RESEARCH ARTICLE

Improving the Efficiency of Care for Pediatric Patients Hospitalized With Asthma

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ABSTRACT

BACKGROUND: Asthma exacerbations are a leading cause of hospitalization among children. Despite the existence of national pediatric asthma guidelines, significant variation in care persists. At Duke Children’s Hospital, we determined that our average length of stay (ALOS) and cost for pediatric asthma admissions exceeded that of our peers. Our aim was to reduce the ALOS of pediatric patients hospitalized with asthma from 2.9 days to 2.6 days within 12 months by implementing an asthma pathway within our new electronic health record.

METHODS: We convened a multidisciplinary committee charged with reducing variability in practice, ALOS, and cost of inpatient pediatric asthma care, while adhering to evidence-based guidelines. Interventions were tested through multiple “plan-do-study-act” cycles. Control charts of the ALOS were constructed and annotated with interventions, including testing of an asthma score, implementation of order sets, use of a respiratory therapy–driven albuterol treatment protocol, and provision of targeted education. Order set usage was audited as a process measure. Readmission rates were monitored as a balancing measure.

RESULTS: The ALOS of pediatric patients hospitalized with asthma decreased significantly from 2.9 days to 2.3 days. Comparing baseline with intervention variable direct cost data revealed a savings of $1543 per case. Improvements occurred in the context of high compliance with the asthma pathway order sets. Readmission rates remained stable throughout the study period.

CONCLUSIONS: Implementation of an asthma care pathway based on the electronic health record improved the efficiency and variable direct costs of hospital care, reduced variability in practice, and ensured adherence to high-quality national guidelines.

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Drs Bartlett and McLean conceptualized and designed the study, analyzed and interpreted data, drafted sections of the initial manuscript, and revised the manuscript; Dr Parente drafted sections of the initial manuscript, analyzed and interpreted data, and revised the manuscript; Ms Morales and Ms Hauser managed, analyzed, and interpreted the data, and reviewed and revised the manuscript; and all authors were active participants in the quality improvement team, approved the final manuscript as submitted, and agree to be accountable for all aspects of the work.
Asthma exacerbations are a leading cause of hospitalization among children, resulting in >150,000 hospital admissions annually, with an estimated health care expenditure exceeding $1.5 billion.1-3 Hospital length of stay (LOS) is one of the main drivers of health care expenditure related to asthma admissions.

We determined at Duke Children’s Hospital (DCH) that our average LOS (ALOS) for a child admitted with an asthma exacerbation exceeded that of our peer institutions by 0.5 days, by using comparative data from the Vizient Clinical Database/Resource Manager (CDB/RM), formerly known as the University Healthsystem Consortium.4 Additionally, our higher ALOS was associated with higher variable direct cost relative to our peers.

Previous studies have demonstrated that implementation of an asthma clinical pathway can decrease variability of care and improve national guideline adherence.5-8 Additionally, asthma clinical pathways have been shown to decrease LOS and improve resource utilization.9-11 Previous inpatient pediatric asthma quality initiatives achieved these outcomes through promotion of systemic corticosteroids,12 use of spacer with metered-dose inhaler,13-15 or use of objective measures to determine albuterol nebulization readiness.16 Most of these studies were completed before the widespread use of the electronic health records (EHRs) and computerized physician order entry (CPOE).17-19 Separately, EHRs and CPOE have been shown to increase physician adherence to evidence-based guidelines and improve patient outcomes.20-22

Past attempts to implement an asthma pathway at DCH were largely unsuccessful. Before 2013, DCH did not have a comprehensive EHR. Each member of the multidisciplinary team used a different system to document care, such that respiratory therapy notes, medication administration records, and nursing charting were not readily visible to providers. A previous attempt to implement a respiratory-therapy-driven bronchodilator treatment protocol was abandoned due to uncertainty about weaning decisions and medication administration. With the implementation of a comprehensive EHR in 2013, we had the opportunity to recreate an asthma pathway that took advantage of the transparency inherent in an EHR and the ability of CPOE to drive physician behavior.

The aim of this study was to evaluate the impact of an EHR-based asthma pathway directed at reducing variability in management, increasing the role of respiratory therapists (RTs), reducing costs, and adhering to high-quality national guidelines without increasing readmission rates. The specific, measurable aim was to decrease the ALOS of pediatric inpatients admitted with asthma exacerbations from 2.9 days to 2.6 days within 12 months of pathway implementation.

METHODS

Ethical Concerns

The Duke institutional review board exempted this study because it did not meet the definition of human subjects research (per Code of Federal Regulations 45§46 and 21§56).

Setting

DCH is a 190-bed tertiary care facility housed within a large academic hospital in Durham, NC. During the project period of May 2013 through March 2016, DCH had approximately 7500 pediatric inpatient admissions per year, and 150 to 175 of these had a primary diagnosis of asthma exacerbation. ALOS for patients admitted with asthma during the baseline period of May 2013 to April 2014 was 2.9 days. Two inpatient teams cared for most patients admitted to DCH with asthma. Faculty pediatric hospitalists or generalists and residents staffed these teams. Before July 2015, a small subset of patients was admitted to the pediatric pulmonary team before it became a consult-only service. A minority of patients spent a portion of their care in the PICU. Pediatric RTs provided all inhaled asthma medications in the hospital. DCH uses a single EHR that was implemented across all health care environments by June of 2013.

Planning the Intervention

In early 2014, we formed an improvement team comprising nurses, an RT, a data manager, pediatric residents, and faculty from pediatric emergency medicine, critical care, hospital medicine, and pulmonology.

This team mapped the process, conducted a modified failure mode and effects analysis, and developed a key driver diagram outlining the theories for improvement and potential interventions (Fig 1).

The improvement team then created institution-specific guidelines for the asthma pathway based on existing best evidence. In the absence of published evidence, pathway recommendations were based on committee consensus. We created asthma-specific order sets and a bronchodilator treatment protocol based on a validated asthma score to drive adherence to the pathway (Supplemental Figs 4-6). The team chose the Modified Pulmonary Index Score (MPIS)23 because of its simplicity and previous successful use in the Duke Pediatric Emergency Department (ED).

Hospitalized children aged 2 to 18 years with a primary diagnosis of asthma exacerbation (International Classification of Diseases (ICD)-9 493 or ICD-10 J45 codes) were included in the pathway. Patients with cystic fibrosis, congenital heart disease, bronchiolitis, bronchopulmonary dysplasia, airway anomalies, sickle cell disease, or neuromuscular weakness were excluded.

Improvement Activities

This study was designed as a time series quality improvement project. Tests of change and interventions focused on 4 key drivers: (1) pathway available and used by all providers, nurses, and RTs; (2) bronchodilators weaned based on asthma scores; (3) location of care based on asthma scores and response to therapy; and (4) key stakeholders committed to improving the efficiency and reliability of inpatient asthma care (Fig 1). Changes were tested through a series of plan-do-study-act cycles.24

Pathway Available and Used by All Providers

Tests of change began with evaluating the usability and reliability of the pathway tools, including admission order sets, an electronic flow sheet for documenting asthma scores, and a bronchodilator treatment protocol to guide escalation or
de-escalation of therapy. Once we tested these tools in the inpatient setting, education was provided for the inpatient teams to increase awareness of the pathway, followed by feedback of compliance with using order sets. We discovered that adherence to the asthma pathway was lowest in the PICU. Providers were using the general PICU admission order set, which contained unit-specific orders for critically ill patients, rather than the asthma order set. To address this issue, we created a separate PICU asthma admission order set that included both standard critical care admission orders and pathway orders.

**Bronchodilators Weaned Based on Asthma Scores**

Nurses, RTs, and physicians participated in feasibility and usability testing of the MPIS, first on paper and then using an EHR flow sheet. Testing began in the step-down unit and then spread to the inpatient ward, PICU, and Pediatric ED. We initially observed variability in the scoring of the pulse oxygen saturation (SpO2) component until we specified “Room air SpO2” to prompt consistent measurement. We observed good interrater reliability of MPIS scoring by RTs, nurses, residents, and faculty across multiple settings consistent with previous MPIS studies. Ultimately, the MPIS order was included in all asthma order sets, allowing RTs to wean the patient per the treatment protocol without requiring a new provider order.

**Location of Care Based on Asthma Scores and Response to Therapy**

The MPIS score was used to improve the flow of patients from the ED to inpatient areas and from the PICU to step-down or inpatient units. In the ED, the patient’s score determined if the patient required admission, as well as the appropriate inpatient location. We created EHR phrases for provider documentation of the MPIS to improve its visibility. In addition, the MPIS was incorporated into the provider, RT, and nursing handovers.

**Key Stakeholders Committed to Improving the Efficiency and Reliability of Inpatient Asthma Care**

The improvement team provided education about the asthma pathway, MPIS scoring, and the asthma treatment protocol for faculty, pediatric residents, nursing staff, and RTs. In addition, an online MPIS module was provided for orientation of new RTs. We created laminated identification badge cards with the MPIS score and asthma treatment protocol for clinicians to wear for quick reference at the point of care. We started testing the pathway with 1 hospitalist team. That team found that incorporating MPIS testing into daily rounds provided an opportunity to promote the guideline, teach learners, and build trust in the RT-driven protocol. Use of the pathway subsequently spread to all inpatient teams. Over time, residents, RTs, and faculty

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**FIGURE 1** Key driver diagram of improvement strategies to reduce ALOS and variable direct cost.
adopted MPIS as a tool to communicate the severity of asthma exacerbations.

Measurement Plans
The improvement team selected the outcome, process, and balancing measures. The primary outcome measure was ALOS, which was defined as the sum of inpatient hospital days divided by the number of asthma cases. Hospital days were defined as the number of days and hours from the admission order to the time the patient left the inpatient unit as documented in the EHR. Use of the inpatient asthma order sets served as a process measure, calculated as the number of patients who had any asthma order set divided by the number of eligible cases. Seven- and 30-day readmission rates were chosen as balancing measures to ensure that a timelier discharge did not negatively impact readmission rates. Readmissions were defined as discharged patients who returned to the hospital for admission or observation with an asthma exacerbation. Data were extracted directly from the EHR. May 2013 through April 2014 was defined as the baseline period because tests of change began in May 2014. The authors validated the abstracted data set by confirming that all patients had an ICD-9 or -10 code for asthma exacerbation. All readmissions during the intervention period were reviewed by one of the authors to ensure that the discharge process was complete during the index hospitalization (asthma teaching, asthma action plan, prescriptions in hand, follow-up appointment made).

A financial analysis was performed to compare baseline variable direct costs to the intervention period. We used internal DCH financial data to determine variable direct cost per case, defined as the cost of direct labor, medications, and supplies used in each patient encounter. We used the Vizient LOS and direct cost indices to compare results with peers. The Vizient CDB/RM is a comparative database with discharge and line-item patient-level detail data from more than 270 principal members and affiliate hospitals. The Vizient risk models use multiple regression techniques adjusted on the basis of Medicare Severity-Diagnosis Related Groups to provide expected LOS, case cost, and mortality for each discharge. The LOS index was calculated as the observed LOS divided by the expected LOS, the direct cost index was calculated as the observed case cost divided by the expected case cost (1.0 is the goal for both).

Analysis
Primary analysis of outcome and process measures was performed by using statistical process control charts with 8 data points above or below the mean line representing special cause variation. X-bar and S control charts of the LOS and percent control chart of order set use were constructed with 3-σ control limits. Charts were annotated with interventions including testing and implementation of the MPIS score and bronchodilator treatment protocol, implementation of the EHR pathway, provision of targeted education, and promotion of the pathway. Univariate analyses were performed with use of $\chi^2$ tests to compare demographic variables between the groups before and after implementation of the pathway. ALOS and readmission rates were compared by using 2-sided $t$ tests. Statistical analyses were performed by using Stata 13.1 (Stata Corp, College Station, TX).

RESULTS
Comparison of demographic data revealed that the pre- and postintervention populations did not differ significantly by age, sex, race, or payer type (Table 1). The ages at hospital admission ranged from 2 to 18 years with 25% to 75% quartile range between 3 and 8 years old.

The primary outcome measure, ALOS of pediatric patients admitted with a primary diagnosis of asthma, decreased from 2.9 days at baseline to 2.3 days, as shown in the annotated X-bar control chart (Fig 2A). The largest decrease in ALOS occurred in June 2014 and resulted in special cause variation. This change was observed after implementation of the asthma pathway and the respiratory therapy–driven treatment protocol. Auditing and feedback of order set usage, targeted education, and improving the visibility of the pathway contributed to sustained improvement for 21 months. The SD control chart (S chart) that is paired with the X-bar chart shows a reduction in the variability over time, indicating a more stable process (Fig 2B).

Use of the pathway order sets was monitored monthly as a process measure. Performance began with a mean compliance rate of ~85% and increased to >90% once the PICU asthma order set was changed (Fig 3). Seven-day readmission rates (Table 2) remained stable throughout the intervention period at 1.5%, compared with 1.3% in the historic cohort ($P = .25$). Thirty-day readmission rates decreased from 5.8% to 2.2% over the course of the

<table>
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<tr>
<th>TABLE 1</th>
<th>Demographic Data for Pediatric Inpatients With Asthma</th>
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<tr>
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<td>Preintervention, %</td>
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<tr>
<td>Age, y</td>
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<tr>
<td>&lt;5</td>
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<tr>
<td>5–12</td>
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<td>&gt;12</td>
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<td>Boys</td>
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<tr>
<td>Race/Ethnicity</td>
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<td>Black</td>
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<td>Self-pay</td>
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</table>
FIGURE 2  X-bar and S control charts of LOS. A, Statistical process control chart (X-bar) for ALOS of pediatric patients with asthma where each dot represents the ALOS for the corresponding month. B, SD control chart for ALOS of pediatric patients with asthma.
intervention, but the difference was not significant ($P = .42$). Chart review of readmissions revealed that all discharge tasks were completed during index hospitalizations. Readmitted patients had risk factors for poorly controlled disease, including tobacco exposure, nonadherence to medications, or loss to outpatient follow-up.

After implementation of the pathway, Vizient LOS index decreased from 1.2 to 1.1 (Table 2). Analysis of internal financial data revealed a decrease in the variable direct cost per case by 30% after implementation of the pathway, which resulted in $1543 of savings per case compared with the baseline period. Decreases in patient days and pharmacy charges were responsible for the bulk of these savings. In addition, we observed a reduction in the Vizient direct cost index from 1.5 to 1.1 (Table 2).

**DISCUSSION**

Use of improvement methods to implement an EHR-based asthma care pathway successfully reduced ALOS for inpatients with asthma and exceeded our goal without adversely affecting readmissions. This significant decrease in ALOS was sustained for 21 months after special cause variation was achieved (Fig 2A). In addition, much of the month-to-month variation in ALOS has decreased since pathway implementation (Fig 2B). The decrease in ALOS coincided with high order set usage (averaging 85% to 95%), suggesting that adherence to the order set contributed to standardization of care and improvement in ALOS. In addition, implementation of the pathway resulted in decreased variable direct costs. The savings resulted from fewer ICU days, fewer inpatient days, and decreased use of intravenous medications, all of which can be attributed to pathway interventions.

Several factors contributed to the project’s success. First, the MPIS guided decisions about the level of care, frequency of therapy, and patient disposition. The MPIS enabled respiratory therapy–driven weaning of bronchodilator treatments. Because the RTs performed the score each time bronchodilator treatments were due, the frequency of assessment increased, leading

<table>
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<th>TABLE 2</th>
<th>ALOS, Readmission Rates, and Vizient Indices for LOS and Direct Variable Direct Cost for Pediatric Patients With Asthma in the Baseline and Intervention Groups</th>
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<tbody>
<tr>
<td></td>
<td><strong>Baseline Group, May 2013–April 2014</strong></td>
</tr>
<tr>
<td>Cases</td>
<td>160</td>
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<tr>
<td>Hospital days</td>
<td>469</td>
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<tr>
<td>ALOS, d</td>
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<tr>
<td>Readmission rate, %</td>
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<td>7-d</td>
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<tr>
<td>30-d</td>
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<tr>
<td>LOS index</td>
<td>1.2</td>
</tr>
<tr>
<td>Direct variable direct cost index</td>
<td>1.5</td>
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</tbody>
</table>

* The LOS index is calculated as the observed LOS divided by the expected LOS; the direct variable direct cost index is calculated as the observed case variable direct cost divided by the expected case variable direct cost (1.0 is the goal for both). There was 1 fewer case in the intervention group for the CDB/RM database likely due to slightly different inclusion criteria for the Vizient CDB/RM database.

*P < .01.
to more timely decisions to wean. Pediatric RTs became the advocates and champions of the pathway, as they appreciated the autonomy and efficiency the RT-driven treatment protocol allowed.

Second, including trainees in the improvement team proved particularly helpful in creation, revision of, and adherence to order sets. At our institution, trainees do most of the ordering, so they were key to understanding the process and determining strategies that would lead to better pathway compliance. Finally, the educational interventions were important components of this project. Use of the RT-driven asthma treatment protocol represented a culture change for our institution. The educational modules, didactic conferences, and badge cards about the MPIS score and treatment protocol were integral to increasing acceptance and utilization of the pathway.

Successful asthma pathways, scoring systems, and non–physician-led treatment protocols have been previously described, but previous attempts to implement them at our institution had met resistance. Use of the Vizient comparative data allowed us to benchmark our performance against peer institutions and adjust for the illness severity of our patients. The direct cost and LOS indices created the rationale and buy-in for institutional change. With implementation of a comprehensive EHR, we had the opportunity to embed the MPIS scoring and treatment protocol within the asthma admission order set to create a default pathway for asthma care. In addition, the score itself was visible in a flow sheet that can be entered by any clinician, which increased transparency and acceptance of the asthma scoring and treatment protocol.

Use of the annotated X-bar chart allows for visualization of the contemporaneous impact of interventions on outcomes of interest (Fig 2A) and alerts the team to outliers. The August 2014 Enterovirus D68 outbreak and the December 2014 peak in influenza infections, although still within the control limits, can explain months with higher ALOS. Both of these events contributed to an increased severity of asthma exacerbations. An audit performed in May 2015 due to an increase in ALOS found that a nonhospitalist provider was uncoupling discharge decisions from MPIS scoring, resulting in an extra hospital day for several patients. This provider was given feedback and education about the pathway. This study was performed at a single site. Given the heterogeneity of inpatient pediatric services, and the numerous EHR systems in use, our pathway may not be generalizable to all other children’s hospitals. In addition, although decreases in ALOS appeared to be temporally related to project interventions, it is possible that other factors contributed to the change. In the postintervention period, pediatric pulmonology became a consult-only service, which may have affected ALOS for a small subset of patients. In addition, there were fewer pediatric asthma admissions in the postintervention group despite spanning the same period as the preintervention group. The demographics and insurance status were similar between the pre- and postintervention populations, but the Vizient LOS index did not decrease as dramatically as the ALOS, which could indicate that asthma severity was less in the postintervention population. Challenges include continued provision of education about the pathway for residents, RTs, nurses, and faculty to keep up with staffing turnover at an academic institution.

CONCLUSIONS

We successfully achieved our aim of reducing the ALOS of patients admitted with asthma at DCH by implementing an asthma care pathway that standardized care, improved the efficiency and variable direct cost of hospital care, and ensured adherence to high-quality national guidelines without compromising readmission rates. These results have been sustained for 12 months after completion of the project. The change in culture seen since implementation combined with the incorporation of the pathway into the EHR should promote future sustainability. The EHR tools created for our project have the potential for spread to other children’s hospitals by using the same system. Next steps include improving timely initiation of the pathway in the ED, and ensuring a more seamless transition to the outpatient setting at discharge. The asthma care pathway will also serve as a model for the approach to other common pediatric conditions in the inpatient setting.

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