OPEN

Implementation of a Critical Care Asthma Pathway in the PICU

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OBJECTIVES: Acute asthma management has improved significantly across hospitals in the United States due to implementation of standardized care pathways. Management of severe acute asthma in ICUs is less well studied, and variations in management may delay escalation and/or deescalation of therapies and increase length of stay. In order to standardize the management of severe acute asthma in our PICU, a nurse- and respiratory therapist–driven critical care asthma pathway was designed, implemented, and tested.

DESIGN: Cross-sectional study of severe acute asthma at baseline followed by implementation of a critical care asthma pathway.

SETTING: Twenty-six–bed urban quaternary PICU within a children's hospital.

PATIENTS: Patients 24 months to 18 years old admitted to the PICU in status asthmaticus. Patients with severe bacterial infections, chronic lung disease, heart disease, or immune disorders were excluded.

INTERVENTIONS: Implementation of a nurse- and respiratory therapist–driven respiratory scoring tool and critical care asthma pathway with explicit escalation/deescalation instructions.

MEASUREMENTS AND MAIN RESULTS: Primary outcome was PICU length of stay. Secondary outcomes were time to resolution of symptoms and hospital length of stay. Compliance approached 90% for respiratory score documentation and critical care asthma pathway adherence. Severity of illness at admission and clinical baseline characteristics were comparable in both groups. Pre intervention, the median ICU length of stay was 2 days (interquartile range, 1–3 d) with an overall hospital length of stay of 4 days (interquartile range, 3–6 d) ($n = 74$). After implementation of the critical care asthma pathway, the ICU length of stay was 1 day (interquartile range, 1–2 d) ($p = 0.0013$; $n = 78$) with an overall length of stay of 3 days (interquartile range, 2–3.75 d) ($p < 0.001$). The time to resolution of symptoms was reduced from a median of 66.5 hours in the preintervention group to 21 hours in the postintervention compliant group ($p = 0.036$).

CONCLUSIONS: The use of a structured critical care asthma pathway, driven by an ICU nurse and respiratory therapist, is associated with faster resolution of symptoms, decreased ICU, and overall hospital lengths of stay in children admitted to an ICU for severe acute asthma.

KEY WORDS: critical care; critical pathway; length of stay; noninvasive ventilation; pediatrics; severe acute asthma

Although there are many guidelines for the management of acute asthma, none are validated for the ICU. The three editions of the National Asthma Education and Prevention Program Expert Panel Reports have

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each had successively fewer recommendations for the management of pediatric asthma in the ICU (1–3). This is likely due to a paucity of high-quality evidence upon which to base recommendations (4–8). Variations in management of severe acute asthma may lead to delays in both escalation and deescalation (weaning) of therapies, as well as increased lengths of stay in the ICU (1). A review of the Cochrane database revealed that only three treatments of severe acute asthma have been proven effective: nebulized continuous beta-agonists, systemic steroids, and IV magnesium (2–4, 9). Low-risk treatments with unclear benefits include nebulized anticholinergic drugs, noninvasive positive pressure ventilation, and a mixture of helium and oxygen (2, 10–13). Inhaled albuterol and systemic corticosteroids remain the mainstays of management for asthma exacerbations (10). Despite the general knowledge and awareness of the efficacy of individual drugs in the management of severe acute asthma, there is considerable variation and subjective decision-making between practitioners and institutions (14), potentially prolonging hospitalization (15).

Standardizing respiratory assessments using a clinical score that facilitates care coordination by physicians, nurses, and respiratory therapists has been shown to improve overall care (16–18). Although acute asthma pathways have been in use for years (19), only recently structured critical care asthma pathways (CCAPs) have been implemented in the complex setting of an ICU in patients with severe acute asthma (15).

In this study, we demonstrate that a PICU nurse- and respiratory therapist–driven approach using respiratory scoring and a CCAP is associated with shorter ICU stays, shorter hospital length of stay (LOS), and overall faster resolution of symptoms.

MATERIALS AND METHODS

Pathway Generation and Definitions

In order to generate a standardized CCAP, a Respiratory Scoring Tool (RST) consisting of age-adjusted numeric scoring of tachypnea, retractions, dyspnea, and wheezing (**Fig. 1**) was first developed. The RST and CCAP were generated by reviewing the literature and comparing published scoring tools and clinical pathways (16). Through a series of multidisciplinary discussions, the RST and the CCAP (**Fig. 2**) were optimized. Both were tested in the PICU prior to implementation and data collection. The primary aim of this study was to show that a PICU nurse- and respiratory therapist–driven CCAP decreases ICU LOS in patients primarily admitted to the PICU for severe acute asthma. Secondary aims were to show faster resolution of asthma symptoms and a decrease in overall hospital LOS, with hospital discharge readiness defined as a RST score less than or equal to 4 for 4 hours while on intermittent albuterol administered every 4 hours. Resolution of symptoms was defined as a durable (≥ 4 hr) low respiratory score of less than or equal to 4 (mild symptoms) followed by successful weaning off of continuous beta-agonists. The time to resolution of symptoms was defined as the time from admission to the ICU to resolution of symptoms. Severe acute asthma was defined as patients primarily admitted to the ICU with the admission diagnosis of "status asthmaticus" (based on *International Classification of Diseases,* 9th Edition [ICD9]: 493.91, 493.92 or *International Classification of Diseases,* 10th Edition [ICD10]: J45.901, J45.902 codes).

Respiratory Scoring and Pathway Implementation

To assess the baseline management and lengths of stay in our PICU and hospital, we conducted a cross-sectional study of severe acute asthma in the PICU of the Children's Hospital at Montefiore by retrospective chart review. We then implemented the newly developed RST (Fig. 1) across the entire Children's Hospital (26 PICU beds, 115 non-PICU beds, non-neonatal ICU beds). Nurses and respiratory therapists initially assessed patients and calculated respiratory scores every 4 hours or more frequently, depending on the severity of illness as defined in the RST and the CCAP instructions. The scores for individual items (tachypnea, retractions, dyspnea, and wheezing) were entered into the electronic medical record flow sheet by the nurse and therapist, and total scores were automatically calculated and immediately visible to all providers reviewing the patients' vital signs. A 4-month training period was performed, followed by random weekly audits and reinforcement by study champions (one ICU physician, a PICU nurse, and the director of respiratory therapy), who were not involved in the primary care of the patients. Interrater reliability (Cohen's kappa) was greater than 0.9 when comparing respiratory scoring and adjustment of management between nurses and respiratory therapists.

Respiratory Scoring Tool

Variable	0 Points	1 Point	2 Points	3 Points
RR				
<2 months		≤60	61-69	≥70
2-12 months		≤50	51-59	≥60
13-23 months		≤40	41-44	≥45
2-3 year		≤34	35-39	≥40
4-5 year		≤30	31-35	≥36
6-12 year		≤26	27-30	≥31
>12 year		≤23	24-27	≥28
Retractions	None	Subcostal or intercostal	2 of the following: subcostal, intercostal, substernal OR nasal flaring (infant)	3 of the following: subcostal, intercostal, substernal, suprasternal, supraclavicular OR nasal flaring/head bobbing (infant)
Dyspnea				
0-23 months	Normal feeding, vocalizations and activity	1 of the following: difficulty feeding, decreased vocalization or agitated	2 of the following: difficulty feeding, decreased vocalization or agitated	Stops feeding, no vocalization, drowsy or confused
2-4 years	Normal feeding, vocalizations and play	1 of the following: decreased appetite, increased coughing after play, hyperactivity	2 of the following: decreased appetite, increased coughing after play, hyperactivity	Stops eating or drinking, stops playing, OR drowsy and confused
>4 years	Counts to ≥10 in one breath	Counts to 7-9 in one breath	Counts to 4-6 in one breath	Counts to ≤3 in one breath
Auscultation	Normal breathing, no wheezing present	End-expiratory wheeze only	Expiratory wheeze only (greater than end-expiratory wheeze)	Inspiratory and expiratory wheeze OR diminished breath sounds OR both

Figure 1. Respiratory Scoring Tool used by Respiratory Therapists and Registered Nurses to assess the patient as indicated on the pathhway. RR = respiratory rate (breaths per minute).

Training and Compliance

Weekly assessments of compliance and accuracy of documenting respiratory scores were conducted by the primary investigators. Training and evaluation of compliance with the newly implemented CCAP took 4 months. A training and compliance check were completed and deemed satisfactory after reaching greater than or equal to 80% compliance rate.

Enrollment

This study was approved by the Institutional Review Board at Albert Einstein School of Medicine (Institutional Review Board number 2016-6274). The need for consent was waived and confirmed compliance with good medical and scientific practice. Subjects were not randomized and no change in medical practice other than a structured approach to medical management, which was specific to the ICU and distinct from current management practices on the wards occurred. Patients and outcomes were documented over a 6-month period. The aim was to collect 85 patients both in the pre- and post-groups (starting in 2013 and 2015, respectively) based on sample size analysis for the primary outcome, hospital LOS, with a goal of reducing LOS by 1 day (effect size = 25%, SD = 50%, alpha = 0.05, power = 0.900). The gap of 2 years was chosen to avoid contamination by wash-in during training and change of practice.

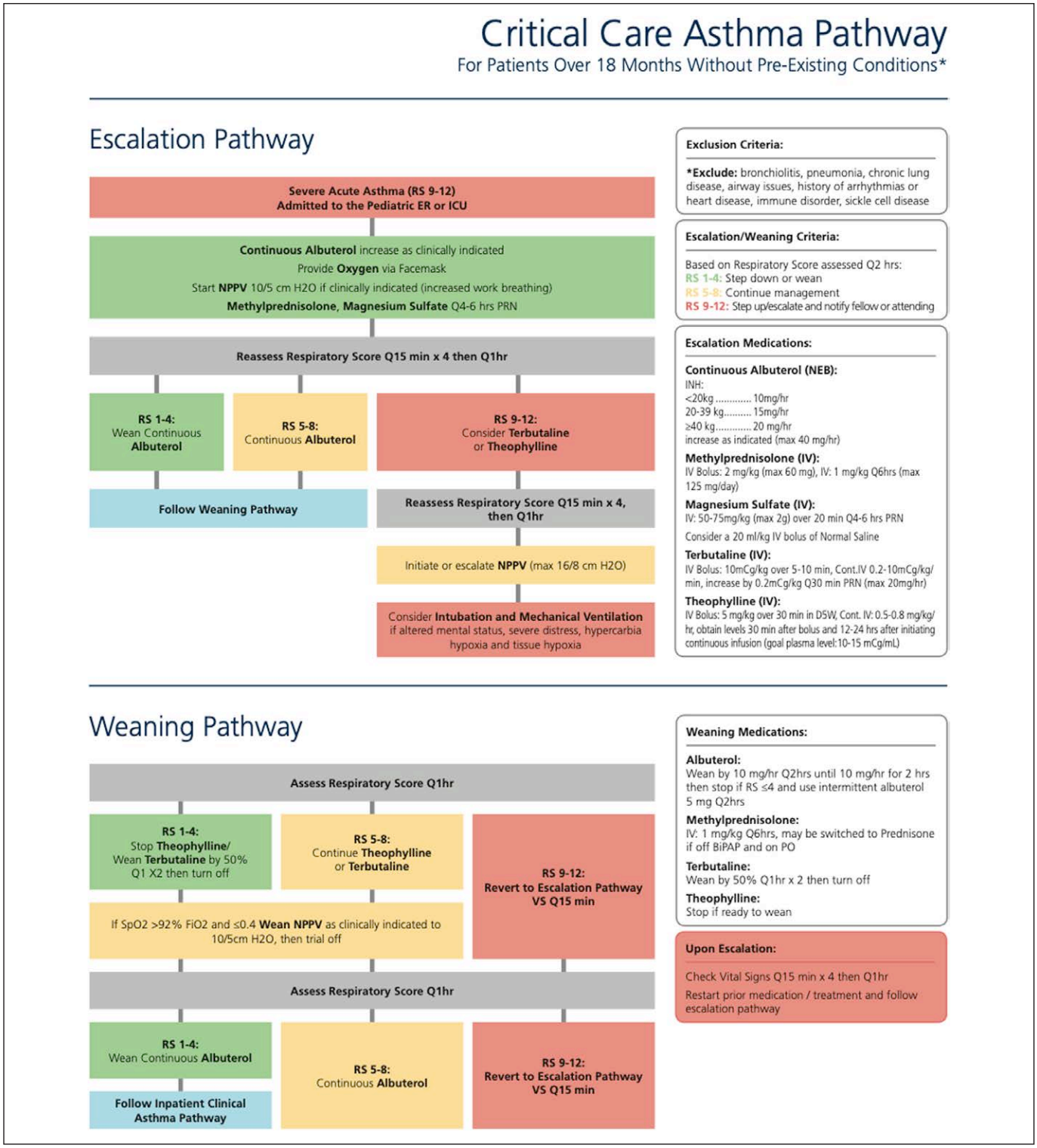

Figure 2. Critical care asthma pathway comprising an escalation and weaning pathway. BiPAP = bi-level positive airway pressure, ER = emergency room, INH = inhaled, NEB = nebulized treatment, NPPV = non-invasive positive pressure ventilation, PRN = *pro re nata*, Q = every, RS = respiratory score, Spo2 = fractional oxygen saturation, VS = vital signs.

We included patients 24 months to 18 years old who were admitted to the PICU with the primary diagnosis of "status asthmaticus" (ICD9 or ICD10 codes as above). Almost all of the patients had a slow onset (> 6 hr) of symptoms and were treated either at home or by outpatient providers prior to admission to the ICU, failed standard emergency department (ED) treatment with three combination of nebulizer treatments (albuterol

and ipratroprium bromide) 20 minutes apart, and required continuous nebulized albuterol and/or noninvasive ventilatory support at the ED physician's discretion. Patients were excluded from the study if they had concurrent severe infections including sepsis with suspected or confirmed bacterial infection, chronic lung disease, heart disease, immune disorder, hemodynamic instability, upper airway obstruction/obstructive sleep apnea, or a seizure disorder with frequent seizures (≥ 1/d).

We collected data on demographics (age, sex, race) and viral infections in patients with signs of upper respiratory infection or fever. Data on antibiotic use and usage of specific asthma management modalities (steroids, continuous nebulized albuterol, noninvasive ventilation, IV magnesium, and IV bronchodilators) were also collected. In our chart review, individual descriptions of clinical findings and vital signs at admission to the ICU in the cohort prior to implementation of the CCAP were comparable into the postintervention cohort despite the absence of a formal respiratory score.

Based on clinician preference, patients underwent testing with the ePLEX Respiratory Panel (GenMarkDiagnostics, Carlsbad, CA) (multiplex nucleic acid amplification detecting seven viruses isolated from nasopharyngeal swabs, including influenza, respiratory syncytial virus, adenovirus, coronavirus, human metapneumovirus, and parainfluenza).

Outcomes and Statistics

The primary outcome of interest was PICU LOS, with the secondary outcomes being time to resolution of symptoms and overall hospital LOS. chi-square test, *t* test, and Wilcoxon rank-sum test were used where appropriate using SigmaStat3.1 software (Richmond, CA). Mean differences with 95% CIs for nonnormally distributed data were calculated using regression analysis. Log rank test for survival analysis with hazard ratio estimates was used for time to resolution of symptoms (that were documented as continuous integers by hourly intervals). Real-time auditing showed that compliance was 96% for respiratory score documentation and 88% for CCAP adherence after the implementation of the pathway.

RESULTS

Baseline Characteristics

In this study, 2,397 patients were screened for eligibility. Of those, 113 were admitted to the PICU in the first time period and 153 in the second time period. After screening for inclusion and exclusion criteria, 74 and 78 were enrolled in the pre- and postintervention groups, respectively (**Fig. 3**). At admission to the ICU, patients in both arms were comparable in terms of demographics and viral coinfections (**Table 1**). Severity of illness was comparable in both groups, based on descriptions of work of breathing and respiratory rate. The use of antibiotics either for presumed bacterial coinfection or for synergistic anti-inflammatory effect (e.g., azithromycin) was identical in both groups. Similarly, there was no difference in the usage of specific asthma treatments between these groups, including, continuously nebulized albuterol use, parenteral steroids, IV magnesium sulfate, and noninvasive positive pressure ventilation, for example, biphasic positive airway pressure (BiPAP) (Table 1). In a single characteristic comparison, we observed a higher rate of IV bronchodilator use (either aminophylline or terbutaline) in the preintervention group (20% vs 4% in the postintervention group; $p = 0.004$) (Table 1). However, overall there was no statistically significant difference in the multiple comparisons of baseline characteristics.

Outcomes

In this study, the use of the CCAP was associated with a reduced LOS. The median PICU LOS was 2 days (interquartile range [IQR], 1–3 d) pre intervention and 1 day (IQR, 1—2 d) post intervention ($p = 0.0013$), with a mean difference of –0.23 days (95% CI, –0.06 to –0.4 d). Similarly, in the CCAP compliant group, the time to resolution of symptoms was reduced from a median of 66.5 hours (95% CI, 27–101 hr) in the preintervention group to 21 hours (95% CI, 12–34 hr) in the post-intervention group (hazard ratio, 0.257; $p = 0.036$) (**Table 2**). Overall, median hospital LOS was also shorter (3 [IQR, 2–3.75] vs 4 d [IQR, 3–6 d]; $p < 0.001$, post intervention vs pre intervention, respectively), with a mean difference of –0.35 d (95% CI, –0.19 to –0.51 d) (Table 2).

DISCUSSION

Severe acute asthma is a common reason for admission into PICUs across the nation (10). Providing high-quality care to these patients is a medical priority, whereas the efficiency of their treatment is an economic issue. The national median hospital LOS for status asthmaticus

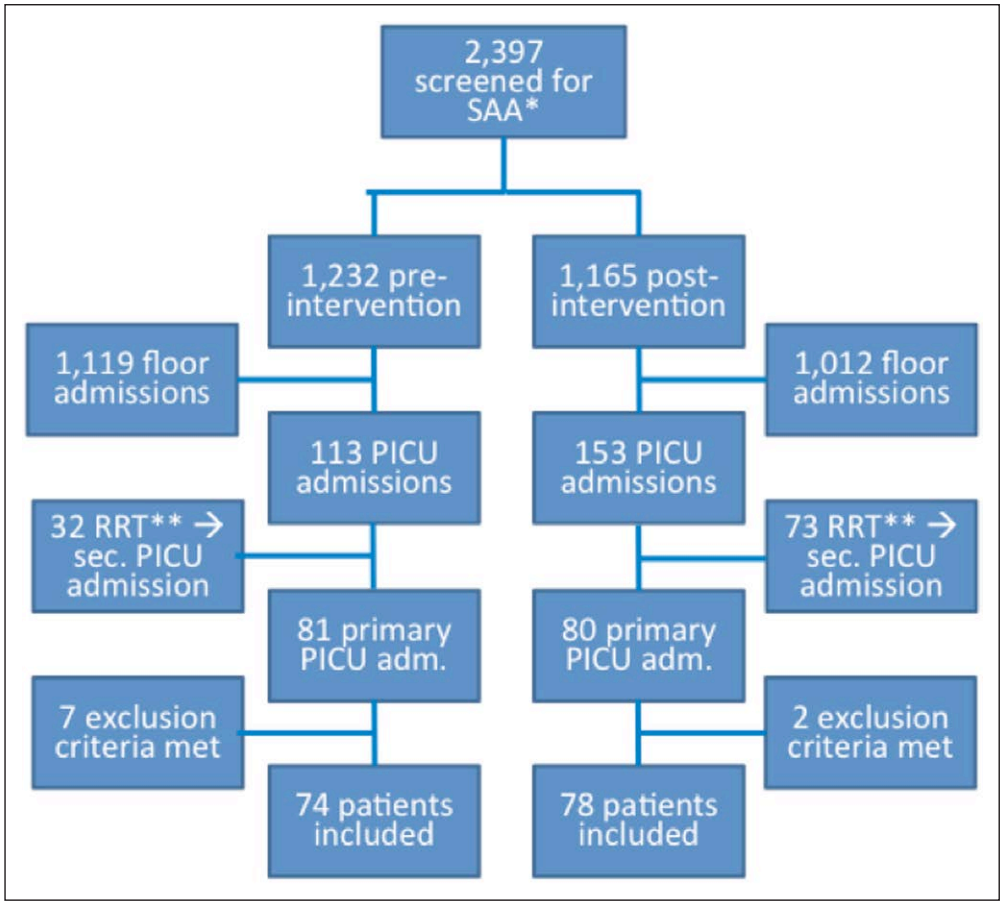

Figure 3. Screening flow chart. RRT = renal replacement therapy. *SAA = severe acute asthma, **RRT = rapid response team, leading to secondary (sec.) PICU admission.

in children (ICD9: 493.91 and 493.92) is 2 days and has not changed since 1997 (20). Our local data from 2013 show that the overall hospital LOS was a median of 4 days, making it an attractive target for improvement for both medical and economic reasons. The discrepancy between LOS in our hospital and the national average has not been explained but may be partly influenced by our center being a unique, inner-city children's hospital with the only quaternary level PICU in a New York City borough of 1.4 million people with 400,000 below the age of 18 years. In the Bronx, NY, 28% of families and 38% of children are below the federal poverty level (21).

In this study, we showed that implementing a standardized approach to managing severe acute asthma in the ICU is associated with a reduction of LOS in both, the ICU, and in the hospital. Despite lower than expected enrollment, we were able to demonstrate a difference in outcomes between the groups. The CCAP used in this study was independent from the management of asthma on the general wards and shared only the RSTs. Improving management of asthma in inpatient wards, EDs, and now in ICU settings (22) has a tremendous impact on individual patient well-being and also potentially saves hundreds of thousands dollars per year in healthcare costs.

The success of this care pathway lies in the strong collaboration between different specialists within the health system. In conjunction with champions from our critical care nurses, respiratory therapists, and physicians from different divisions (emergency medicine, regular hospital ward, and ICU) we were able to initiate, maintain, and improve objective assessment and care of our patients. Although this study was unable to answer with certainty which of the CCAP items—scoring, escalation or weaning pathway—were most influential in reducing LOS, we propose that being "on track" with the weaning pathway potentially makes a big difference in dramatically reducing time to resolution of symptoms. This, in turn, is related to reduced LOS in both the ICU and overall hospital stay.

All of the patients were managed according to practice standards for severe acute asthma (2, 10, 13). Continuous beta-agonists were used in 64% with a median duration of 1 d (IQR, 0–2 d). Systemic steroids were used in 100% (median duration, 1 d (IQR, 1–2 d]) of patients. Particularly, the early administration of systemic corticosteroids has been shown in the past to decrease hospital admission rate and length of active treatment (23, 24) and hence plays an integral role in our CCAP. Ipratropium was documented in 48% of cases with the majority given in the ED. IV magnesium sulfate in addition to bronchodilators seems to be safe and beneficial for people with severe asthma attacks or those for whom bronchodilators are not working (2), and our pathway includes this medication which was used in more than half of the patients with severe acute asthma (including IV magnesium

TABLE 1.
Baseline Demographics and Clinical Data

Characteristics	Pre ($n = 74$)	Post ($n = 78$)
Age (yr), mean ± SD	7.2 ± 5.5	8.0 ± 5.2
Female, *n* (%)	40 (54)	32 (41)
Race, *n* (%)		
Hispanic	33 (45)	44 (56)
African American	29 (39)	23 (30)
Caucasian	6 (8)	3 (4)
Other	6 (8)	8 (10)
Coinfection tested, *n* (%)	39 (53)	50 (64)
Any virus	16 (41)	19 (38)
Flu	0 (0)	4 (8)
Rhinovirus	15 (38)	11 (22)
Human metapneumo virus	1 (3)	2 (4)
Respiratory syncytial virus	0 (0)	4 (8)
Antimicrobials, *n* (%)		
Any antibiotics	15 (20)	15 (19)
Azithromycin	9 (12)	12 (15)
Specific treatment and support, *n* (%)		
Continuous albuterol	61 (82)	63 (81)
Methylprednisolone	74 (100)	78 (100)
Magnesium sulfate	50 (68)	41 (53)
Biphasic positive airway pressure	39 (53)	34 (44)
Terbutaline/aminophylline	15 (20)	3 (4)

sulfate given in the ICU rather than ED administration only, 1–2 doses total). In the preintervention group, aminophylline was used in 14% and terbutaline in 7.4% (on average < 1 d duration), and most often only a bolus was given. There is no consistent evidence favoring either IV beta-agonists or IV aminophylline for patients with acute asthma (13), so we left this choice to the practitioner, and our pathway includes both agents. Interestingly, these agents were used less frequently in the postintervention group. We believe the implementation of the pathway decreased variability of care as all the initial interventions were all done in a systematic and timely manner.

Noninvasive ventilation (BiPAP: 46.9%, high-flow humidified nasal cannula: 3.7%, and continuous positive airway pressure: 2.5%) was used for a median of 1 day and sometimes exceeded the use of continuous nebulized albuterol use. We think it is possible that some of these patients had symptoms that were attributable to a viral illness with acute respiratory failure that was less responsive to bronchodilators. This highlights the diagnostic difficulties in separating severe acute asthma from viral pneumonia in some of the cases. Current evidence does not support any positive outcome effects of noninvasive positive pressure ventilation for treatment of children with acute asthma other than symptom relief and decrease of work of breathing (11). It is still widely used, however, across ICUs worldwide, and our pathway also includes this mode of support early in the management of severe acute asthma. Three patients (3.7%) in the preintervention group were intubated in the ED prior to admission to the ICU. Two patients were mechanically ventilated invasively for less than 24 hours, and one for 3 days. There is no evidence that antibiotics improve outcomes in patients with severe acute asthma in the absence of pneumonia (12). Even with the use of azithromycin, which is sometimes used for its anti-inflammatory effect at the treating physicians' discretion, we did not see any difference in the pre- and postintervention groups. There is also limited evidence in the literature of its effectiveness (25).

Clinical pathways have been associated with reduced in-hospital complications (19), LOS, and beta-agonist use. They also help reduce cost without increasing adverse outcomes (22, 26, 27). Due to their focus of care and the direct interaction of care with fewer patients by nurses and respiratory therapists, they are the ideal decision-makers in weaning from or escalating therapy. This has been shown to be equally effective and safe with other protocols (22, 26, 27). Input from respiratory therapists is very useful in the decision-making of escalation/deescalation of respiratory support and should be used. Our study supports the utility of a Respiratory Therapist and Registered Nurse-driven pathway in the ICU. A potential limitation is related to the type of this observational study that only unearths correlations rather than causality. Although our intervention was associated with an improved outcome, the populations pre and post intervention were not identical.

TABLE 2.
Primary and Secondary Outcomes

Time	Pre ($n = 74$)	Post ($n = 78$)	p
PICU LOS (d), median (IQR)	2 (1–3)	1 (1–2)	0.0013[b]
Time to resolution of symptoms (hr), median (95% CI)	66.5 (27–101)	21 (12–34)	< 0.036[a]
Hospital LOS (d), median (IQR)	4 (3–6)	3 (2–3.75)	< 0.001[c]

IQR = interquartile range, LOS = length of stay.
[a]$p < 0.05$.
[b]$p < 0.01$.
[c]$p < 0.0001$.

In recent years, a pathway approach to severe acute asthma management has gained considerable interest (15, 28–30). Brennan et al (15) showed that a respiratory therapist–driven ICU pathway was feasible but did not show any difference in LOS. His study excluded patients who were on noninvasive positive pressure ventilation (3, 30), which represented greater than 4 0% of the population in our study. To date, there is only one publication showing that the implementation of an asthma pathway is associated with decreased time on continuous albuterol and hospital LOS through a tiered approach (31). In that study, the authors demonstrated a higher BiPAP use prior to pathway implementation (42% pre intervention vs 28% post intervention), which we have not observed in our study.

This is an exploratory study in terms of investigating the feasibility and effectiveness of the intervention with a CCAP on ICU LOS, resolution of symptoms, and overall hospital LOS. Even though it is beyond the scope of this study to investigate, which part of the CCAP is most influential, we have the impression that the adherence to the deescalation pathway appears to play a significant role in our outcomes. There is a need to further investigate the role of the different parts of the pathway used in the ICU setting. Another question to be answered is whether aggressive upfront pathway-guided management in the ED could equally affect outcomes.

CONCLUSIONS

Our study supports the notion that high compliance with respiratory scoring and CCAP adherence is associated with faster resolution of symptoms, decreased ICU, and hospital LOS. Its use appears to be highly beneficial to the patient and severe acute asthma care overall. It is paramount to continue reinforcement of pathway adherence in order to sustain the positive effects. In addition, standardizing care for asthma patients to include objective admission criteria early in the ED course may optimize patient care and improve overall hospital management from ED to discharge from the ICU (31).

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