Implementation of a Critical Asthma Protocol in a Pediatric ICU

Nicholas M Kucher, Danielle S Dhaliwal, Gwenyth A Fischer, Cynthia S Davey, and Sameer Gupta

BACKGROUND: Protocol-driven therapy has been successful in managing patients with asthma on pediatric wards, but there is wide variability in ICU-level management that is often provider-dependent. This study aimed to determine if a standardized protocol for critical asthma treatment could improve clinical outcomes. METHODS: A pre-intervention cohort consisting of subjects age 2–18 y, excluding patients with airway obstruction that was not felt to be due to asthma, who were admitted to the ICU for critical asthma. Demographics and data along with medication administration information were gathered using the hospital electronic medical record. A post-intervention cohort was obtained over 13 months in an identical manner. The primary end point was time on continuous albuterol. Subjects adhering to the protocol were examined as a subset. RESULTS: 71 post-intervention subjects were compared with a historical cohort of 52 pre-intervention subjects over a similar time frame. There were no significant differences in demographic characteristics. Median time on continuous albuterol (14.4 h vs 8.1 h, $P = .14$) and secondary end points of median ICU length of stay (LOS), hospital LOS, and time from discontinuing continuous albuterol to transfer out of ICU were not significantly reduced in the post-intervention cohort. Overall adherence to the clinical protocol through completion was 42%. When comparing the pre-intervention cohort with the protocol-adherent subjects, significant reductions were seen in time on continuous albuterol (14.4 h vs 3.0 h, $P < .001$), ICU LOS (38.7 h vs 21.0 h, $P < .001$), and hospital LOS (2.8 d vs 1.7 d, $P = .005$). CONCLUSIONS: Implementation of an asthma protocol in the pediatric ICU did not result in significant improvements in time on continuous albuterol or hospital and pediatric ICU LOS, likely due to low adherence to the protocol. However, in subjects who did adhere to the protocol there were significant reductions in the outcome measures. *Key words: status asthmaticus; critical pathways; albuterol; intensive care units; pediatrics; length of stay; protocol; asthma protocol.* [Respir Care 2021;66(4):635–643. © 2021 Daedalus Enterprises]

Introduction

Asthma is a common cause of pediatric admissions to hospitals.[1] Critical asthma, also known as severe asthma or status asthmaticus, is a common cause of admission to pediatric ICUs (PICUs) and is associated with significant morbidity and health care costs.[2,3] Protocols and pathways have long been used for pediatric patients admitted to general wards with asthma exacerbations and have shown reductions in overall stay and hospital costs without

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increased readmission rates. However, most protocols are focused on patients in general wards.[4-7] Traditionally, studies examining therapies for critical asthma have focused on specific therapies rather than protocols.[8,9] A retrospective review done previously at our institution found a wide variety of patient management strategies that were largely provider-dependent (unpublished data). It also found overall poor adherence to accepted medication dosages for some of the most common pharmacologic therapies for critical asthma. With a growing focus on standardization and quality in care, critical asthma patients admitted to a PICU are an ideal population for protocolized treatments to improve clinical outcomes.

There are limited studies that have evaluated protocols for the management of critical asthma in the PICU, and these have yielded inconsistent results due to varied populations, methods used, type of institution, and differences in baseline severity of illness.[10-14] Wong et al[10] reported a reduction in duration of continuous albuterol but not a reduction in hospital length of stay (LOS), mainly through use of a helium-oxygen mixture in the protocol. Brennan et al[11] showed a reduction in PICU LOS, median duration of continuous albuterol, and median hospital LOS. Two recent studies that utilized respiratory therapist-driven PICU protocols showed conflicting results in duration of continuous albuterol and PICU LOS.[12,13] In a study looking at implementation of an asthma protocol that included continuous albuterol in a community hospital without a PICU, Smith et al[14] reported that, despite increasing time on continuous albuterol, hospital LOS and need for transfer to higher care were reduced.

In this study, we aimed to assess the implementation and effectiveness of an asthma protocol with both escalation and de-escalation pathways along in addition to standardized medication dosing. We hypothesized that the use of this protocol would reduce clinically relevant end points, with the primary outcome measure being time receiving continuous albuterol.

QUICK LOOK

Current knowledge

Asthma is a common cause of pediatric hospitalization, and critical asthma is a common cause of admission to pediatric ICUs (PICUs). Use of protocol-driven therapy has been shown to be successful in managing patients with asthma on general wards, but there is a wide variability in PICU-level management that is often provider-dependent. There exists conflicting and limited data of protocolized care in PICUs.

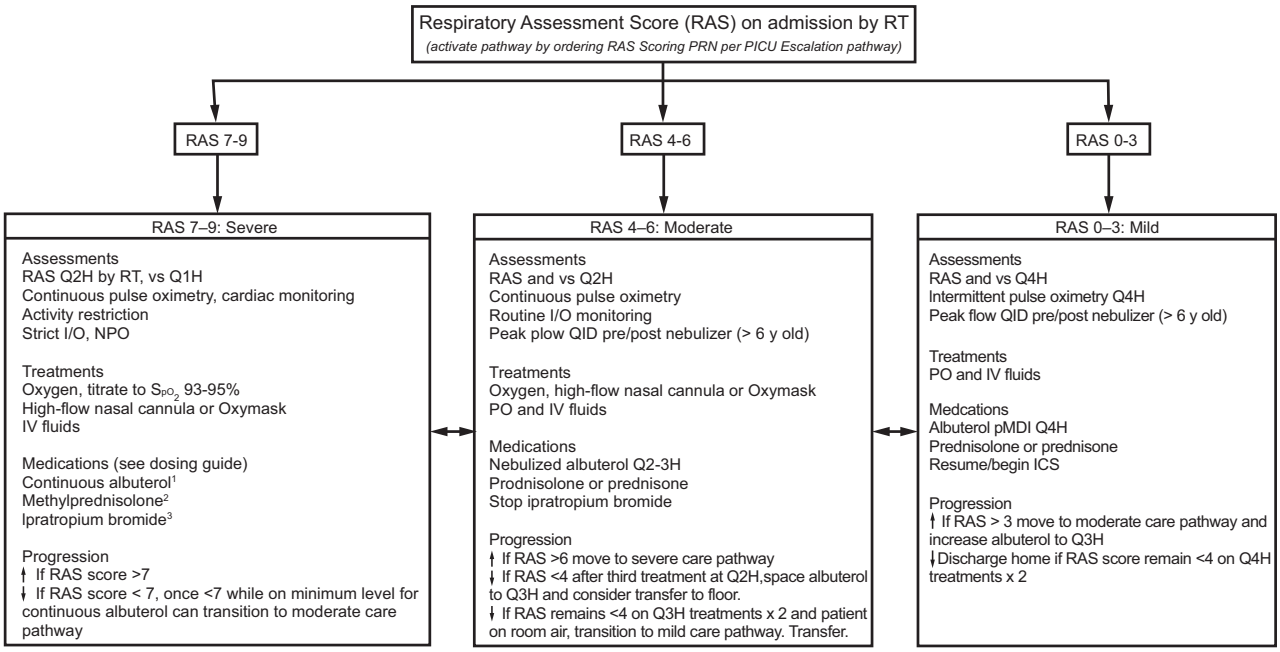
What this paper contributes to our knowledge

Implementation of a critical asthma protocol including escalation and de-escalation arms did not change clinically relevant outcomes, including time on continuous albuterol, hospital length of stay (LOS), PICU LOS, and time from discontinuing continuous albuterol to transfer out of ICU. However, a subset of subjects treated in adherence to the protocol had less time on continuous albuterol and shorter PICU and hospital LOS. Adherence was problematic, limiting the effectiveness of the clinical protocol.

Methods

Patients

After approval from the institutional review board of the University of Minnesota, a pre-intervention cohort age 2–18 y was identified by problem list and discharge diagnosis codes of critical asthma, status asthmaticus, asthma with exacerbation, and asthma without status asthmaticus using a patient database (Virtual Pediatric Systems, Los Angeles, CA). The Virtual Pediatric Systems database is a large, multi-institutional database that allows for patients to be identified in a variety of ways, in this instance by diagnosis codes. This cohort timeframe of January 1, 2015, to December 31, 2016, was intentionally selected to be outside of an outbreak of enterovirus D68 from mid-August 2014 to January 2015 that led to severe respiratory symptoms in children as described by many, including the Centers for Disease Control and Prevention (https://www.cdc.gov/non-polio-enterovirus/about/ev-d68.html, *Accessed September 2, 2019*).[15-16] Patients were then reviewed by the authors to ensure inclusion and exclusion criteria were met. Subjects were included if they were 2–18 y old when presenting and symptoms were thought to be consistent with an obstructive respiratory pattern due to asthma exacerbation. Patients were excluded if they had a condition causing wheezing or obstruction that was not felt to be due to asthma per the emergency department and PICU physicians, or if they had any of the following comorbidities: congenital or acquired heart disease, congenital airway anomalies, severe developmental delay, neuromuscular disease, severe bronchopulmonary dysplasia, pulmonary hypertension, primary immunodeficiency, or cystic fibrosis. Demographics and data pertaining to primary and secondary end points along with other medication administration information were gathered using the hospital electronic medical record. The Respiratory Assessment Score (RAS) was also collected at multiple points including initial emergency department score, subsequent emergency department score, and score upon admission to PICU. The RAS was adapted for use at University of Minnesota Medical Center from the Pulmonary Score, which has been validated for use in pediatric asthma patients aged 5–17 y in the emergency



Inclusion
- 2–18 y - Primary diagnosis of asthma exacerbation
Exclusion
- Condition causing wheezing that is non-bronchodilator responsive (foreign body, aspiration, bronchiolitis) - Congenital or acquired heart disease, congenital airway anomalies, severe developmental delay, neuromuscular disease, severe BPD. pulmonary hypertension, primary immunodeficiency, cystic fibrosis

Respiratory Assessment Scoring (RAS)				
	0 points	1 point	2 points	3 points
Breathing frequency by age group 0 – 1 y 2 – 3 y 3 – 6 y ≥ 7 y	 ≤ 45 breaths/min ≤ 40 breaths/min ≤ 30 breaths/min ≤ 20 breaths/min	 46-55 breaths/min 41-45 breaths/min 31-45 breaths/min 21-35 breaths/min	 56-60 breaths/min 46-60 breaths/min 46-60 breaths/min 36-50 breaths/min	 ≥ 60 breaths/min ≥ 60 breaths/min ≥ 60 breaths/min ≥ 50 breaths/min
Retractions	None	ONE of the following: Subcostal Intercostal	TWO of the following: Subcostal Intercostal Substernal	THREE of the following: Subcostal Intercostal Substernal Suprasternal Supraclavicular
Auscultation	Normal breathing no wheezing	End-expiratory wheeze only	Full-expiratory wheeze only	Inspiratory and expiratory wheeze OR diminished breath sounds

Fig.1. Respiratory Assessment Score (RAS) scoring system, initial therapies, and inclusion/exclusion criteria. RT = respiratory therapist; NPO = nil per oral; PO = per oral (by mouth); I/O = input/output; IV = intravenous; QID = 4 times daily; Q*n*H = every *n* hours; pMDI = pressurized metered-dose inhaler; ICS = inhaled corticosteroids; BPD = bronchopulmonary dysplasia; RAS = Respiratory Assessment Score.

department, and is the standard assessment by which respiratory status is serially monitored across our institution.[17] The RAS score reflects patient's symptoms including age-dependent breathing frequency, auscultatory findings, and retractions. On a scale of 1–9, we defined 1–3 as mild, 4–6 as moderate, and 7–9 as severe (Fig. 1). Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at the University of Minnesota. REDCap is a secure, web-based application designed to support data capture for research studies, providing an intuitive interface for validated data entry, audit trails for tracking data manipulation and export procedures, automated export procedures for seamless data downloads to common statistical packages, and procedures for importing data from external sources.

Asthma Protocol

A standardized critical asthma protocol, the Pediatric Severe Asthma Pathway (PSAP, see Fig. 2), was developed using results of a provider survey, a literature review, and knowledge of unit practices. Goals of the PSAP include both rapid escalation and de-escalation of interventions, starting with those that are the least invasive and best tolerated. Patients are placed into categories based on RAS scores, with initial treatments often starting in the pediatric emergency department or outside hospital. The PSAP standardizes the frequency of monitoring, assessments, and administration of continuous albuterol, intravenous steroids, and intermittent ipratropium inhalation for all patients admitted to the PICU with severe asthma (ie, initial RAS scores of

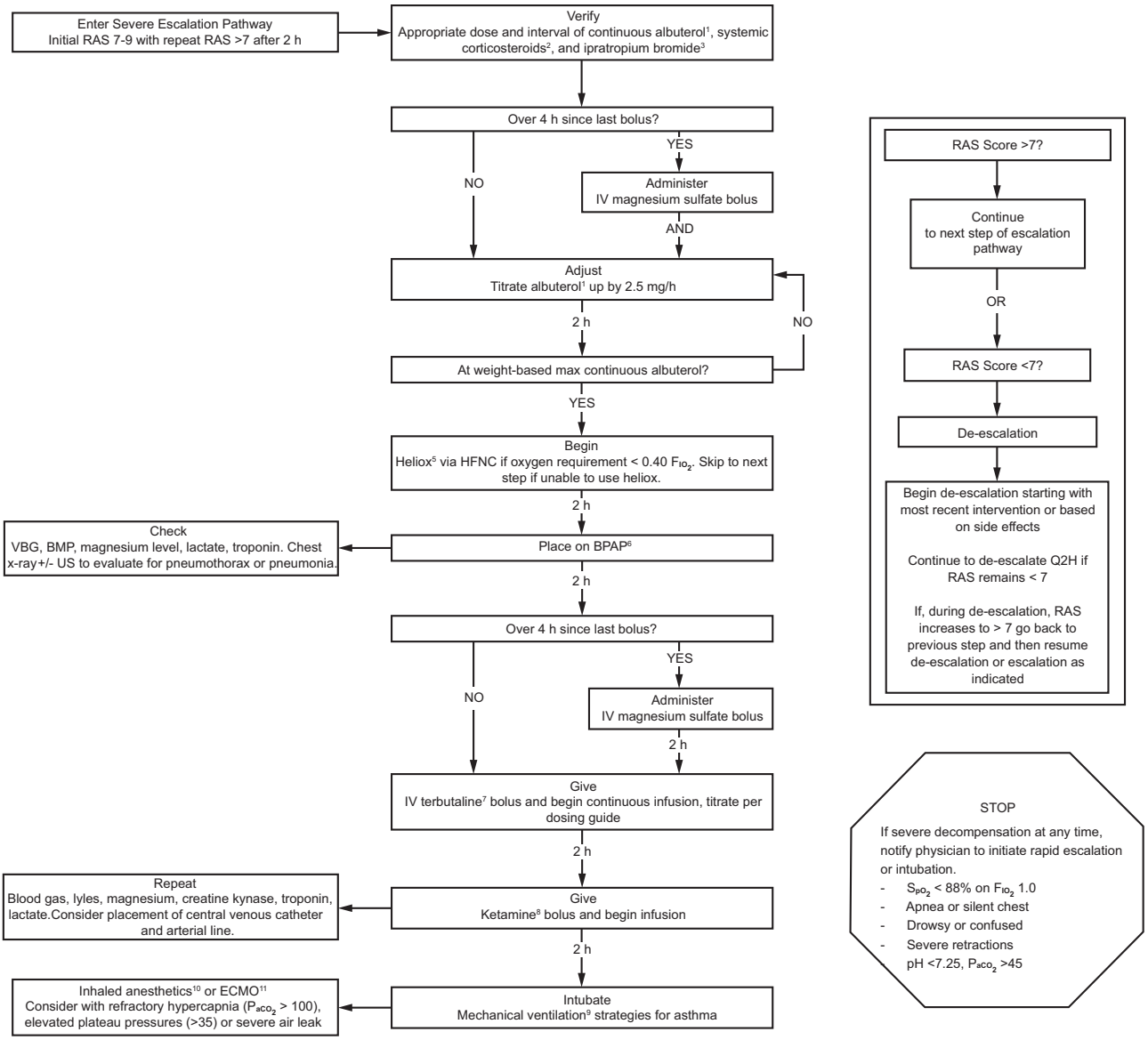


Fig. 2. Escalation/de-escalation protocol. RAS = Respiratory Assessment Score; IV = intravenous; HFNC = high-frequency nasal cannula; VBG = venous blood gas; BMP = basic metabolic panel; US = ultrasound; BPAP = bi-level positive airway pressure; Q2H = every 2 h; ECMO = extracorporeal membrane oxyenation.

7–9, which have traditionally been started on continuous albuterol by the institution's pediatric emergency department and thus require admission to the PICU). While critical asthma patients are typically assessed hourly in our institution, a 2-h interval was chosen to determine improvement, deterioration, or no change to allow for an effect to be seen. A RAS score of 7 was used as the cutoff for escalation or de-escalation, as this represents the minimum score our institution classifies as severe asthma. RAS scores of 7 or above progressed stepwise along the protocol, while scores 6 or below would de-escalate stepwise in reverse order. In addition to the escalation and de-escalation protocol, all medication usage was standardized in terms of dosage, frequency, and delivery. Medication administration was tracked throughout the study by recording dosages given and whether boluses were given if indicated, and medication administration was documented as given correctly or incorrectly in a binary fashion. As part of the PSAP, respiratory therapists document RAS score hourly, as well as changes in management and rationale for deviation from the protocol using a paper form. PSAP teaching sessions were conducted for staff physicians, fellows, residents, and respiratory therapists. A copy of the PSAP is included at the bedside of every asthma patient in the PICU. Continuous albuterol is

administered with an Aerogen Solo (Aerogen, Galway, Ireland) using a 25-mL syringe setup through a standard face mask or through a heated system if on high-flow nasal cannula. In our institution, this is run through the Aerogen box or through a Servo-i ventilator (Getinge, Wayne, NJ) using a T-piece.

Outcome Measures

A 22-month post-intervention cohort was reviewed from August 1, 2017, to May 5, 2019, through the Virtual Pediatric Systems database with queries using the same inclusion and exclusion criteria as the pre-intervention cohort. As with the pre-intervention cohort, patient charts were reviewed to ensure inclusion and exclusion criteria were met, and all data were taken directly from the institution's electronic medical record. The primary end point was time on continuous albuterol, with secondary end points of hospital LOS, PICU LOS, and time from end of continuous albuterol to transfer out of ICU. The latter end point is used as a marker for possible confounders to PICU LOS. All post-intervention subjects were analyzed for adherence to protocol. Subject treatment was deemed not protocol-adherent if escalation or de-escalation was not taken every 2 h as dictated by the RAS score at that time. Medication dosing and administration were also reviewed and deemed appropriate or off-protocol per the schedule defined by the protocol. After preliminary results, a separate cohort, labeled the protocol-adherent cohort, was identified post hoc if adherence was completely maintained, and results were analyzed as a subset to evaluate the protocol.

Statistical Analysis

Demographic distribution differences between the cohorts were evaluated with the chi-square test for gender and with the Fisher exact test for race due to small numbers for some categories. A 2-sample *t* test was used to test for differences in mean age. Unadjusted distribution differences in time on continuous albuterol, time off albuterol prior to discharge, PICU LOS (in hours) and hospital LOS (in days) were evaluated with the Wilcoxon rank-sum test, a non-parametric test appropriate for skewed distributions.

Generalized linear models for each outcome measure were run to evaluate differences between pre- and post-intervention cohort's mean values for time on continuous albuterol, time off albuterol prior to PICU discharge, PICU LOS, and hospital LOS adjusted for age and gender. Sensitivity analyses included unadjusted analysis excluding 4 subjects with outlier values in one or more outcomes (> 100 h on continuous albuterol, PICU LOS > 100 h, or hospital LOS > 15 d) and generalized linear models for each outcome adjusted for race in addition to age and gender.

Results

The 52 pre-intervention subjects were compared with 71 post-intervention subjects, which we labeled the intention-to-treat (ITT) cohort. There were no significant differences in demographic characteristics nor initial RAS scores between these 2 cohorts (Table 1). The primary end point of median time on continuous albuterol was not significantly different between the pre-protocol and ITT subjects (14.4 h vs 8.1 h, $P = .14$). Secondary end points were also not significantly different: median PICU LOS (38.7 h vs 27.6 h, $P = .055$), hospital LOS (2.8 d vs 2.6 d, $P = .29$), or time from stopping continuous albuterol to transfer out of ICU (18.0 h vs 14.8 h, $P = .060$). Median and interquartile ranges reflect the general mean trends for all end points (Table 2, Fig. 3).

Overall adherence to the clinical protocol was low, with only 42.3% of subjects receiving treatment per the protocol to completion. The most common reason for this was failure to de-escalate as indicated by an improving RAS score, which accounted for 75.6% of those who did not follow the protocol, followed by failure to escalate appropriately (36.6%), improper dosing of medications (31.7%), and medications given when not indicated per RAS scoring (12.2%).

The subgroup of ITT subjects ($n = 30$) whose treatment adhered completely to the protocol, termed the protocol-adherent cohort, was compared with the pre-intervention cohort. There were no significant differences in age, gender, or race between the pre-intervention and protocol-adherent subjects (Table 3). The primary end point of median time on continuous albuterol was significantly different between the median pre-intervention and protocol-adherent subjects (14.4 h vs 3.0 h, $P < .001$). There were also significant differences in median PICU LOS (38.7 h vs 21.0 h, $P < .001$) and median hospital LOS (2.8 d vs 1.7 d, $P = .005$), but not for median time from stopping continuous albuterol to transfer out of ICU (18.0 h vs 18.5 h, $P = .21$) (Table 4, Fig. 3). Median and interquartile ranges reflect the general mean trends for all end points except for time off albuterol prior to transfer out of PICU. Adjusting for age and gender did not affect the significance or direction of differences for any outcome measures when comparing the pre-intervention cohort with the protocol-adherent cohort. Results for adjusted models that included race in addition to age and gender were consistent with results adjusted for age and gender only. Results of sensitivity analysis excluding 4 subjects with outlier values for one or more outcomes were consistent with results reported above for both ITT and protocol-adherent comparisons with pre-intervention patients.

The percentage of medications given per-protocol increased during our study for most common medications in asthma treatment in both the ITT and protocol-adherent cohort. There were no differences in adjuvant respiratory support between the pre-intervention cohort and both the ITT and protocol-adherent cohorts (Table 5, Table 6).

Table 1. Demographics

	Pre-Intervention ($n = 52$)	Post-Intervention Intention-to-Treat* ($n = 71$)	*P*
Age, y	6.0 (4.0–1.0)	6.0 (3.0–9.0)	.98
Male	27 (51.9)	42 (59.1)	
Race			.52
White	17 (32.7)	31 (44.9)	
Hispanic/Latino	3 (5.8)	2 (2.9)	
African-American/Black	28 (53.9)	28 (40.6)	
Native American/American Indian	0 (.0)	1 (1.5)	
Asian/Pacific Islander	2 (3.9)	5 (7.3)	
Other	2 (3.9)	2 (2.9)	
Home controller use	29 (55.8)	44 (62.0)	.49
Significant comorbidity	4 (7.7)	6 (9.0)	> .99
Viral infection (if tested)	17 (54.8)	19 (59.4)	.72
Subject origin			.62
Home emergency department	34 (65.4)	50 (70.4)	
Outside emergency department	10 (19.2)	15 (21.1)	
Floor transfer	4 (7.7)	4 (5.6)	
Direct admission	4 (7.7)	2 (2.8)	
Initial emergency department RAS	6.0 (3.0–7.0)	6.0 (4.0–7.0)	.31
Initial emergency department RAS severity			.38
0–3: Mild	11 (28.2)	10 (16.7)	
4–6: Moderate	17 (43.6)	29 (48.3)	
7–9: Severe	11 (28.2)	21 (35.0)	
Admit RAS	4.5 (3.0–5.0)	5.0 (4.0–6.0)	.36
Admit RAS severity			.55
0–3: Mild	7 (31.8)	14 (23.7)	
4–6: Moderate	12 (54.6)	31 (52.5)	
7–9: Severe	3 (13.6)	14 (23.7)	

Data are presented as *n* (%) or median (interquartile range).
* $n = 69$ for Race, $n = 63$ for Ethnicity.
RAS = Respiratory Assessment Score

Table 2. Unadjusted Outcomes

	Pre-Intervention ($n = 52$)	Post-Intervention Intention-to-Treat ($n = 71$)	*P*
Time on continuous albuterol, h	14.4 (5.2–29.2)	8.1 (2.7–26.3)	.14
Pediatric ICU LOS, h	38.7 (20.1, 61.8)	27.6 (2.0, 42.5)	.055
Hospital LOS, d	2.8 (1.95, 3.95)	2.6 (1.7, 3.6)	.29
Time off albuterol before pediatric ICU discharge, h	18 (12.1, 27.3)	14.8 (9.6, 22.9)	.060

Data are presented as median (interquartile range).
LOS = length of stay

Discussion

In this study, we designed and evaluated a new critical asthma protocol for children admitted to the PICU. While there was a trend toward improvement in clinical outcomes, the study did not show a statistically significant difference after implementation of the protocol. We found that it was difficult to achieve adherence to the protocol, with only 42% of subjects receiving treatment with good adherence. The subgroup with good adherence to the protocol did have significant improvements in these outcome measures.

The PSAP differs from previously published PICU critical asthma protocols by including all of the escalation and de-escalation arms without increasing assessments, by including sicker patients, and by adding additional therapies in each arm. Of the studies reviewed, 2 had no escalation component and 1 study could only escalate to a helium-oxygen mixture.[11,12,14] Our protocol also allows for continued escalation with sicker patients as compared to some protocols in which patients are transferred if scoring high on their symptom scale or requiring high F_{IO_2}.[14] The PSAP also attempts to avoid the possible confounder of increasing the total number of assessments[11] or decreasing time between assessments[13] seen in other studies, including

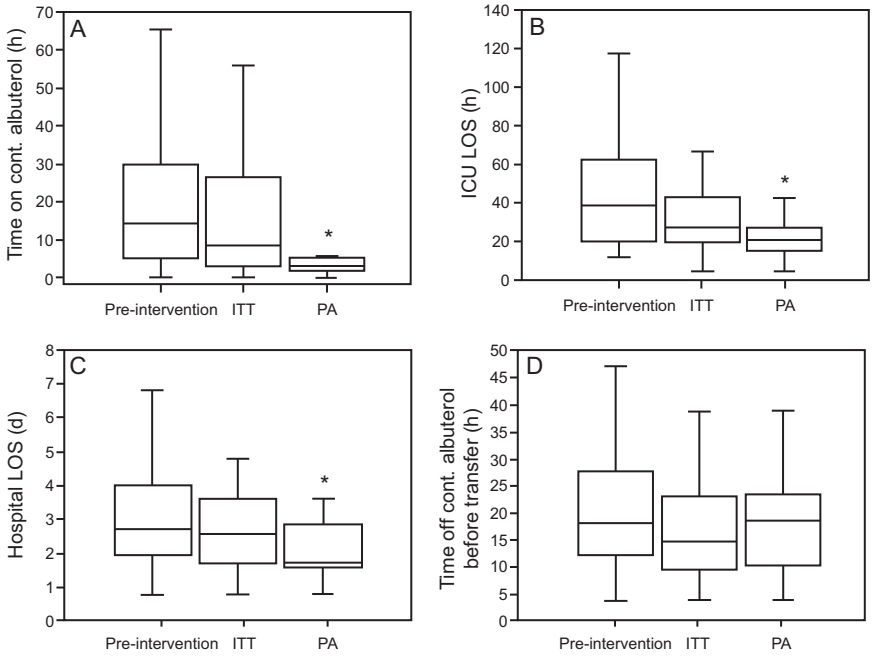


Fig. 3. Median values of pre-intervention versus intention-to-treat (ITT) and protocol-adherent (PA) cohorts for primary and secondary end points. * $P < .05$ compared to pre-intervention. LOS = length of stay.

those with escalation pathways. This might lead to better outcomes due to quicker recognition of improving or deteriorating patients. A recent study by Melendez et al,[18] which was a continuation of the prior iteration by Wong et al,[10] reported a reduction of time on continuous albuterol and LOS with a protocol that contains both escalation and de-escalation pathways. While showing excellent results overall, it differs from our study because it does not protocolize the approach beyond the use of a helium-oxygen mixture and relies on hourly assessments, which may not be practical in all settings.

Failure to show significant improvement via the protocol is largely attributed to poor adherence. Our overall adherence of 42.3% is similar to that reported in a study examining another protocol (37.6%) in a tertiary care facility, but less than that reported in 2 other such studies (68.3% and 60%).[10,11,14] A third study with 3 iterations showed widely varying adherence of 32%, 70%, and 31% despite occurring sequentially at the same institution.[18] This is an ongoing challenge for protocolized care, although it may represent clinically appropriate care. Our adherence improved during the recruitment process, aided by monthly presentations to rotating resident physicians and quarterly presentations to respiratory therapy staff. However, despite improved adherence to the protocol, overall clinical outcomes remained constant within the ITT cohort through time. To promote adherence, frequent educational presentations were given to respiratory therapists and residents on the protocol, and an order set was built into the electronic medical record. While these were well received and expanded awareness of the initiative, it was difficult to overcome the institutional culture of physician-led asthma titration. To increase use of the protocol, more formal presentations to the entire ICU staff might allow for all involved stakeholders to appreciate the interprofessional support. Identifying protocol "champions" within the respiratory therapist group and regular review of cases not adherent to the protocol are other possible means to promote adherence.

Because we believe the largest benefits from the protocol came from de-escalating patients who are improving, the titration down and ultimately off continuous albuterol was essential. Prior to this protocol, physician providers managed the titration of medication in critical asthma patients. Our protocol allowed for the titration of albuterol, the most commonly adjusted medication, to be driven by respiratory therapists, which was a significant practice change requiring a cultural shift for many health care providers. This was likely was the largest contributor to low adherence rates. Children with critical asthma who are improving clinically may have relatively low clinical acuity compared to other PICU patients, resulting in less attention and therefore slower responses to improvement. While part of our goal was to improve on this response, our results show more work is needed. Our total population of critical asthma may be low relative to other hospitals of our size and quaternary status, which led to a lower sample size than comparative studies. This likely prolonged recruitment time and contributed to difficulty in standardization and a prolonged washout time needed to fully implement the protocol. Another source of low adherence was concern from providers about weaning

Table 3. Demographics of Protocol-Adherent Subjects

	Pre-Intervention ($n = 52$)	Post-Intervention Protocol-Adherent* ($n = 30$)	*P*
Age, y	6.0 (4.0–1.0)	5.0 (3.0–9.0)	.78
Gender			.90
Male	27 (51.9)	16 (53.3)	
Race			.49
White	17 (32.7)	9 (32.1)	
Hispanic/Latino	3 (5.8)	2 (7.1)	
African-American/Black	28 (53.9)	13 (46.4)	
Native American/American Indian	0 (0.0)	0 (0.0)	
Asian/Pacific Islander	2 (3.9)	4 (14.3)	
Other	2 (3.9)	0 (0.0)	
Home controller use	29 (55.8)	20 (66.7)	.33
Significant comorbidity	4 (7.7)	2 (6.9)	> .99
Viral infection (if tested)	17 (54.8)	4 (4.0)	.48
Subject origin			.19
Home emergency department	34 (65.4)	24 (80)	
Outside emergency department	10 (19.2)	6 (20)	
Floor transfer	4 (7.7)	0 (0)	
Direct admission	4 (7.7)	0 (0)	
Initial emergency department RAS	6.0 (3.0–7.0)	5.0 (4.0–6.5)	.57
Initial emergency department RAS severity			.70
0–3: Mild	11 (28.2)	5 (20.8)	
4–6: Moderate	17 (43.6)	13 (54.2)	
7–9: Severe	11 (28.2)	6 (25.0)	
Admit RAS Value	4.5 (3.0–5.0)	5.0 (2.5–6.5)	> .99
Admit RAS Severity			.68
0–3: Mild	7 (31.8)	7 (29.2)	
4–6: Moderate	12 (54.6)	11 (45.8)	
7–9: Severe	3 (13.6)	6 (25.0)	

Data are presented as *n* (%) or median (interquartile range).
* $n = 28$ for race, $n = 25$ for ethnicity.
RAS = Respiratory Assessment Score

Table 4. Unadjusted Outcomes for Protocol-Adherent Subjects

	Pre-Intervention ($n = 52$)	Post-Intervention Protocol-Adherent ($n = 30$)	*P*
Time on continuous albuterol, h	14.4 (5.2–29.2)	3.0 (1.9–5.5)	< .001
Pediatric ICU LOS, h	38.7 (20.1–61.8)	21.0 (15.7–26.8)	< .001
Hospital LOS, d	2.8 (1.95–3.95)	1.7 (1.6–2.8)	.005
Time off albuterol before pediatric ICU discharge, h	18 (12.1–27.3)	18.5 (10.3–23.4)	.21

Data are presented as median (interquartile range). Pre-intervention: $n = 52$; Post-intervention protocol-adherent: $n = 30$.
LOS = length of stay

Table 5. Medication Administered Correctly per Protocol

Medication	Pre-Intervention ($n = 52$)	Post-Intervention Intention-to-Treat ($n = 71$)	*P*
Albuterol	52 (35)	70 (74)	< .001
Steroid bolus	27 (16)	45 (84)	.007
Steroid maintenance	52 (75)	69 (94)	.003
Ipratropium	24 (79)	40 (90)	.23
Magnesium	46 (67)	54 (52)	.12
Terbutaline bolus	5 (40)	7 (29)	.68
Terbutaline infusion	5 (20)	10 (40)	.44
Ketamine	1 (100)	2 (50)	.33

Data are presented as *n* (%).

off continuous albuterol earlier than previously practiced. Continuous albuterol would typically have continued until near-resolution of all symptoms. However, out of 71 subjects in the study, only 1 (1.4%) required a return to continuous albuterol after discontinuation, and this was subsequently seen by providers at the institution as an acceptable risk.

Table 6. Adjuvant Therapies

	Pre-Intervention ($n = 52$)	Post-Intervention Intention-to-Treat ($n = 71$)	*P*
Helium-oxygen mixture	3 (5.7)	9 (12.7)	.94
Noninvasive ventilation	4 (7.7)	8 (11.3)	.12
High-flow nasal cannula	31 (59.6)	30 (42.2)	.09

Data are presented as *n* (%). Pre-intervention: $n = 52$; Post-intervention intention-to-treat: $n = 71$.

In the post-intervention cohort, medication administration per the protocol improved for 3 most common medications (ie, albuterol, steroids, and ipratropium). Of note, medication administration per the protocol increased similarly for the most common medications in both the ITT and the protocol-adherent subgroup. This shows that, while some improvement seen in our study may be due to correcting improper dosing, the difference between the nonsignificant findings in the post-intervention cohort overall and the significant improvements in the protocol-adherent cohort might be attributed to the escalation and de-escalation components of the protocol.

Our study had several limitations. Other than practical implementation issues, our results are also driven by the large benefit for the subset of subjects who only required the most standard treatment, namely steroids, magnesium, ipratropium, and continuous albuterol. Patients who required many adjuvant therapies usually did not have therapy according to protocol as these therapies were typically started on admission to the PICU and therefore did not follow the stepwise escalation in the protocol. This might have introduced a selection bias into our protocol-adherent subset. This also suggests that the majority of the benefit seen in our study is due to faster de-escalation.

Specifically, our study results support the contention that asthma protocols, when adhered to, can be effective in the PICU setting. As compared to prior studies, our protocol standardized both escalation and de-escalation of interventions, and it did not rely on increasing the number of assessments to drive improvement. Our study also included all asthma patients admitted to the ICU and did not exclude patients with the most severe scores, allowing for better generalizability to outside populations. Future iterations of this protocol would likely include a faster escalation with or without a faster de-escalation, a possible stratification of sicker patients into a faster escalation arm of the protocol, and exploration of RAS score cutoffs to find the ideal escalation and de-escalation values.

Conclusions

We found that implementation of an asthma protocol in the management of children with asthma admitted to a PICU, when adhered to, resulted in less time receiving continuous albuterol and shorter PICU and hospital LOS. However, protocol adherence was problematic with the treatment of less than half of subjects meeting adherence criteria.

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