Safety and Effectiveness of Continuous Aerosolized Albuterol in the Non–Intensive Care Setting

WHAT’S KNOWN ON THIS SUBJECT: Continuously aerosolized albuterol been shown to be safe and effective for the treatment of severe status asthmaticus in the emergency department and ICU. Little evidence supports its use in the non–intensive care setting.

WHAT THIS STUDY ADDS: With the appropriate resources and support, continuous albuterol may be administered in the non–ICU setting with a low incidence of clinical deterioration and adverse effects. Certain clinical factors may help identify which patients may benefit from higher acuity care.

OBJECTIVE: To describe the design features, utilization, and outcomes of a protocol treating children with status asthmaticus with continuous albuterol in the inpatient setting.

METHODS: We performed a retrospective cohort analysis of children ages 2 to 18 treated in the non–intensive care, inpatient setting on a standardized treatment protocol for status asthmaticus from July 2011 to June 2013. We assessed characteristics associated with continuous albuterol therapy and, for those treated, duration of therapy and the proportion who clinically deteriorated (ICU transfer or progression to enhanced respiratory support) or who were identified as having hypokalemia or an arrhythmia. Using multivariable logistic regression, we determined which factors were associated with clinical deterioration or prolonged (>24 hours) continuous albuterol.

RESULTS: Of 3003 children meeting study criteria, 1298 (43%) received continuous albuterol. Older age, black race, lower initial oxygen saturation, and higher initial age-standardized heart rate and respiratory rate were associated with initiation of continuous albuterol therapy (P < .001 for all). Median duration of therapy was 14.4 hours (interquartile range, 7.7, 24.6); 340 children (28%) experienced prolonged therapy. Seventy children (5%) experienced clinical deterioration, and 33 children (3%) had identified hypokalemia or arrhythmia. Comorbid pneumonia and emergency department administration of intravenous magnesium or subcutaneous terbutaline were associated with prolonged therapy and clinical deterioration.

CONCLUSIONS: With appropriate support structures and care processes, continuous albuterol can be delivered effectively in the non–ICU, inpatient setting with low rates of adverse outcomes. Certain initial clinical characteristics may help identify patients needing more intensive therapy. Pediatrics 2014;134:e976–e982

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KEY WORDS status asthmaticus, continuous aerosolized albuterol, hospitalization

ABBREVIATIONS CAA—continuous aerosolized albuterol

CDW—CHOP Data Warehouse

CHOP—The Children’s Hospital of Philadelphia

ED—emergency department

ICD-9—International Classification of Diseases, Ninth Revision

IQR—interquartile range

Dr Kenyon conceptualized and designed the study, carried out the initial analysis, and drafted the initial manuscript; Drs Fieldston, Keren, and Zorc helped conceptualize and design the study and reviewed and revised the manuscript; Mr Luan developed the data extraction tools, coordinated and supervised data extraction, and critically reviewed the manuscript; and all authors approved the final manuscript as submitted.

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Status asthmaticus is a leading cause of pediatric hospitalization. Children hospitalized with severe status asthmaticus may need treatment with continuous aerosolized albuterol (CAA), which has been demonstrated to have greater efficacy than intermittent therapy in clinical trials in the emergency department (ED) and the ICU. Given the location of care of these trials, the use of CAA has traditionally been limited to the ICU or intermediate care units. As evidence demonstrating the safety and effectiveness of CAA has accumulated, some hospitals have developed protocols to administer CAA outside the ICU. However, there is a paucity of published data on the characteristics and outcomes of such programs. If proven to be safe and effective, administering CAA in the non-ICU setting could improve use of limited resources, reduce unnecessary ICU transfers, and reduce costs.

We sought to assess the care and outcomes of patients treated with CAA in the non-ICU setting. Specifically, we sought to describe the design features of a program that delivers CAA in the non-ICU setting, describe the characteristics of patients selected for CAA therapy, and assess the effectiveness and safety of this program, including the characteristics of those with clinical deterioration or prolonged therapy.

METHODS

This was a retrospective cohort analysis of electronic medical record data for children treated for status asthmaticus in the inpatient setting at a large, freestanding children’s hospital in an urban area. About 2700 patients are admitted for asthma in a given year, accounting for 17% of the total admissions.

Description of the Asthma Pathway

The Children’s Hospital of Philadelphia (CHOP) first implemented an asthma pathway in the ED and inpatient settings in 1996. ED clinicians initiate the pathway upon initial evaluation of children presenting with wheezing and known or suspected asthma. In the ED, patients with moderate or severe distress receive systemic steroids and 1 hour of continuous aerosolized albuterol sulfate and ipratropium bromide treatment. Based on the patient’s response to this therapy and a standardized respiratory assessment with a clinical asthma score, clinicians designate the appropriate severity level (“mild,” “moderate,” or “severe”). The clinical asthma score used has demonstrated good interobserver agreement in previous research. Patients for whom the “severe” pathway is designated are started on CAA at weight-based doses displayed in Fig 1; they may also receive therapies for enhanced bronchodilation such as intravenous magnesium sulfate, subcutaneous or intravenous terbutaline, or additional therapies based on the clinician’s judgment. If the patient stabilizes with these therapies and is deemed safe for the inpatient unit by the ED physician, he or she is admitted to the non-ICU, inpatient setting, where another physician evaluates and reassigns a pathway severity designation upon arrival (Fig 1).

Progression through the pathway is determined by standardized assessments by trained respiratory therapists and nurses. Patients assessed as “severe” on continuous albuterol therapy receive continuous cardiorespiratory monitoring and pulse oximetry and are assessed hourly with vital signs and a standardized respiratory assessment, including the clinical asthma score. Hourly assessments, alternating between the nurse and respiratory therapist, continue until patients receive 2 subsequent “moderate” assessments, at which time they are advanced to intermittent albuterol, given every 2 hours. The standard nurse to patient ratio of 1:4 is not routinely altered for patients on continuous albuterol, and they can be admitted to any medical floor in the hospital. A critical assessment team, in addition to a code blue team, assists front-line providers in the care of patients with early signs of clinical deterioration. An asthma protocol order set supports the reliable use of the pathway. More details on the asthma pathway can be found at http://www.chop.edu/pathways/emergency-department/asthma/ and http://www.chop.edu/pathways/inpatient/asthma-practice/.

Data Source

To gather data on the use of various therapies for hospitalized children with asthma, we used visit-level demographic, diagnosis, medication administration, and procedure order data from the CHOP Data Warehouse (CDW). CDW archives these categories of data, among others, from the Epic electronic medical record.

We included children age 2 to 18 discharged from an inpatient floor from July 1, 2011 to June 30, 2013 with a primary or secondary diagnosis of asthma (International Classification of Diseases, Ninth Revision [ICD-9] 493.XX), an order for the asthma pathway during the hospitalization, and a standing order for inhaled albuterol administered at least every 2 hours, via nebulizer or metered dose inhaler. We identified those who received CAA by querying the Epic order table for patients who were administered albuterol with “continuous” frequency. Medication administration is routinely documented at the time of receipt, which we verified at the outset of the study with a convenience sample audit of contemporary medical records. We excluded all patients with a concomitant diagnosis of bronchiolitis, those who were transferred from an outside institution, and those not admitted through the ED.

Outcomes

We assessed 3 primary outcomes: clinical deterioration, prolonged therapy, and...
adverse medication effects. We defined clinical deterioration as transfer to the ICU or enhanced respiratory support, indicated by use of high-flow nasal canula, continuous positive airway pressure, bilevel positive airway pressure, or mechanical ventilation, individually or in combination. We defined prolonged therapy as CAA duration beyond 24 hours (approximately the 75th percentile of overall CAA duration based on preliminary data analysis) without transfer to the ICU or enhanced respiratory support. Adverse medication effects included hypokalemia (defined as serum potassium level < 3 mEq/L), cardiac arrhythmia (ICD-9 427.XX), and death. Because cardiac arrhythmia diagnoses could represent a range of conditions, we reviewed the charts of these patients to obtain more specific diagnoses. Potassium levels and electrocardiograms were not routinely checked as part of the pathway. Other outcomes included duration of therapy with CAA (from initiation of therapy) and overall length of stay.

Covariates

We included a number of patient, ED presentation and treatment, and inpatient presentation and treatment variables in our analysis. Patient characteristics included demographic data (age, gender, race or ethnicity); the following comorbidities identified by ICD-9 codes from index hospitalization and outpatient records: obesity, complex chronic condition, gastroesophageal reflux, environmental allergy, food allergy, and pneumonia (index hospitalization only); and previous year utilization (number of previous year ED visits and hospitalizations at CHOP for asthma in preceding 365 days). ED data collected included initial vital signs (age-standardized heart rate and respiratory rate Z scores and oxygen saturation) upon presentation to the ED and receipt of intravenous magnesium or subcutaneous terbutaline in the ED. Inpatient variables included initial vital signs (age-standardized heart rate and respiratory rate Z scores and oxygen saturation) upon admission to the inpatient unit, fractional concentration of inspired oxygen, and receipt of intravenous magnesium sulfate, intravenous terbutaline, or inhaled ipratropium bromide and time of administration. Covariates were selected based on the results of previous work linking specific factors to poor status asthmaticus outcomes, such as ICU admission or fatal asthma, and hypothesized factors defined a priori where there was little literature to guide covariate selection. All covariates were extracted electronically from the CDW.

Statistical Analysis

To assess the differences between children with status asthmaticus treated with CAA and those treated with intermittent therapy alone, we used bivariate statistics to compare the 2 groups with respect to the patient, clinical presentation, and treatment variables described earlier to assess which factors were associated with initiation of continuous albuterol. We used $\chi^2$ tests for categorical variables, 2-sample $t$ tests for normally distributed continuous variables, and Wilcoxon Mann–Whitney rank sum tests for nonnormally distributed continuous variables.

For patients who were treated with CAA, we calculated the median and interquartile range (IQR) for CAA duration, establishing the 75% percentile as prolonged CAA. Then, using bivariate
analysis, we compared the proportion of children who experienced clinical deterioration or were diagnosed with hypokalemia or a cardiac arrhythmia between the CAA cohort and those who received only intermittent albuterol. We then restricted the analysis to only those who received CAA and used multi-variable logistic regression to assess which covariates were most associated with our 3 outcomes of interest: clinical deterioration, prolonged therapy, and adverse medication effects.

We conducted statistical analyses by using Stata version 12.1 (Stata Corp, College Station, TX). We used a standard 2-tailed $P$ value of <.05 to designate statistical significance. The study was approved by the CHOP Institutional Review Board.

RESULTS

There were 4921 patients who met initial study inclusion criteria for inpatient admission for status asthmaticus. Of these, 176 patients (4%) were admitted directly to the ICU, 1608 patients (33%) were initially admitted to the ED observation unit, and 134 were admitted to the inpatient unit without an asthma pathway order and were excluded from the study’s primary analysis. Of the 3003 initially admitted to the inpatient unit with an asthma pathway order, 1298 of children (43%) received CAA and 1705 children (57%) received intermittent albuterol only (Fig 2).

Compared with patients receiving intermittent therapy, patients receiving continuous albuterol tended to be older and of black race (Table 1). A higher percentage of patients treated with CAA had ≥1 previous year CHOP ED visit (53% vs 40%, $P < .001$) and hospitalization (31% vs 22%, $P < .001$). Compared with those on intermittent therapy, those needing CAA had higher age-standardized heart rate and respiratory rate $Z$ scores, both on presentation to the ED and on admission to the hospital.

Of the 1298 patients who received CAA, the median duration of therapy was 14.4 hours (IQR 7.7, 24.6). Patients receiving CAA averaged 3.6 hours longer on the moderate portion of the pathway (albuterol treatments every 2 hours) (28.4 vs 24.8, $P < .001$). Average length of stay was 16.8 hours longer for patients on CAA when compared with those on intermittent albuterol therapy (57.0 vs 40.2, $P < .001$).

**Prolonged Therapy and Clinical Deterioration**

Of those receiving CAA, 340 of 1298 (26%) received treatment for >24 hours. Thirty-three of 340 (10%) were subsequently transferred to the ICU and were thus included in both the prolonged therapy and the clinical deterioration cohorts. Seventy patients (5%) clinically deteriorated based on being transferred to the ICU ($n = 53$), receiving some form of enhanced respiratory support ($n = 49$), or both ($n = 32$). Seventeen children received enhanced respiratory support on the floor, the majority via high-flow nasal cannula. No children in the CAA group were intubated (Table 2).

In multivariate analysis, factors associated with prolonged therapy but not clinical deterioration included age >5, diagnosis of gastroesophageal reflux disease or a food allergy, and higher age-standardized heart rate upon admission to the inpatient unit (Table 3). Higher numbers of previous ED visits were associated with a lower odds of prolonged therapy. Higher numbers of previous hospitalizations, ED administration of magnesium or terbutaline, and concomitant diagnosis of pneumonia were associated with both prolonged therapy and failure to respond. Higher age-standardized respiratory rate upon admission to the inpatient unit was associated with higher odds of clinical deterioration.

**Adverse Medication Effects**

For those who had serum potassium levels measured, the percentage of children with a level <3 mEq/L was not significantly different between the CAA and intermittent cohort (12.2% vs 11.0%, $P = .74$ (Table 2). Similarly, the proportion of children with an arrhythmia diagnosis on intermittent albuterol was not significantly different from that of the CAA cohort (0.8% vs 0.5%, $P = .30$). Arrhythmia diagnoses included premature atrial or ventricular contractions.
TABLE 1 Characteristics of Study Cohort and Bivariate Comparison of Those Treated With Continuous Versus Intermittent Albuterol

<table>
<thead>
<tr>
<th></th>
<th>Entire Cohort</th>
<th>Intermittent Albuterol Only (n = 1705)</th>
<th>Continuous Albuterol (n = 1298)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female (%)</td>
<td>1173 (39)</td>
<td>886 (39)</td>
<td>507 (39)</td>
<td>.99</td>
</tr>
<tr>
<td>Age (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2–3 y</td>
<td>880 (30)</td>
<td>594 (35)</td>
<td>296 (25)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>4–11 y</td>
<td>1618 (54)</td>
<td>851 (50)</td>
<td>767 (59)</td>
<td></td>
</tr>
<tr>
<td>&gt;12 y</td>
<td>495 (16)</td>
<td>260 (15)</td>
<td>235 (18)</td>
<td></td>
</tr>
<tr>
<td>Race or ethnicity (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>316 (11)</td>
<td>232 (14)</td>
<td>84 (6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Black</td>
<td>2354 (78)</td>
<td>1265 (74)</td>
<td>1089 (84)</td>
<td></td>
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<tr>
<td>Hispanic</td>
<td>142 (5)</td>
<td>89 (5)</td>
<td>53 (4)</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>78 (3)</td>
<td>43 (3)</td>
<td>35 (3)</td>
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<tr>
<td>Other</td>
<td>115 (4)</td>
<td>76 (4)</td>
<td>37 (3)</td>
<td></td>
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<tr>
<td>Insurance payer (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>792 (26)</td>
<td>488 (27)</td>
<td>324 (25)</td>
<td>.19</td>
</tr>
<tr>
<td>Public or government</td>
<td>2121 (71)</td>
<td>1182 (68)</td>
<td>539 (72)</td>
<td></td>
</tr>
<tr>
<td>Other or unknown</td>
<td>90 (3)</td>
<td>55 (3)</td>
<td>35 (3)</td>
<td></td>
</tr>
<tr>
<td>Comorbidities (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pneumonia</td>
<td>236 (8)</td>
<td>149 (9)</td>
<td>87 (7)</td>
<td>.04</td>
</tr>
<tr>
<td>Seasonal allergies</td>
<td>1600 (53)</td>
<td>901 (53)</td>
<td>699 (54)</td>
<td>.58</td>
</tr>
<tr>
<td>Food allergy</td>
<td>1172 (39)</td>
<td>654 (39)</td>
<td>518 (40)</td>
<td>.39</td>
</tr>
<tr>
<td>Obesity</td>
<td>437 (16)</td>
<td>245 (14)</td>
<td>192 (15)</td>
<td>.75</td>
</tr>
<tr>
<td>Gastroesophageal reflux disease</td>
<td>747 (25)</td>
<td>476 (28)</td>
<td>271 (21)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Complex chronic condition</td>
<td>945 (31)</td>
<td>573 (34)</td>
<td>372 (29)</td>
<td>.004</td>
</tr>
<tr>
<td>Previous year ED (%)</td>
<td>1584 (45)</td>
<td>678 (40)</td>
<td>866 (53)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Previous year hospitalization (%)</td>
<td>785 (26)</td>
<td>378 (22)</td>
<td>405 (31)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

TABLE 2 Outcomes by Continuous Albuterol Exposure

<table>
<thead>
<tr>
<th></th>
<th>Intermittent Only Overall, N = 1705 (%)</th>
<th>Continuous Albuterol Overall, N = 1298 (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum potassium &lt;3 mEq/L</td>
<td>14/127 (11.0)</td>
<td>29/238 (12.2)</td>
<td>.74</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>13 (0.8)</td>
<td>6 (0.5)</td>
<td>.30</td>
</tr>
<tr>
<td>Transfer to the ICU</td>
<td>10 (0.6)</td>
<td>53 (4.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>High-flow nasal cannula, continuous positive airway pressure, bilevel positive airway pressure</td>
<td>21 (1.2)</td>
<td>48 (3.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intubation</td>
<td>2 (0.1)</td>
<td>0 (0)</td>
<td>.22</td>
</tr>
</tbody>
</table>

For those who received prolonged continuous therapy compared with those who did not, there were no statistically significant differences between the percentage of children with serum potassium <3 mEq for those who had a level checked (9.4% vs 16.0%, P = .12) or arrhythmia diagnoses (0.3% vs 0.5%, P = .59). Given the infrequency of serum potassium levels <3 mEq/L and cardiac arrhythmia diagnoses, we were unable to power the multivariate models sufficiently for these outcomes. No patients died in either group.

**DISCUSSION**

In this study, we describe the design features, utilization, and outcomes of a program treating children with status asthmaticus with CAA in an inpatient, non-ICU setting. When compared with children admitted on intermittent therapy, children receiving CAA had more abnormal vital signs, including higher age-adjusted respiratory rates and lower oxygen saturations, both at presentation to the ED and on admission to the floor. With respect to outcomes, 5% of children clinically deteriorated on CAA, necessitating transfer to an intensive care setting or enhanced respiratory support or both, and about 3% had an adverse effect associated with β agonists. Although these findings must be interpreted in the context of the resources available for respiratory support, our results suggest that continuous albuterol therapy may be delivered effectively in non-ICU settings with a low incidence of clinical deterioration and adverse events.

Given that this is a single-center study, it is important to consider the setting and resources for the care of children on continuous albuterol at our institution. As indicated earlier, children on continuous albuterol do not routinely need nursing staffing ratios greater than 1:4. However, they do receive hourly assessments that alternate between nursing and respiratory therapy. Intravenous magnesium and subcutaneous terbutaline can be administered, with close observation, in the non-ICU setting. And as indicated in our results, enhanced respiratory support, usually in the form of high-flow nasal cannula, can occasionally be administered on specific units familiar with these therapies. With these
TABLE 3 Factors Associated With Clinical Deterioration and Prolonged CAA

<table>
<thead>
<tr>
<th></th>
<th>Prolonged CAA</th>
<th></th>
<th>Clinical Deterioration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>P</td>
<td>OR (95% CI)</td>
<td>P</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2–4 y</td>
<td>Reference</td>
<td></td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>5–11 y</td>
<td>2.3 (1.6–3.4)</td>
<td>&lt;.001</td>
<td>0.9 (0.5–1.6)</td>
<td>.68</td>
</tr>
<tr>
<td>12–18 y</td>
<td>2.3 (1.4–3.7)</td>
<td>&lt;.001</td>
<td>0.5 (0.2–1.4)</td>
<td>.22</td>
</tr>
<tr>
<td>Previous ED visitsa</td>
<td>0.9 (0.8–1.0)</td>
<td>.05</td>
<td>0.9 (0.7–1.1)</td>
<td>.35</td>
</tr>
<tr>
<td>Previous hospitalizationsa</td>
<td>1.3 (1.1–1.6)</td>
<td>.01</td>
<td>1.5 (1.0–2.1)</td>
<td>.03</td>
</tr>
<tr>
<td>Food allergy</td>
<td>1.6 (1.2–2.1)</td>
<td>&lt;.001</td>
<td>1.4 (0.8–2.5)</td>
<td>.20</td>
</tr>
<tr>
<td>Gastroesophageal reflux disease</td>
<td>1.5 (1.0–2.1)</td>
<td>.03</td>
<td>0.6 (0.3–1.3)</td>
<td>.20</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>2.3 (1.4–3.9)</td>
<td>&lt;.001</td>
<td>3.9 (1.9–7.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Magnesium (ED)</td>
<td>1.5 (1.1–2.1)</td>
<td>.01</td>
<td>1.8 (1.0–3.3)</td>
<td>.05</td>
</tr>
<tr>
<td>Terbutaline (ED)</td>
<td>2.3 (1.4–3.6)</td>
<td>&lt;.001</td>
<td>3.2 (1.5–6.8)</td>
<td>.003</td>
</tr>
<tr>
<td>Respiratory rate (IP)b</td>
<td>1.2 (1.0–1.9)</td>
<td>.06</td>
<td>1.9 (1.1–3.0)</td>
<td>.01</td>
</tr>
<tr>
<td>Heart rate (IP)b</td>
<td>1.6 (1.2–2.1)</td>
<td>.003</td>
<td>0.8 (0.5–1.4)</td>
<td>.39</td>
</tr>
</tbody>
</table>

CI, confidence interval; IP, OR, odds ratio.

* Ordinal variables, i.e., number of ED visits and hospitalizations in previous year.

† Modeled as age-normalized Z scores for respiratory rate and heart rate. Interpretation: eg, an increase of 1 SD in age-normalized respiratory rate is associated with 1.9-fold increased odds of failure to respond. IP, Inpatient.

contextual factors in mind, our findings suggest that CAA can be safely administered in a properly resourced non-ICU setting and provide effective treatment of severe asthma exacerbations.

The safety and effectiveness of continuous albuterol have been reported previously in higher-acuity settings. With respect to adverse effects of continuous albuterol including tremor, hypokalemia, and arrhythmia, previous studies in the ICU14 and ED15,16 demonstrated low rates of these side effects, although the duration of continuous albuterol was generally shorter than what was observed in this study. With regard to effectiveness, the practice of treating severe asthma exacerbations with continuous albuterol is based, on one hand, on studies demonstrating more rapid improvement and less deterioration compared with intermittent hourly treatment in the ED5 and ICU17 and, on the other, outcome equivalence and superior adverse effect profile compared with systemic infusion of β-agonists,18 also in the ICU. The question of whether continuous albuterol is effective for the management of children in the non-ICU setting is most relevant in the common scenario when patients experience recurrent wheezing or respiratory distress <2 hours after their previous aerosolized albuterol dose. For this question, there is less evidence.

We identified a number of factors that could help distinguish patients who may fail CAA or need prolonged therapy. These factors may help institutions without pediatric ICUs or those with a limited number of beds to identify patients who may benefit from enhanced therapy or the additional monitoring of a higher-acuity setting. For instance, patients with concomitant pneumonia or those who need enhanced bronchodilation with either magnesium or terbutaline in the ED may need additional support or admission to an institution with a pediatric ICU. Our findings that abnormal vital signs upon admission—but not upon presentation to the ED—predict severity of exacerbation are consistent with previous literature showing that components of the clinical assessment predicted admission and hospital course after ED therapy but not before.19

With accruing evidence that continuous albuterol is generally well tolerated, but without definitive evidence indicating for whom it may be most effective, an institution’s decision to implement CAA on the inpatient unit may be based on institutional factors such as the number of admissions for severe status asthmaticus, the availability of ICU beds, and the proportion of ICU transfers considered acceptable. Additional considerations include financial investments in appropriate equipment and time to educate inpatient unit nursing staff and respiratory therapy on the specific medication delivery systems and evaluation for patients on continuous albuterol. Cost—benefit analyses will help institutions determine the relative investments and benefits of CAA on inpatient floors.

Lastly, safely matching patient acuity with resource and staff support is an important foundation of high-value health care. An earlier study of 215 hospitals demonstrated a $3000 cost difference between standard asthma admissions and asthma admissions to the ICU without mechanical ventilation.20 Although this study included adults and may not directly reflect the cost differential for ICU care for children with asthma, our findings have implications for strategies to safely reduce the cost of asthma hospital care.

Our findings are best interpreted in light of a few limitations. This is a single-institution study; therefore, the results may not be broadly generalizable beyond our patient population. We identified arrhythmias and comorbidities using ICD-9 billing codes. Therefore, ascertainment of this outcome and these predictors depended on appropriate diagnosis and characterization of this diagnosis in the patient’s medical record. Although we used a more objective measure of identifying low serum potassium levels, these levels were checked more frequently in the continuous albuterol cohort, which could lead to bias in the ascertainment of this outcome in the CAA group. Presumably, this would bias our results toward an association between hypokalemia and CAA, but we observed no significant difference between the 2 groups with respect to this finding. We
used archived electronic order entry data to determine the timing and duration of various therapies. These orders may not correspond precisely with the time these specific therapies were given or stopped, but, based on our convenience sample chart audit performed at the outset of the study, we found no evidence of systematic bias in these time points.

CONCLUSIONS
This single-institution study provides data on the care and outcomes for patients with severe asthma exacerbations treated with continuous albuterol outside an ICU setting. Our data suggest that CAA may be safely provided on the inpatient floor with appropriate staff support. These data may serve as a starting point for future assessments of continuous albuterol across institutions, with varying staffing models and approaches to the inpatient care of severe asthma.

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