

Continuous Albuterol in Pediatric Acute Care: Study Demonstrates Safety Outside the Intensive Care Unit

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Abstract

Introduction: There are little data to support the use of continuous aerosolized albuterol (CAA) in the non-intensive care unit (ICU) or non-emergency department (ED) setting for pediatric asthma patients. A 2014 study demonstrated low rates of adverse outcomes associated with administration of CAA on the acute care unit; however, the authors do not describe additional outcomes. We sought to determine whether administration of CAA within a respiratory cohort on an acute care floor was feasible and safe. **Methods:** This quasi-experimental study evaluates data 1 year before and after (2014–2016) the initiation of CAA on the acute care inpatient unit for asthma patients 2–18 years of age. Outcome measures included ED and hospital length of stay (LOS), readmission rate, rapid response team activations, and transfers to ICU. Use of chest x-rays, viral studies, and hospital charges were also studied. **Results:** Seven hundred thirty-two patients met study criteria. Population demographics and severity of acute presentation were similar pre- and poststudy. ED LOS decreased poststudy, whereas overall hospital LOS was unchanged. Fifteen-day readmission rate decreased in the poststudy group. Only 4 rapid response activations occurred in the poststudy population. The poststudy group utilized fewer chest x-rays and viral studies. There was no change in overall hospital charges. **Conclusions:** With appropriate resources and safety processes in place, care of pediatric patients with status asthmaticus receiving CAA on an acute care unit, outside of the ICU, resulted in improved ED LOS with evidence of lower resource utilization and rare adverse outcomes. (*Pediatr Qual Saf* 2019;4:e225; doi: 10.1097/pq9.000000000000225; Published online December 5, 2019.)

BACKGROUND

Hospital admissions for pediatric asthma patients totaled over 136,000 in the United States in 2010.¹ Continuous aerosolized albuterol (CAA) is recommended by the National Heart, Lung and Blood Institute as a treatment for severe status asthmaticus

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and has been supported in subsequent studies.^{2,3}

In studies conducted in the intensive care unit (ICU) and emergency department (ED), CAA is safe and superior in efficacy to intermittent albuterol for acute, severe asthma exacerbations.^{4–8} Historically, in tertiary care pediatric hospitals, CAA was administered in only the ED or ICU settings. Currently, pediatric CAA protocols vary widely across the country. Some hospitals and guidelines mandate that CAA only be given in a critical care area. Others allow its administration on an acute care floor.^{9–13} Aside from one study describing low rates of adverse outcomes (hypokalemia, life-threatening arrhythmias, and intubations) associated with CAA administered on an acute care pediatric floor, there are little pediatric data to support the use of CAA outside the ED or ICU.¹⁴

At a large, quaternary children's hospital, CAA was historically administered exclusively within the ED and critical care settings. Downstream effects of this protocol included a persistently high critical care census and prolonged stay in the ED while awaiting a critical care bed. Patients often waited in the ED in attempts to wean off continuous albuterol so they would meet criteria for admission to the acute care floor. Mounting frustrations with the long-standing protocol and a growing need for more critical care beds led to an initiative which allowed administration of CAA on the acute care floor. This study examines data before and after this change to determine



whether administration of CAA on the acute care floor is feasible and safe when appropriate resources are in place.

METHODS

The Baylor College of Medicine Institutional Review Board approved this study.

Setting

This study took place at a large, quaternary care, pediatric hospital with 75,000 ED visits, and >18,000 pediatric hospital admissions annually. Historically, CAA administered in the hospital was only allowed in the ED, progressive care unit (PCU, an intermediate-level ICU which provides higher-level respiratory support but not intubation/ventilation), or pediatric ICU (PICU). Even those patients who were clinically appropriate for the floor, but with poor response to intermittent albuterol, required admission to the PCU solely for CAA. Critical care beds were in high demand, and the PICU (31 beds) and PCU (36 beds) were often full. Patients would stay for extended amounts of time in the ED on CAA while waiting for a critical care bed or while attempting to wean off CAA so that they were eligible for the acute care floor. In this hospital, any transfer from the acute care floor to the PCU or PICU requires a rapid response team (RRT) call, which anyone in the hospital can initiate. An RRT typically consists of an ICU fellow, critical care faculty, a respiratory therapist (RT), and a registered nurse (RN). The RRT evaluates and either transfers the patient to a critical care unit (PCU or PICU) or forms a treatment plan with a reevaluation within 1 hour. Before this change, any patient necessitating CAA required an RRT to be moved to the PCU, a substantial use of ICU resources even if only for CAA. Of note, intravenous (IV) magnesium is only administered in the ED and ICU settings in this hospital; therefore, this therapy was not trialed before CAA.

The hospital's satellite site has allowed for CAA on the acute care floor since its opening in 2011. In September 2015, to maximize critical care bed availability and better utilize other areas of the hospital, CAA was allowed for the first time on the acute care unit at the main medical center campus, specifically within a designated respiratory cohort unit. The cohort unit was established the previous year to allow for cohorts of bronchiolitis patients requiring high-flow nasal cannula. This floor has a dedicated RT and a nurse-to-patient ratio of 1:4. In 2015, the respiratory cohort expanded to include those patients requiring CAA. Most patients admitted to the Pediatric Hospital Medicine (PHM) team with respiratory-related diagnoses stayed on this floor, including any patients requiring high-flow oxygen or CAA. However, other general pediatrics patients may be housed here depending on hospital bed availability. After the change to allow CAA on this acute care unit, patients receiving CAA may still require PCU admission, even if clinically stable, if the respiratory cohort was full. Upon its formation, nurses and RTs in this

cohort received extensive training on high-flow nasal cannula equipment and recognizing and responding to respiratory distress. Before the initiation of CAA on the unit in 2015, nurses and RTs received refresher training on nebulizer equipment and asthma care. Physician faculty and residents received education on CAA recommendations via in-person sessions and email.

An evidence-based, internally validated asthma protocol titled "Respiratory Assessment and Management Protocol" (RAMP) and an Asthma/Recurrent Wheezing Clinical Guideline also exist at this hospital to guide escalation of albuterol, decision support for using CAA, and albuterol weaning (at 2-, 3-, and 4-hour intervals) (Fig. 1). Included in RAMP is the Clinical Respiratory Score (CRS), an internally validated score that is utilized universally by all departments and by all providers (RNs, RTs, and medical doctors [MDs]), within the hospital (Fig. 2).

Substantial safety processes exist at this institution. On RAMP, the dedicated unit RT or RN assess and record CRS every 1–4 hours (depending on progress in the protocol). Additionally, patients on CAA require monitoring by continuous pulse oximetry. The patients on CAA are made "watchers," meaning they are followed more closely and require MD assessments every 4–6 hours with documentation and focused nursing assessments every 3 hours. While on CAA, the RT monitors the patient every 1–2 hours to assess progress and eligibility to wean off continuous albuterol. An MD must examine the patient and place an order for the cessation of CAA. This hospital has 24-hour coverage by resident doctors and PHM fellows or faculty.

There is not a standard protocol in place for CAA dosing, although most PHM providers at this hospital do not dose >20 mg/h. The RAMP algorithm suggests steroid route and dose. The protocol does not dictate nil per os (NPO) status or IV fluids for patients receiving CAA. However, the typical practice is that patients receiving CAA are made NPO and given IV fluids containing saline and dextrose, and usually 20 mEq/L potassium chloride, at maintenance rate.

Protocol

This quasi-experimental study evaluated a hospital's pediatric asthma population 1 year before and after a bundle of interventions allowing for the use of CAA on the acute care floor (September 1, 2014, to August 31, 2015, and September 1, 2015, to August 31, 2016, respectively). Participants met the following criteria: 2–18 years of age, diagnosis of asthma or recurrent wheezing (>2 documented episodes) listed as 1 of the first 4 admission diagnoses, and received a short-acting β agonist and a systemic corticosteroid during the admission. Investigators cross-referenced the asthma database with a pharmacy database to include only those patients who met the above criteria and received CAA during the admission.

Before September 1, 2015, patients could only receive CAA in the ED, PCU, or PICU at this hospital. After September 1, 2015, patients could also receive CAA in a

respiratory cohort on an acute care floor with the PHM service. The study ultimately included patients who received CAA using the above criteria pre- and postintervention, seen in the ED, and admitted to the hospital on the PHM or PCU service. To evaluate the effects of this change on the hospital comprehensively, the poststudy population includes patients admitted to both the PCU and acute care floor.

Excluded patients include those with chronic medical diagnoses other than asthma, including underlying cardiac disease, malignancy, respiratory anatomic abnormalities, and chronic lung diseases, and patients with active acute infections such as bronchiolitis, bacterial pneumonia, and tuberculosis. Patients admitted to the PICU from the ED

were also excluded because these are only the most severe asthma patients and outside the scope of this study.

Metrics

Demographics included age, sex, race, ethnicity, insurance status, inpatient versus observation status, first admitted inpatient department (acute care floor versus PCU), and an initial CRS as a marker of severity of respiratory distress at the time of triage in the ED.

The primary outcome measure was the length of stay (LOS), both in the ED and overall hospital. We measured ED LOS in time from first documented assessment by triage RN to the time of admission order. Hospital LOS is measured in sum hours from the time of admission order to the

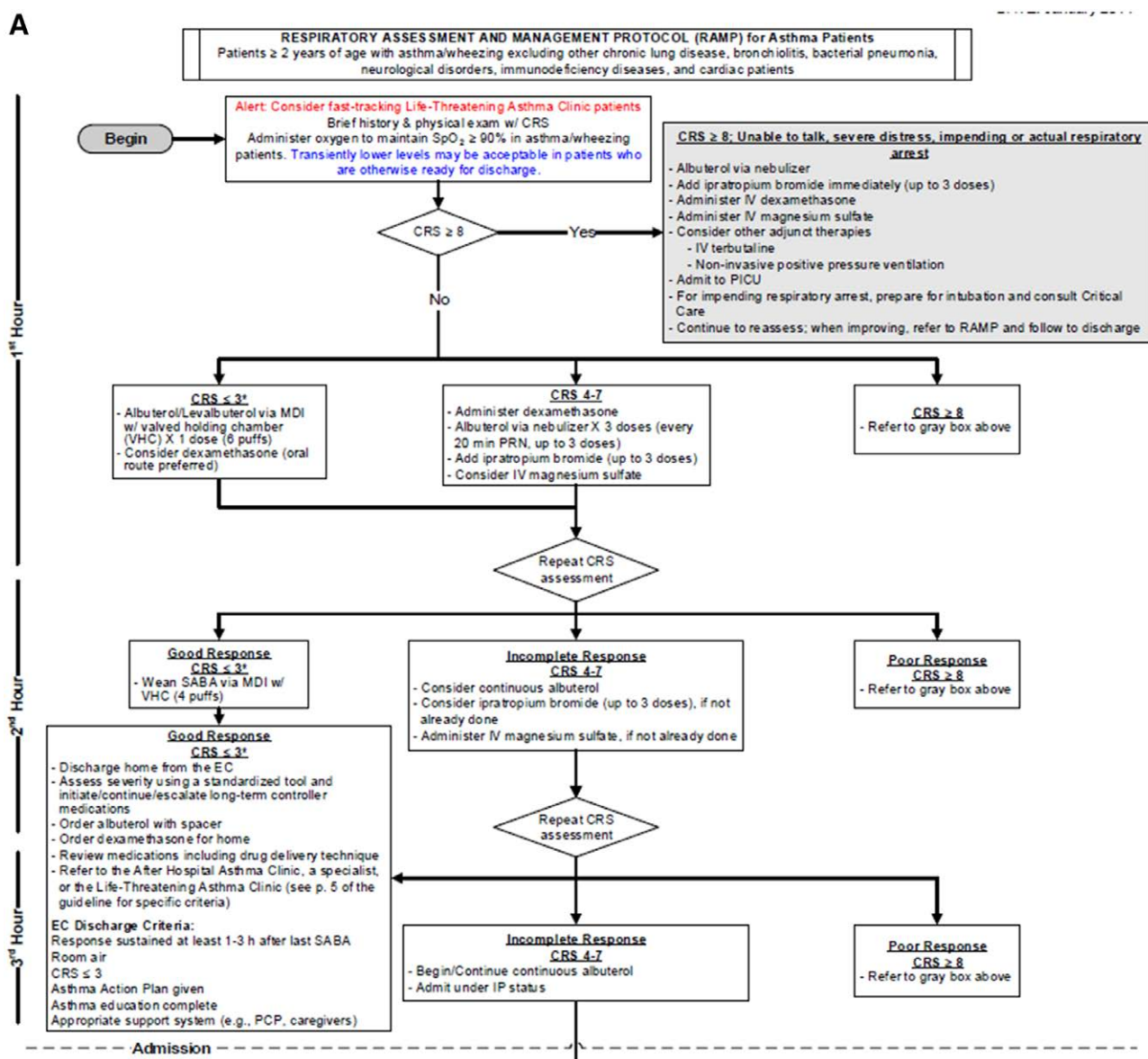


Fig. 1. RAMP for asthma patients. O₂, oxygen; VHC, valved holding chamber. MDI, metered dose inhaler; PRN, *pro re nata*, or as needed; SABA, short-acting beta agonist; EC, emergency center; PCP, primary care physician; IP, inpatient; RT, respiratory therapist; VS, vital signs; PO, *per os*, or orally; q1h, every 1 hour; q2h, every 2 hours; q3h, every 3 hours; q4h, every 4 hours; q24h, every 24 hours; SpO₂, peripheral oxygen saturation.

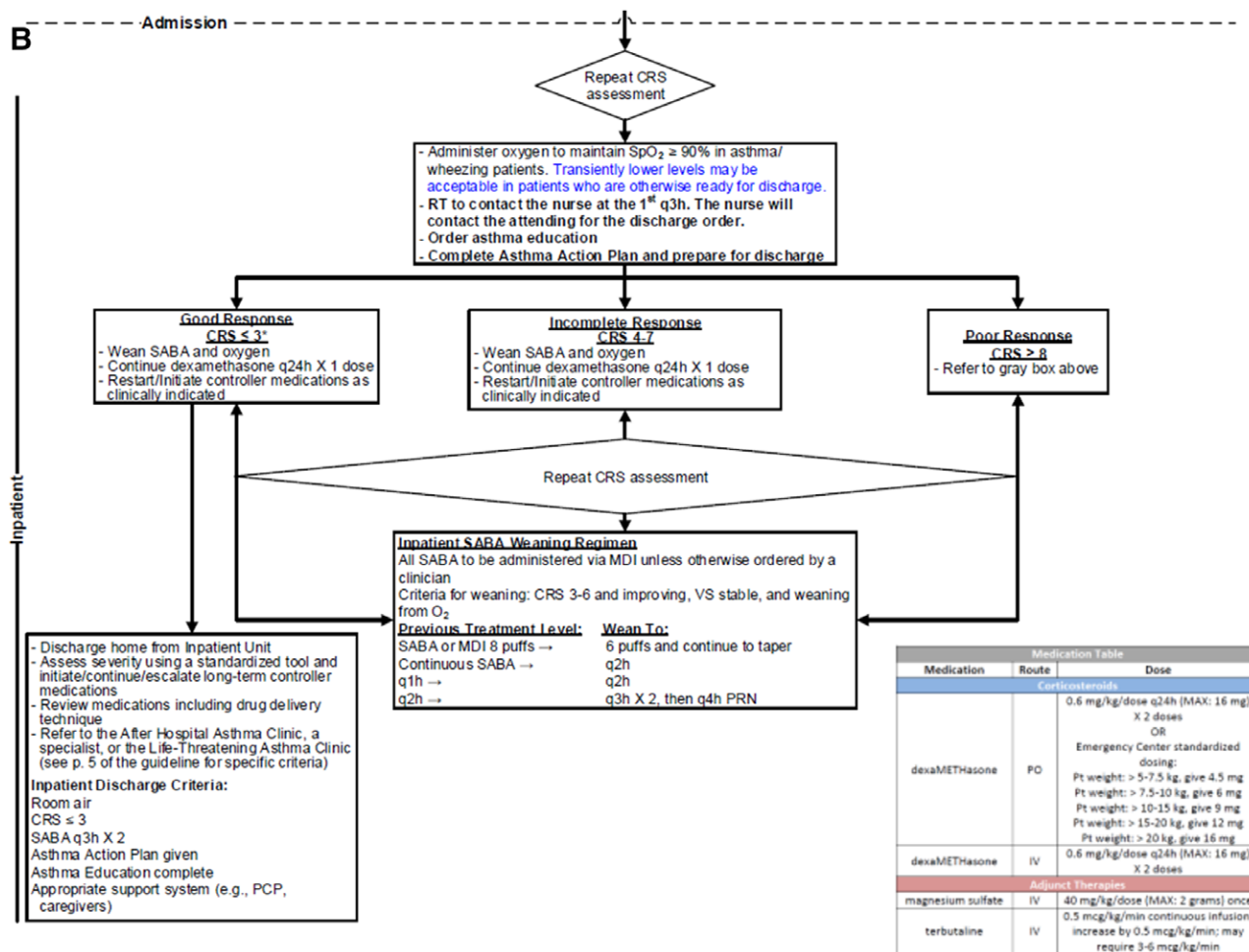


Fig. 1. (Continued)

time of discharge order. Balance measures include 15-day hospital readmission for an asthma-related diagnosis (including patients who presented to an affiliated ED or hospital after discharge), number of RRTs called, and transfers to critical care units postintervention. There is no preintervention data for RRTs as patients requiring CAA before the study stayed in a critical care area, where RRTs are not utilized. Respiratory viral studies and chest x-ray usage are included to assess resource utilization. Charges include room fee, supplies, medications, laboratory and imaging fees, respiratory therapy charges, and associated nursing charges.

Data Source and Analysis

Data for this study were obtained using an internally developed QlikView application to view data from the Electronic Data Warehouse, originally extracted from the Electronic Health Record (Epic Systems, Verona, Wis.) and billing program. The application maintains an ongoing compilation of all patients within a designated asthma cohort (criteria described above).

For all descriptive comparisons, this study utilized the Pearson chi-square test to find statistically significant differences between groups among categorical variables,

unless cell values were <5, then Fischer exact test was used. The Mann-Whitney test was used to find significant differences between continuous variables, given the nonnormal distribution of the data. Potentially significant associations ($P < 0.10$) between study groups were further adjusted using linear regression modeling. We considered potential demographic and clinical confounders with a P value of < 0.25 for further adjustment in subsequent models. For adjustment in all outcome models with only retained cofactors having a P value of < 0.05 , a backward-step approach is used. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 23 software (IBM Corp., Armonk, N.Y.).

RESULTS

The initial data query identified 1,281 patient encounters. We excluded 549 patients from the analysis: 2 direct transfer patients, 49 patients initially admitted to the PICU, and 498 patients discharged from the ED. The final sample contained 732 patients. Groups were divided by discharge date: preintervention patients were discharged between September 1, 2014, and August 31,

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

(Add score from all rows to calculate total CRS score)

Fig. 2. Institutional CRS. SpO₂, peripheral oxygen saturation.

2015 (n = 329 [44.9%]), and postintervention patients were discharged between September 1, 2015, and August 31, 2016 (n = 403 [55.1%]). The distribution of all continuous variables was positively skewed to the right. Therefore, nonparametric testing (Mann–Whitney) was appropriate to utilize when making comparisons between study timeframes.

Demographics between the 2 groups were equivalent. As expected, there was a significant difference in “first admitted inpatient department” between the 2 groups, with an increase in acute care admissions (29% versus 75%) and decrease in PCU admissions (71% versus 25%) after the intervention (*P* < 0.001) (Table 1). Notably, there was no significant difference between ED triage CRSs (5 versus 5; *P* = 0.83). There was a significant decrease in ED LOS from pre- to postintervention (8.53 versus 6.92 hours, respectively; *P* < 0.001), whereas there was no change in total hospital LOS (31.28 versus 31.75; *P* = 0.68) (Table 1). After using a backward-step approach to modeling, the postintervention timeframe significantly reduced ED LOS (β = -3.13 [95% CI, -3.98 to -2.29]; *P* < 0.001).

Readmissions within 15 days decreased significantly after the change (4% versus 1%; *P* = 0.01) (Table 2). The days between discharge and readmission were not

significantly changed pre- to postintervention (6 versus 9, respectively; *P* = 0.45).

During the 1-year postintervention study period September 1, 2015, to August 31, 2016, 125 RRT activations were called on 116 unique patients in this acute care unit. Of these, only 4 RRT activations occurred for patients with an admission diagnosis of asthma (regardless of CAA use): 2 of these patients required transfer to the critical care service—1 resulted in an asthma-related transfer to the PCU with no escalation in care and subsequent discharge the following day, and 1 resulted in asthma-related intubation. The additional 2 patients who had an RRT activation remained on the acute care unit: one had no change in care, and the other was previously taking intermittent albuterol, but improved once given CAA by the RRT on the acute care unit. There was no comparison for this measure in the preintervention group because all patients receiving CAA in the preintervention group required admission to a critical care unit.

There were significantly less viral studies (22% versus 16%; *P* = 0.047) and chest x-rays (48% versus 34%; *P* < 0.001) ordered. Hospital charges were obtained and remained equivalent pre- to postintervention (\$11,000 versus \$11,000; *P* = 0.50) (Table 2).

Table 1. Comparison of Patient Demographics and Study Outcomes for All Eligible Patients between Study Timeframes (N = 732)

	Pre-CAA N = 329 (44.9%) N (%) or Median (IQR)	Post-CAA N = 403 (55.1%) N (%) or Median (IQR)	P*
Age	6.0 (5.0–9.0)	6.0 (4.0–9.0)	0.40
Missing	0	0	
Sex			0.41
Female	116 (35.3)	154 (38.2)	
Male	213 (64.7)	249 (61.8)	
Race			0.91
White	179 (55.4)	223 (56.9)	
African American	134 (41.5)	158 (40.3)	
Other†	10 (3.1)	11 (2.8)	
Missing	6	11	
Ethnicity			0.74
Non-Hispanic	180 (54.9)	213 (53.7)	
Hispanic	148 (45.1)	184 (46.3)	
Missing	1	6	
Insurance status			0.84
Private	84 (25.5)	106 (26.3)	
Public/government	229 (69.6)	274 (68.0)	
None	16 (4.9)	23 (5.7)	
Patient type			0.06
Inpatient	229 (69.6)	306 (75.9)	
Observation	100 (30.4)	97 (24.1)	
First admitted inpatient department			<0.001
Acute care floor	81 (29.1)	293 (74.7)	
Progressive care unit	197 (70.9)	99 (25.3)	
Missing	51	11	
Initial CRS	5.0 (4.0–5.0)	5.0 (3.0–5.0)	0.83
Initial CRS severity			0.31
Mild	77 (23.4)	114 (28.3)	
Moderate	243 (73.9)	277 (68.7)	
Severe	9 (2.7)	12 (3.0)	
Length of stay			
ED LOS (h)	8.53 (6.26–11.94)	6.92 (5.20–9.08)	<0.001
Missing	51	11	
Total hospital LOS (h)	31.28 (24.40–42.27)	30.75 (23.98–41.70)	0.68
Missing	0	0	

*P values for categorical variables were calculated using the Pearson chi-square test, unless any cell value was <5, then the Fisher exact test was utilized. P values for continuous variables were calculated using the Mann–Whitney test.

†Other races include Native American, Pacific Islander, and Asian.

IQR, interquartile range.

DISCUSSION

ED LOS significantly decreased in the postintervention group. The addition of CAA on the acute care floor allowed for faster patient throughput in the ED by decreasing delays surrounding high critical care census or acute care floor criteria. ED physicians and RTs no longer needed to attempt to wean CAA in the ED in order to meet eligibility for the acute care floor. Overall hospital LOS was unaffected, demonstrating no untoward effects on LOS with CAA use outside of the ICU setting.

The administration of CAA on the floor resulted in the positive effects previously noted. Additionally, there was a significant decrease in the 15-day readmission rate in the postintervention period. Readmissions are rare and affected by multiple factors, so one cannot credit this change to the intervention alone. However, the data do imply that CAA administered outside of the ICU was not associated with an increase in readmissions. Only 4 RRT calls were made for any patient with an admission diagnosis of asthma in the 1-year postintervention time frame. Two of those calls resulted in a transfer to a critical care unit: 1 patient met discharge criteria the next morning,

and 1 patient ultimately required intubation. In this large quaternary children’s hospital, where 125 total RRTs occurred for this acute care unit in the 1-year postintervention period, an extremely small portion (3.2%) occurred in asthma patients. For context, this unit holds 20 patient beds and typically operates at 80%–90% capacity, making for an estimated 5,840–6,570 patient days over 1 year.

Certain data were not extracted and were outside the scope of this study, including associated rates of clinically significant hypokalemia and arrhythmia. Previous data showed low rates of these outcomes.¹⁵ Although this information was not specifically studied, we used RRT data as a surrogate marker for clinical decompensation requiring resuscitation beyond typical PHM practice.

Our study demonstrates decreased use of chest x-rays and viral studies in the postintervention group, aligning with evidence-based practice.¹⁵ In the postintervention period, the hospital’s chest x-ray utilization approached appropriate benchmarks established in previous literature. Quality improvement efforts to increase adherence to evidence-based institutional guidelines and order sets for the asthma population were already in place 9

Table 2. Comparison of Readmission and Diagnostic Tests Between Study Timeframes (N = 732)

	Pre-CAA N = 329 (44.9%) N (%) or Median (IQR)	Post-CAA N = 403 (55.1%) N (%) or Median (IQR)	P*
Readmitted within 15 d			0.01
No	315 (95.7)	399 (99.0)	
Yes	14 (4.3)	4 (1.0)	
No. days to readmission	5.50 (2.0–11.25)	8.50 (2.50–13.75)	0.45
Viral study obtained			0.047
No	257 (78.1)	338 (83.9)	
Yes	72 (21.9)	65 (16.1)	
Chest x-ray obtained			<0.001
No	171 (52.0)	265 (65.8)	
Yes	158 (48.0)	138 (34.2)	
Charges	\$11,289.65 (\$9,177.83–\$13,269.56)	\$11,043.73 (\$9,318.77–\$14,066.88)	0.50

*P values for categorical variables were calculated using the Pearson chi-square test, unless any cell value was <5, then the Fisher exact test was utilized. P values for continuous variables were calculated using the Mann–Whitney test.

IQR, interquartile range.

months before the pre- and poststudy periods, suggesting that cohorting these patients led to decreased non-evidence-based testing. Factors that may have contributed to this change include additional clinical decision support within order sets, cohorting patients with 1 dominant admitting service, and the possible perception of acuity based on acute care or critical care placement. Hospital charges remained equivalent before and after the intervention. A formal cost analysis is needed to investigate financial implications further.

Limitations of this study include its quasi-experimental design and its single-center nature. Confounding factors, including ongoing improvements in asthma care (discharge education, asthma action plans, and primary care follow-up), likely contributed to improvements. This study took place within a designated respiratory cohort unit, which may not be generalizable for all pediatric acute care floors without resources for higher nursing and respiratory therapy support. The investigators were unable to account for variations in medical practice, including physician decisions to initiate or stop CAA. The CRS score, although widely used internally, is not externally validated, so differences in acute severity may have been unaccounted for, as the study did not include additional markers of illness severity. Institutions may have different levels of illness severity which would prompt administration of CAA, rendering this practice change challenging to adopt without internal study.

Future directions should include a formal cost analysis to measure the impact of the intervention on the hospital system. Study of expansion of this change to areas such as additional acute care units or community hospital sites without a respiratory cohort could potentially provide generalizability to typical acute care settings. Ongoing research is needed for CAA in inpatient settings. Currently, dosing regimens vary widely among providers and institutions. Although there are no standardized, evidence-based dosing regimens for CAA, recent studies have demonstrated success with specific CAA protocols.¹⁷

CONCLUSIONS

Although the safety of CAA use in the ED or critical care unit is well-established, data for use outside of those areas are limited. This study suggests that the care of pediatric patients with status asthmaticus on CAA in a non-ICU, pediatric acute care unit is feasible and safe when adequate resources and processes are in place, including monitoring by continuous pulse oximetry and frequent assessments by all team members. With appropriate planning, education, and resources, the administration of CAA on the acute care floor under the PHM service in this study improved patient flow in the ED, had very low rates of adverse outcomes, and was associated with decreased use of non-evidence-based testing, without any negative impact on hospital charges. Because this is a single-center study, future directions for research would include expanding to multiple areas and institutions and completing a formal cost analysis.

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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