

Underuse of guideline-recommended long-term asthma management in children hospitalized to the intensive care unit: a multicenter observational study



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ABSTRACT

Background: Despite the significant burden of childhood asthma, little is known about prevention-oriented management before and after hospitalizations for asthma exacerbation.

Objective: To investigate the proportion and characteristics of children admitted to the intensive care unit (ICU) for asthma exacerbation and the frequency of guideline-recommended outpatient management before and after the hospitalization.

Methods: A 14-center medical record review study of children aged 2 to 17 years hospitalized for asthma exacerbation during 2012–2013. Primary outcome was admission to the ICU; secondary outcomes were 2 preventive factors: inhaled corticosteroid (ICS) use and evaluation by asthma specialists in the pre- and posthospitalization periods.

Results: Among 385 children hospitalized for asthma, 130 (34%) were admitted to the ICU. Risk factors for ICU admission were female sex, having public insurance, a marker of chronic asthma severity (ICS use), and no prior evaluation by an asthma specialist. Among children with ICU admission, guideline-recommended outpatient management was suboptimal (eg, 65% were taking ICSs at the time of index hospitalization, and 19% had evidence of a prior evaluation by specialist). At hospital discharge, among children with ICU admission who had not previously used controller medications, 85% were prescribed ICSs. Furthermore, 62% of all children with ICU admission were referred to an asthma specialist during the 3-month post-hospitalization period.

Conclusion: In this multicenter study of US children hospitalized with asthma exacerbation, one-third of children were admitted to the ICU. In this high-risk group, we observed suboptimal pre- and post-hospitalization asthma care. These findings underscore the importance of continued efforts to improve prevention-oriented asthma care at all clinical encounters.

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Introduction

Childhood asthma is a major public health problem in the United States, with continued reports of increasing prevalence.^{1,2} Asthma affected approximately 7.1 million US children in 2011.² Asthma exacerbations in children contribute to this burden (eg, 137,000 hospitalizations with the direct cost of \$502 million in 2009).³ Parallel to the increasing asthma prevalence in children, an analysis of administrative claims data from New Jersey reported a 6-fold increase in the use of intensive care units (ICUs) in children with asthma exacerbations between 1992 and 2006.⁴ However, given the inevitable questions about generalizability

(eg, single state data from >8 years ago), along with potential errors in data collection and coding in claims data, the burden of ICU admission for children with asthma exacerbation remains unclear.

Most hospitalizations for asthma exacerbations represent a treatment or maintenance failure and are deemed to be preventable through guideline-recommended longitudinal disease management (eg, use of long-term controller medications and outpatient management by an asthma specialist).^{5,6} To date, most studies of children hospitalized in the ICU for asthma exacerbation have focused on short-term asthma management (eg, mechanical ventilation) and their outcomes (eg, hospital length of stay and in-hospital deaths).^{7–17} By contrast, little is known about the outpatient long-term asthma management of these children before and after hospitalization.

To address the knowledge gap in the literature, we conducted a multicenter study of children hospitalized for asthma exacerbation to investigate the proportion and characteristics of children admitted to the ICU and the frequency of guideline-recommended outpatient management in the pre- and posthospitalization periods. A better understanding of these important issues in long-term asthma care will inform strategies to improve the long-term prevention-oriented management of these hospitalized children with high-risk asthma.

Methods

Study Design and Setting

This is a preplanned analysis of data from a multicenter medical record review study that characterized children and adults hospitalized with asthma exacerbation as part of the Multicenter Airway Research Collaboration (MARC). This study, called MARC-37, was coordinated by the Emergency Medicine Network (EMNet), a collaboration with 234 participating hospitals.⁸ We recruited hospitals primarily by inviting sites that had participated in the University HealthSystem Consortium Asthma Clinical Benchmarking Project that evaluated patients hospitalized for asthma exacerbation during 1999 to 2000.^{18–20} A total of 25 hospitals across 18 US states completed the MARC-37 study (eTable 1 and eFig 1). All patients were treated at the discretion of the treating physician. The institutional review board of each participating center approved the study.

Selection of Participants

Using the *International Classification of Diseases, Ninth Revision, Clinical Modification* code 493.xx,⁹ each MARC-37 site identified all visits with a principal hospital discharge diagnosis of asthma during a 12-month period from January 1, 2012, through December 31, 2013 (ie, each site used a 24-month window from which to select the 12-month study period). Inclusion criteria of the MARC-37 were hospitalization at aged 2 to 54 years and a history of physician-diagnosed asthma before the index hospitalization. We excluded (1) hospitalizations of patients with a history of physician-diagnosed chronic lung disease (eg, cystic fibrosis); (2) transfer hospitalizations; (3) hospitalizations not prompted largely by asthma exacerbation, in the judgment of the site investigators; and (4) additional hospitalizations during the 12-month study period by the same individual. In the case of additional hospitalizations, we included only the first randomly sampled hospitalization and defined it as the index hospitalization. These criteria were the same as in our earlier research on patients hospitalized for asthma exacerbation.^{18–20} For the purposes of the current analysis, we then identified all children aged 2 to 17 years with asthma exacerbation from the overall MARC-37 cohort.

Methods of Measurement

Onsite medical record abstractors reviewed medical records (emergency department [ED], inpatient, primary care physician, and/or specialist records) of 40 patients who were randomly selected by the EMNet Coordinating Center at Massachusetts General Hospital. All abstractors were trained with a 1-hour online lecture, followed by the completion of 2 practice medical records, which were evaluated with a criterion standard. If a reviewer's accuracy was less than 80% per medical record, the reviewer was retrained.

Data abstraction was performed with a standardized form and included patients' demographics (age, sex, and race/ethnicity), primary insurance type, median household income, primary care practitioner status, asthma history, prehospitalization asthma controller medications, specialty care status, details of the current asthma exacerbation (eg, vital signs), short-term asthma management in the ED or clinic, inpatient asthma management, hospital disposition (eg, ICU), discharge medications or plan (eg, asthma action plan), and posthospitalization asthma care (eg, referral to an asthma specialist or allergy testing). Primary insurance types were categorized into private sources, public insurance (eg, Medicaid), self-pay, and other. Median household income was estimated using home zip codes.¹⁰ Primary care was defined as coordinated, comprehensive, longitudinal care including prevention, and primary care practitioner included family physician, internist, or nurse practitioner regardless of payer assignment or duration of longitudinal care. Specialty care was defined as outpatient asthma care by an allergist/immunologist, pulmonologist, or other physician specifically focusing on asthma care (eg, a general pediatrician who is director of the local asthma center).

Statistical Analysis

The primary outcome was admission to the ICU at any time during the hospital course. The secondary outcomes were 2 preventive factors: inhaled corticosteroid (ICS) use and evaluation by an asthma specialist during both the prehospitalization period (during the preceding year) and posthospitalization period (within 3 months after discharge from the hospital).

We classified children into 2 ED groups based on admission to the ICU (yes/no). First, we tested unadjusted associations of patient characteristics with admission to the ICU using the χ^2 , Fisher exact, or Mann-Whitney tests, as appropriate. We also examined the proportion of children with the pre- and posthospitalization preventive care in each group. Second, to examine independent associations of patient characteristics with admission to the ICU for asthma exacerbation, we fitted a 2-level mixed-effects model with binomial response by using random intercepts for hospitals to account for the clustering of patients within hospitals. We chose a set of variables based on a priori knowledge and potential clinical significance.^{5,9–11,21} We did not include markers for acute severity (eg, vital signs at the presentation) because they are likely intermediates for the association of interest. All analyses were performed with SAS statistical software, version 9.3 (SAS Institute, Cary, North Carolina). All tests were 2-tailed, and $P < .05$ was regarded as statistically significant.

Results

Of 1,000 enrolled patients in the MARC-37 study, the analytic cohort was composed of 385 children hospitalized for asthma exacerbation at 1 of 14 hospitals across 12 states. For the 385 children, the median age was 5 years (interquartile range, 3–9 years), and 38% were female; 34% were non-Hispanic white, 43% were non-Hispanic black, and 18% were Hispanic. In addition, 95% of children had a primary care physician. During their hospitalization course, 130 children (34%) had an admission to the ICU, including 111

children (29% of total) with ICU as the initial location of hospitalization and 19 children (5% of total) with subsequent admission to the ICU (eg, transfer to the ICU after admission to the ward). The median ICU length of stay was 2 days (interquartile range, 1–2 days).

Patient Characteristics

Table 1 gives the unadjusted associations of patient demographics, chronic asthma factors, and prehospitalization asthma management according to ICU admission status. Although most of the patient characteristics did not differ across the groups, children with ICU admission were more likely to have public insurance compared with children without ICU admission. In addition, children with ICU admission were more likely to have received ICS treatment before the index hospitalization (both $P < .05$).

However, the proportion of patients who received the guideline-recommended preventive measures was low across the groups. Indeed, among children with ICU admission, 65% were taking ICSs at the time of index hospitalization. Furthermore, only 19% of these children with ICU admission had evidence in their medical record that they had been seen by an asthma specialist. Similarly, medical record review (including all health system–associated testing) revealed that 5% or more of this population had undergone allergy testing (eg, specific IgE or skin prick testing) in the preceding year.

Predictors of ICU Admission

To examine the independent predictors of ICU admission for asthma exacerbation, a multivariable logistic regression model was

fit (Table 2). Female sex, having public insurance, and a marker of chronic asthma severity (ICS use) were associated with a higher risk of ICU admission (all $P < .05$). By contrast, an evaluation by an asthma specialist before the index hospitalization was associated with a significantly lower risk of ICU admission (odds ratio, 0.46; 95% CI, 0.22–0.94; $P = .04$).

Acute Asthma Presentation and In-Hospital Management

Acute asthma presentation, ED or clinic course, and inpatient course differed across the groups (Table 3). For example, children with ICU admissions were more likely to be treated with inhaled anticholinergics, subcutaneous epinephrine, terbutaline, and mechanical ventilation in both the ED or clinic and inpatient settings (all $P < .05$) compared with those without ICU admission. Among children with ICU admission, only 11 children (9%) underwent noninvasive positive pressure ventilation, and 3 children (2%) underwent intubation. None of the randomly selected children died in the hospital.

Discharge and Posthospitalization Asthma Management

Table 4 summarizes asthma management at hospital discharge and during the 3-month period after index hospitalization. Overall, 93% of children with ICU admission were discharged with a prescription for ICS. However, when limiting the analysis to those who had not previously used a controller medication, this proportion decreased; only 85% of these children were discharged with a prescription for ICS. Similarly, among children with ICU admission,

Table 1
Demographic characteristics and asthma history of children with asthma exacerbation, according to ICU admission^a

Patient characteristics	ICU admission (n = 130 [34%])	No ICU admission (n = 255 [66%])	P value
Demographics			
Age, median (IQR), y	6 (4–9)	5 (3–9)	.46
Age groups, y			
2–4	50 (38)	96 (38)	.86
5–11	61 (47)	126 (49)	
12–17	19 (15)	33 (13)	
Female sex	57 (44)	88 (35)	.07
Race/ethnicity			.27
Non-Hispanic white	39 (30)	87 (34)	
Non-Hispanic black	54 (42)	106 (42)	
Hispanic	29 (22)	39 (15)	
Others	4 (3)	14 (5)	
Unknown	4 (3)	9 (4)	
Health insurance			.03
Private	39 (30)	105 (41)	
Public	84 (65)	121 (48)	
No insurance	5 (4)	11 (4)	
Unknown	2 (2)	18 (7)	
Estimated median household income, median (IQR), \$	41,201 (35,555–54,285)	41,954 (32,067–54,823)	.52
Have primary care physician	123 (95)	241 (95)	.76
Chronic asthma factors			
Exposure to passive smoke in home	40 (31)	62 (24)	.17
Ever intubated for asthma	5 (4)	9 (4)	.88
ED visit for asthma in past 12 months	58 (45)	132 (52)	.09
Hospitalization for asthma in past 12 months	49 (38)	85 (33)	.57
Prehospitalization asthma management			
Current asthma medications			
Any ICS	85 (65)	138 (54)	.04
ICS monotherapy	64 (49)	96 (38)	.03
ICS-LABA	21 (16)	42 (16)	.94
Leukotriene receptor antagonists or modifiers	32 (25)	63 (25)	.97
Oral corticosteroids ^b	0 (0)	6 (2)	.10
Omalizumab ^c	0 (0)	1 (3)	.99
Seen by asthma specialist in past 12 months	25 (19)	75 (29)	.17
Total IgE checked in past 12 months	5 (4)	17 (7)	.48
Allergen specific IgE checked in past 12 months	4 (3)	12 (5)	.60
Skin prick testing checked in past 12 months	6 (5)	13 (5)	.84

Abbreviations: ED, emergency department; ICU, intensive care unit; ICS, inhaled corticosteroid; IQR, interquartile range; LABA, long-acting β -agonist.

^aData were presented as number (percentage) of patients unless otherwise indicated.

^bLong-term treatment (≥ 14 days).

^cAnalyzed for children 12 years or older (n=52).

Table 2Multivariable random-effects model for factors associated with intensive care unit admission among children hospitalized for asthma exacerbation (n = 385)^a

Variable	Odds ratio (95% CI)	P value
Age, y		
2–4	1 [Reference]	
5–11	0.74 (0.41–1.35)	.33
12–17	0.89 (0.37–2.15)	.80
Female sex (vs male sex)	1.97 (1.11–3.49)	.02
Race/ethnicity		
Non-Hispanic white	1 [Reference]	
Non-Hispanic black	1.11 (0.53–2.32)	.79
Hispanic	0.54 (0.22–1.36)	.19
Health insurance		
Private	1 [Reference]	
Public	1.88 (1.01–3.55)	.049
No insurance	1.55 (0.36–6.63)	.55
Quartiles for median household income		
1 (lowest)	2.17 (0.79–5.93)	.13
2	2.24 (0.78–6.44)	.13
3	1.49 (0.58–3.80)	.41
4 (highest)	1 [Reference]	
Ever intubated for asthma	1.66 (0.39–6.98)	.49
Hospitalization for asthma in past 12 months	1.34 (0.75–2.41)	.33
Current use of ICS or ICS-LABA	2.10 (1.12–3.93)	.02
Seen by asthma specialist in past 12 months	0.46 (0.22–0.94)	.04
Concomitant medical disorders	1.10 (0.53–2.30)	.80

Abbreviations: ICS, inhaled corticosteroid; LABA, long-acting β -agonist.^aBold results are statistically significant.

posthospitalization longitudinal management was suboptimal. For example, approximately 60% were referred to asthma specialists and only 5% or less underwent allergy testing within 3 months after the index hospitalization.

Discussion

In this study of 385 children hospitalized at 14 US hospitals for asthma exacerbation, we found that one-third (34%) of children were admitted to the ICU during their hospitalization. We also found 3 independent predictors of ICU admission: female sex, having public health insurance, and a marker of more severe chronic asthma (ICS use). In contrast, prior evaluation by an asthma specialist was associated with a lower risk of ICU admission. Our data serve to update and build on the few prior studies of the burden of ICU admission for asthma exacerbation among US children, a finding of major clinical and public health significance. Furthermore, our data extend prior research by demonstrating suboptimal prevention-oriented outpatient asthma care (eg, ICS use and outpatient care by asthma specialists) in this population at the highest risk.

Substantial Burden of Children Admitted to the ICU

Despite the clinical and public health relevance, few studies have examined the proportion of children admitted to the ICU among those hospitalized for asthma exacerbation. An analysis of an administrative database (the NDCHealth Hospital Patient Level Database) reported that approximately 8% of children hospitalized for asthma were admitted to the ICU in 2000.²² Another analysis of an administrative database (New Jersey State Inpatient Database) reported an increase in the proportion of children admitted to the ICU during the last 2 decades: from 3% in 1990 to 20% in 2006.⁴ Likewise, our recent analysis of nationally representative data of pediatric hospitalizations (Kids' Inpatient Database) also revealed a 28% increase in the use of mechanical ventilation in children hospitalized for asthma exacerbation between 2000 and 2009.³ Although inferences from the administrative data are somewhat limited because of potential error in data collection and coding, the current study involving 14

Table 3Presentation and in-hospital management of children with asthma exacerbation according to ICU admission^a

Variable	ICU admission (n = 130 [34%])	No ICU admission (n = 255 [66%])	P value
Presentation and ED or clinic course			
Duration of symptoms ≤ 24 hours	36 (28)	64 (25)	.57
Vital signs			
Initial respiratory rate, median (IQR), min	36 (28–46)	32 (24–42)	.003
Initial oxygen saturation, median (IQR), %	92 (88–96)	94 (91–96)	.003
Concomitant medical disorders ^b	21 (16)	59 (23)	.11
Acute asthma treatment			
Inhaled short-acting β -agonist	128 (99)	251 (98)	>.99
Inhaled anticholinergics	96 (74)	159 (62)	.02
Systemic corticosteroids	121 (93)	225 (88)	.04
Intravenous magnesium	61 (47)	61 (24)	.03
Subcutaneous epinephrine	10 (8)	7 (3)	.02
Terbutaline	5 (4)	1 (<1)	.02
Noninvasive positive pressure ventilation	6 (5)	2 (1)	.02
Intubation	3 (2)	0	.04
Inpatient course			
Initial admission location ^c			<.001
ICU	111 (85)	0	
Hospital ward or stepdown unit	16 (12)	250 (98)	
ED observation unit	3 (2)	5 (2)	
Acute asthma treatment			
Inhaled short-acting β -agonist	130 (100)	255 (100)	
Inhaled anticholinergics	68 (52)	74 (29)	<.001
Systemic corticosteroids	130 (100)	244 (96)	.07
Intravenous magnesium	24 (19)	29 (11)	.06
Subcutaneous epinephrine	10 (8)	7 (3)	.03
Terbutaline	10 (8)	0	<.001
Noninvasive positive pressure ventilation	11 (9)	1 (<1)	<.001
Intubation	3 (2)	0	.04
Hospital length of stay, median (IQR), d	3 (2–4)	2 (1–3)	<.001
Disposition			
Sent home	130 (100)	255 (100)	
Died in the hospital	0	0	

Abbreviations: ED, emergency department; ICU, intensive care unit; IQR, interquartile range.

^aData were presented as number (percentage) of patients unless otherwise indicated.^bThe medical conditions included pneumonia (n = 30), otitis media (n = 5), and others (n = 45).^cNineteen patients were initially admitted to the ward or observation unit before transfer to the ICU.

hospitals across 12 states revealed that 34% of children hospitalized with asthma exacerbation were admitted to the ICU during 2012 to 2013. These data collectively indicate a substantial burden of ICU use among US children with asthma exacerbation. The reasons for the high level of ICU use is likely multifactorial. Studies have reported that the prevalence of children with chronic medical conditions has increased in the US population^{23–27} and in children hospitalized for asthma exacerbation,³ thereby leading to more intensive resource use. Alternatively, the population with asthma exacerbation may be similar in severity,⁴ whereas the criteria for ICU admission changed and their resource use increased. A lack of consensus among clinicians as to the best practices, suggested by a wide practice variation for care of the children with severe asthma exacerbation,^{8,10,12} might, in part, contribute to this phenomenon.

Risk Factors for ICU Admission

We were also struck by the disproportionate health care–associated disparities for the risk of ICU admission. Consistent

Table 4Discharge and posthospitalization management for children with asthma exacerbation according to ICU admission^a

Variable	ICU admission (n = 130 [34%])	No ICU admission (n = 255 [66%])	P value
Discharge medications			
Oral corticosteroids	123 (95)	234 (92)	.31
Any ICS	121 (93)	216 (85)	.02
ICS monotherapy	107 (82)	183 (72)	.02
ICS-LABA	14 (11)	33 (13)	.54
Leukotriene receptor antagonists or modifiers	42 (32)	75 (29)	.56
Discharge medications if not receiving a controller medication before the index hospitalization ^b			
Oral corticosteroids	38 (93)	100 (89)	.53
Any ICS	35 (85)	78 (70)	.05
ICS monotherapy	34 (83)	76 (68)	.06
ICS-LABA	1 (2)	2 (2)	.99
Leukotriene receptor antagonists or modifiers	3 (7)	12 (11)	.76
Smoking cessation intervention for parents ^c	17 (43)	29 (47)	.67
Received written asthma action plan	114 (88)	186 (73)	.001
Follow-up appointment made before discharge	90 (69)	138 (54)	.02
Posthospitalization management within 3 months after hospital discharge			
Referred to asthma specialist	81 (62)	117 (46)	.002
Total IgE checked	4 (3)	6 (2)	.74
Allergen specific IgE checked	6 (5)	5 (2)	.19
Skin prick testing checked	4 (3)	7 (3)	.99

Abbreviations: ICS, inhaled corticosteroid; ICU, intensive care unit; LABA, long-acting β -agonist.^aData are presented as number (percentage) of patients unless otherwise indicated.^bAnalyzed for 153 children who were not treated with ICS, ICS-LABA, or leukotriene modifiers before index hospitalization.^cAnalyzed for children exposed to passive smoke in home (n = 102).

with a prior study in the late 1990s,¹⁷ our data indicate that publicly insured (eg, Medicaid) children were at a higher risk of ICU admission for asthma exacerbation, suggesting ongoing and uneven disease burden in this vulnerable population. Although the pathway through which insurance status affects acute asthma severity and intensive resource use is undoubtedly complex, studies indicated that limited self-management education (or management by the primary care giver), poorer indoor environment, and limited access to preventive care might lead to more severe asthma exacerbation.^{21,28,29}

It may seem intuitive for some clinicians that children with more severe chronic asthma will have more severe asthma exacerbations compared with those with milder disease. However, severe asthma exacerbations, such as fatal asthma, are known to be equally common in patients with mild, moderate, or severe chronic asthma.^{30,31} Previous studies reported that children taking ICSs, a marker of chronic asthma severity, are at higher risk of ICU admission for asthma exacerbation.^{11,32} In agreement with these studies, we identified an independent association of the current use of ICS with the risk of ICU admission. By contrast, the observed association of female sex with a higher risk of ICU admission is discordant with a previous study³³; the finding warrants further investigation.

In addition to these predictors of ICU admission, we also found a novel association: a prior evaluation by an asthma specialist and lower risk of ICU admission in children. In conjunction with the earlier studies reporting that longitudinal outpatient care by a specialist is associated with fewer subsequent ED visits or hospitalizations and better asthma control,^{34,35} our data lend significant

support to this guideline-recommended care in children with high-risk asthma.

Suboptimal Preventive Asthma Management

Despite the large proportion of children admitted to the ICU, the data indicate suboptimal prevention-oriented longitudinal care before and after the hospitalization in this population. Although most of these children had a primary care physician, many children did not receive these guideline-recommended long-term controller medications or outpatient management by an asthma specialist,⁵ which reflects the inadequacy of current measures to manage this population at the highest risk. Our findings were also mirrored by the studies that demonstrate underuse of controller medications,^{10,36} asthma education,³⁷ outpatient management by specialists,³⁶ and suboptimal coordination of care with asthma centers³⁸ in patients with asthma. These observations are further complicated by limited disease insights and poor adherence with prescribed medications.³⁹ Taken together, the data suggest that knowledge translation initiatives in longitudinal prevention-oriented asthma management at all clinical encounters should remain a top priority area of quality improvement efforts. However, because of the limited resource (eg, time and reimbursement) in the outpatient setting, hospitalization might be an opportune setting to initiate or reinforce the prevention efforts in children with asthma. Furthermore, given the complex reasons for poor asthma control, strategies to address these factors must be multifaceted, including novel strategies (eg, the use of midlevel practitioners, social media, email, and text messaging).

Potential Limitations

The multicenter study has several potential limitations. First, this study relied on medical record review for data collection; therefore, error in data measurement is possible. However, we used a previously applied standardized data collection system with uniform definitions and rigorous training, which achieved a high interobserver agreement in our recent study.⁴⁰ Second, as with any observational study, the observed associations with ICU admission do not necessarily prove causality and might be confounded by unmeasured factors, such as indoor air quality, parental smoking, childhood stress, and institutional variation in resource use for children with asthma exacerbation. Indeed, in this observational study, we did not standardize criteria for ICU admission across the participating hospitals. Nevertheless, we addressed the possibility of patient clustering within the hospitals by using mixed-effects model. Third, the present study investigated only hospitalized children; therefore, those who were treated and released in the emergency department or clinics were not examined. Nevertheless, we focused on the population with the highest morbidity and health care use; our findings are directly relevant to the hundreds of thousands of US children hospitalized for asthma exacerbation (and their families) each year. Lastly, our study population consisted of children hospitalized in urban teaching hospitals; therefore, our findings may not be generalizable to rural or community hospitals. However, children in urban areas have disproportionately high asthma morbidity.⁴¹ It is in precisely this population for which targeted preventive measures are most urgently warranted.

In conclusion, this study of 385 children hospitalized in 14 US hospitals for asthma exacerbation found that one-third of patients were admitted to the ICU and thereby present an important public health challenge. In addition, despite the large burden of children with ICU admission, many of these children did not receive guideline-recommended long-term controller medications or outpatient management by an asthma specialist, reflecting the inadequacy of current approaches to manage this population. For clinicians and policymakers, our findings not only underscore the

importance of continued efforts to improve prevention-oriented longitudinal asthma care at all clinical encounters but also indicate an urgent need for improved access to asthma specialists in children with high-risk asthma. Furthermore, we also found the association of public insurance with a higher risk of ICU admission; however, the pathway through which this health care–related factor affects the risk of ICU admission remains to be elucidated. The study results will facilitate further investigation of barriers to the delivery of high-quality asthma care to this high-risk group of asthmatic children admitted to the ICU.

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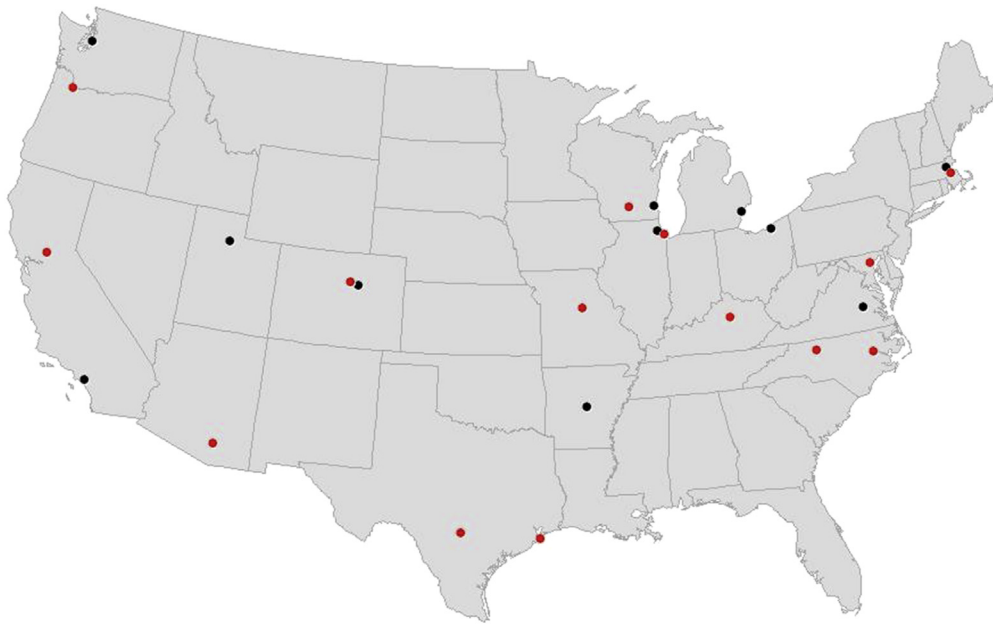
Supplementary Data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.anai.2015.05.004>.

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eFigure 1. Location of the 25 participating sites in the Multicenter Airway Research Collaboration 37 (MARC-37) study. The red dots indicate the location of the 14 sites in MARC-37 with pediatric hospitalizations for asthma exacerbation.

eTable 1

Site investigators at the participating sites in the Multicenter Airway Research Collaboration 37 Study

Institution	Investigator
Brigham and Women's Hospital	Jason Ahn, MD, MPA
Denver Health Medical Center ^a	Stacy A. Trent, MD, MSPH
Froedtert Hospital/Medical College of Wisconsin	John M. Routes, MD
Harborview Medical Center/University of Washington	Taketo Watase, MD, MBA
Henry Ford Hospital	Richard Nowak, MD
Loyola University Medical Center	Beatrice D. Probst, MD
Massachusetts General Hospital ^a	Samantha J. Stoll, MD
Oregon Health & Science University Hospital ^a	Stephanie Nonas, MD
University Health System – San Antonio ^a	Roberto Villarreal, MD
University Hospital Case Medical Center	Barry Brenner, MD, PhD
University of Arizona Medical Center ^a	Mark A. Brown, MD
University of Arkansas for Medical Sciences	Carly Snipes, MD
University of California Davis Medical Center ^a	Suzanne S. Teuber, MD
University of California Irvine Medical Center	Ravi C. Gutta, MD
University of Chicago Medical Center ^a	Valerie G. Press, MD, MPH
University of Colorado Hospital	Nee-Kofi Mould-Millman, MD
University of Maryland Medical Center ^a	Veronica Pei, MD, MPH, MEd
University of Kentucky ^a	Mehdi Khosravi, MD
University of Missouri Hospitals & Clinics ^a	Jonathan Heidt, MD
University of Utah Medical Center	Scott Youngquist, MD, MS
University of Wisconsin Hospital and Clinics ^a	Sima K. Ramratnam, MD, MPH
University of Texas Medical Branch – Galveston ^a	William Calhoun, MD
Vidant Medical Center/East Carolina University ^a	John E. Gough, MD
Virginia Commonwealth University	Taruna Aurora, MD
Wake Forest Baptist Medical Center ^a	Wendy C. Moore, MD

^aThe 14 hospitals that had children hospitalized for asthma exacerbation.