma fell by 19.4% following implementation.

Hospital Returns

Confidence that returns were rare and unchanged by the AACP is increased by inclusion of returns to most local hospitals, ensuring reduced costs represent improvements rather than cost shifting to return visits at other sites.

Improvements in Process and Outcome Measures

The AACP improved process, outcome, and financial measures, which do not always move in parallel. Prior reports of increased use of IVMg (Rutman et al., 2016), decreased ED length of stay (Rutman et al., 2016), or reduced time to nebulized treatment (Qazi et al., 2009) did not also find reduced hospitalization of children with asthma. Other published studies that improved the timing of treatment found reduced hospitalization of children with asthma—from 27.5% to 13.5% with increased steroid administration and improved timing of albuterol treatment (Norton et al., 2007), from 26.4% to 20.4% with improved timing of albuterol treatment alone (Gray et al., 2016), and from 24% to 15% with improved timing of steroid administration alone (Brown et al., 2012). Bhogal et al. (2012) found that administration of steroid within 75 minutes of arrival was associated with a 15% relative reduction in odds of admission. We found that changes in the timeliness of albuterol treatment following our improvements were not statistically significant. This may simply reflect a higher baseline attainment of the albuterol-related process measures relative to steroid-related measures.

Timing of asthma treatment, especially the timeliness of steroid administration, is impactful on outcomes and should be included in any efforts to analyze changes in asthma care delivery. Despite having evidence-based order sets in the ED, there was room for improvement in care delivery, and a similar examination at any site is likely to identify room for improvement. Building on the literature of quality improvement work in pediatric emergency care, we add the valuable finding that efforts in improving ED asthma care for children reduced costs, suggesting that comprehensive process change can produce direct and measurable economic impact.

Speed of Implementation

The success of the initiative is likely a result of three main factors: the AACP simplified care delivery for providers, there was a comprehensive change in asthma care delivery, and a change that was implemented intensively over a relatively short time frame. These factors likely discouraged providers from maintaining prior behavioral patterns of care delivery. Improvements persisted 6 months after all individual feedback was stopped, suggesting that improvements are facilitated and maintained by the AACP rather than simply due to Hawthorne effect (Grimshaw & Russell, 1993). More detailed understanding of the causal impact of the AACP or components of the AACP on outcome measures will require implementation in more diverse institutional settings.

Human Factors and Nurse Initiation

The AACP challenges the view that ideal patient outcomes are driven by an individual physician crafting a unique yet optimal therapeutic plan customized for each patient. The workflow formalized by the AACP shifts much of the work of identifying patients and selecting treatment to an interdisciplinary team including nurses and RTs. Treatment initiation on arrival to the ED improves the therapeutic reliability of interventions by minimizing the effects of ED crowding on quality (Bekmezian et al, 2013; Sills et al., 2011). Treatment is directed to patients using validated instruments rather than individual calculations for each patient. This recognizes that ED clinicians work in an environment prone to promote cognitive errors that affect treatment choices and patient outcomes (Croskerry, 2003).

Limitations

Over the study period, 16% of patients treated using the AACP did not have a primary diagnosis of asthma, suggesting that in some patients the primary billing code may not reflect the clinical impression of asthma at the time of ED treatment. No longitudinal changes were made that affect coding practices, making it unlikely that this misclassification would affect these findings.

This study was not designed to calculate the total cost of asthma treatment, which includes direct and indirect costs. Many children with acute asthma have significant symptoms after ED discharge (Stevens & Gorelick, 2001). The indirect costs of these symptoms are significant (Szefler et al., 2011) and should be considered in the design of future studies.

Conclusions

This paper described the development and impact of an Acute Asthma Care Pathway (AACP) implemented in an ED for children with acute asthma on care delivery and outcomes, including direct costs. Provision of a steroid within 30 minutes and 60 minutes of arrival increased by 21 and 22 percentage points respectively, IV magnesium sulfate administration increased by 30 percentage points, the proportion hospitalized decreased from 44.8% to 32.2%, and mean direct costs per patient decreased from $2,663 to $2,303 (13.5%). These improvements remained significant in multivariable analysis. Implementation of the AACP improved timeliness of treatment, hospitalization, and direct costs of children receiving ED treatment for acute asthma.

Acknowledgements

The study team appreciates the special QI expertise of Bernhard Fassl and Karmella Coopmeiners in designing the AACP and of Darden Swords and Shawn Steidinger in gathering and organizing the evidence base.

Special thanks to the detailed and careful work of Jeffrey Povilus, Callie Thackeray, Allison Neeley, Susan Masotti, and Alexandria White in gathering and organizing study data.

Special thanks to the other ED asthma QI directors who lent their insight on their own care processes, including Chad Atkins, Rus Magita, Matthew Gray, Joseph Zorc, Steven Laffey, Kevin Carney, and Marion Sills.

Contributor Statement

Dr. Johnson contributed substantially to conception and design and led all aspects of the process change. He contributed substantially to acquisition, analysis, and interpretation of data. He wrote the first and subsequent drafts of the manuscript, and approved the final manuscript submitted. He agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Dr. Yoo contributed substantially to conception and design of the analysis, conducted all analyses, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Dr. Nelson contributed substantially to conception and design of the analysis, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of

the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Dr. Nielson contributed substantially to acquisition of data, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ms. Allen contributed substantially to design and implementation of the process change, to the acquisition of data, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Dr. Dudley contributed substantially to the design and implementation of the process change, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Mr. Anderson contributed substantially to the design and implementation of the process change, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Dr. Orme contributed substantially to the design and implementation of the process change, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Mr. McFarland contributed substantially to the implementation of the process change and to the acquisition of data, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Mr. Mundorff contributed substantially to the conception and design of the process change, contributed substantially to the acquisition, analysis, and interpretation of data, revised the article for important intellectual content, approved the final version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding Source

This investigation was supported by the University of Utah Study Design and Biostatistics Center, with funding in part from the National Center for Research Resources and the National Center for Advancing Translational Sciences, National Institutes of Health, through Grant 5UL1TR001067-02 (formerly 8UL1TR000105 and UL1RR025764).

Financial Disclosure and Conflict of Interest

There are no financial relationships relevant to this work for any of the authors. There are no conflicts of interest for any of the authors.

Corresponding Author

Michael D. Johnson, MD
University of Utah Department of Pediatrics
Division of Pediatric Emergency Medicine
295 Chipeta Way, Salt Lake City, Utah 84108
mike.johnson@hsc.utah.edu
(801) 587-7440

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