

ORIGINAL CONTRIBUTION

Association of Guideline-concordant Acute Asthma Care in the Emergency Department With Shorter Hospital Length of Stay: A Multicenter Observational Study

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Abstract

Objectives: The objectives were to determine whether guideline-concordant emergency department (ED) management of acute asthma is associated with a shorter hospital length of stay (LOS) among patients hospitalized for asthma.

Methods: A multicenter chart review study of patients aged 2–54 years who were hospitalized for acute asthma at one of the 25 U.S. hospitals during 2012–2013. Based on level A recommendations from national asthma guidelines, we derived four process measures of ED treatment before hospitalization: inhaled β -agonists, inhaled anticholinergic agents, systemic corticosteroids, and lack of methylxanthines. The outcome measure was hospital LOS.

Results: Among 854 ED patients subsequently hospitalized for acute asthma, 532 patients (62%) received care perfectly concordant with the four process measures in the ED. Overall, the median hospital LOS was 2 days (interquartile range = 1–3 days). In the multivariable negative binomial model, patients who received perfectly concordant ED asthma care had a significantly shorter hospital LOS (–17%, 95% confidence interval [CI] = –27% to –5%, $p = 0.006$), compared to other patients. In the mediation analysis, the direct effect of guideline-concordant ED asthma care on hospital LOS was similar to that of primary analysis (–16%, 95% CI = –27% to –5%, $p = 0.005$). By contrast, the indirect effect mediated by quality of inpatient asthma care was not significant, indicating that the effect of ED asthma care on hospital LOS was mediated through pathways other than quality of inpatient care.

Conclusion: In this multicenter observational study, patients who received perfectly concordant asthma care in the ED had a shorter hospital LOS. Our findings encourage further adoption of guideline-recommended emergency asthma care to improve patient outcomes.

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Asthma is a significant public health burden in the United States, affecting 26 million Americans in 2011, with an estimated direct health cost of \$50 billion annually.¹ Acute asthma is responsible for a substantial burden—e.g., approximately 2 million

emergency department (ED) visits and 373,000 hospitalizations in 2012.² In response to this public health problem, the federal government set a Healthy People 2020 objective of “increasing the proportion of persons with current asthma who receive appropriate asthma care

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according to the 2007 National Institutes of Health (NIH) guidelines.”³

Concordance with process measures, as derived from guideline recommendations, is frequently used to assess the quality of care.⁴ To implement process measures as performance metrics, greater concordance should lead to improved patient outcomes.⁵ To date, studies of the process–outcome link in the quality of ED acute asthma care have focused on risks of hospitalization.^{6–10} For instance, several studies have demonstrated that delivery of guideline-concordant asthma care in the ED is associated with a reduced hospitalization rate.^{6–8} However, little is known about how the guideline concordance in the ED affects acute asthma outcomes in patients who are subsequently hospitalized—the population with the highest morbidity and health care utilization. To address the knowledge gap, we used data from a 25-center observational study of 854 patients hospitalized with acute asthma to test the hypothesis that guideline-concordant ED management of acute asthma is associated with a shorter hospital length of stay (LOS).

METHODS

Study Setting and Population

We performed a multicenter chart review study of children and adults hospitalized for acute asthma to determine the quality of their ED and inpatient asthma care, 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 235 participating hospitals.¹¹ The design, setting, and methods of data collection used in this study have been reported previously.^{12–14} A total of 25 hospitals across 18 U.S. states completed the study (see Data Supplement S1, available as supporting information in the online version of this paper). Participating hospitals had a median annual hospitalization volume of 25,949 and a median of 189 hospitalizations for acute asthma per site. All patients were managed 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 (ICD-9-CM) code 493.xx,¹⁵ each hospital first identified all hospitalizations with a principal discharge diagnosis of asthma during a 12-month period, between January 1, 2012, and December 31, 2013 (i.e., each site used a 24-month window from which to select the 12-month study period). Next, site investigators further screened these patients to identify hospitalizations for acute asthma made by patients aged 2 to 54 years with a history of physician-diagnosed asthma before the index hospitalization. We excluded 1) hospitalizations made by patients with a history of chronic obstructive pulmonary disease or cystic fibrosis; 2) transfer hospitalizations; 3) hospitalizations not prompted largely by acute asthma; and 4) repeat hospitalizations during the 12-month study period by the same individual (i.e., each hospitalization was a unique patient).

Methods of Measurement

Among the eligible patients, the EMNet Coordinating Center randomly selected 40 patients by using random numbers that were generated by SAS 9.4 (SAS Institute). Onsite chart abstractors reviewed the medical records of the 40 selected patients. All abstractors were trained with a 1-hour online lecture, followed by the review of two practice medical records, which were evaluated with a criterion standard. If a reviewer’s accuracy was <80% per medical record, the reviewer was retrained. All chart abstractors had some medical training, with the vast majority being physicians or research nurses. Additionally, the abstractors were blinded to this specific aim.

Data abstraction was performed with a standardized form and included patients’ demographics (age, sex, and race/ethnicity), primary health insurance, median household income, primary care physician status, past asthma history, current asthma medications, specialty care status, details of the current asthma exacerbation (e.g., vital signs), asthma management in the ED, inpatient asthma management, and hospital disposition. Primary insurance types were categorized into private sources, public insurance (e.g., Medicaid, Medicare), self-pay, and other. Median household income was estimated using residential zip codes.¹⁶ All data were reviewed at the EMNet Coordinating Center; site investigators were queried about missing data and discrepancies were identified by manual data checks.

Data Analysis

For the purposes of the current analysis, from the overall MARC-37 cohort, we excluded patients who received initial prehospitalization management in the non-ED setting (e.g., urgent care) and those who left the hospital against medical advice. We also excluded those who died during the hospital course because inpatient death is a competing risk of prolonged hospital LOS. We categorized patients into two groups according to the quality of acute asthma care in the ED: patients who received perfectly concordant ED care and those who did not. On the basis of recommendations with level A evidence included in the 2007 NIH guidelines¹⁷ and methods similar to those of previous studies,^{6–8} four process measures were used to define the guideline-concordant acute asthma care in the ED: 1) use of inhaled β -agonists, 2) use of inhaled anticholinergic agents, 3) use of systemic corticosteroids, and 4) nonuse of methylxanthines. The ED guideline concordance was treated as a dichotomous variable because dichotomizing concordance into perfect versus imperfect concordance enabled us to determine how results differ using an all-or-none quality metric.^{6,7,18} We then tested unadjusted associations of guideline concordance with patient characteristics and hospital course by using chi-square, Fisher exact, or Wilcoxon-Mann-Whitney tests.

Next, to investigate the association between guideline concordance in the ED and hospital LOS, we constructed a multivariable negative binomial model with the generalized estimating equation to account for patient clustering within hospitals. Based on clinical plausibility and a priori knowledge,^{6–8,19} we adjusted for

the 11 patient-level characteristics (age, sex, race/ethnicity, primary health insurance, hospitalization for asthma in the preceding year, current use of oral and inhaled corticosteroids, respiratory rate, oxygen saturation and peak expiratory flow [in adults] at ED presentation, and comorbidities) and quality of inpatient acute asthma care. Similar to the guideline concordance in the ED, quality of inpatient asthma care was defined by four level A evidence-based care treatments (i.e., use of inhaled β -agonists and systemic corticosteroids, nonuse of inhaled anticholinergics or methylxanthines during the inpatient course),¹⁷ and was dichotomized to perfect versus imperfect concordance. The negative binomial model has the advantage that there is no need to define an arbitrary cutoff point of LOS and that this model appropriately accounts for statistical overdispersion.²⁰

We performed a series of sensitivity analyses to assess the robustness of our findings. First, to address confounding by severity in the association between ED guideline concordance and hospital LOS (i.e., critically ill patients were hospitalized quickly before receiving all of the recommended care in the ED and stayed in the hospital longer), we repeated the model excluding patients hospitalized within 60 minutes of ED arrival or those admitted directly to the intensive care unit. Second, we stratified the analysis by age group, examining separately children (aged 2–17 years) and adults (aged 18–54 years).

Finally, to address the possible effects of ED acute asthma care on hospital LOS through the effects of *inpatient* asthma care, we performed a mediation analysis fitting negative binomial models with 1,000 bootstrap samples.²¹ This method enables users to examine the extent to which the effect of an exposure on an outcome is direct (i.e., direct effect) and to what extent it is mediated by an intermediate variable (i.e., indirect effect). This method also accommodates an interaction between ED and inpatient asthma care in assessing direct effects and indirect effects. More specifically, the *direct effect* can be interpreted as the percent reduction of hospital LOS among patients who received perfectly concordant ED asthma care versus those who did not if quality of inpatient care were what it would have been without perfectly concordant ED asthma care (i.e., the counterfactual definitions of direct effects²¹). The *indirect effect* can be interpreted as the percent reduction of hospital LOS for those with perfectly concordant ED asthma care comparing the LOS if quality of inpatient care were what it would have been with versus without perfectly concordant ED asthma care (i.e., the counterfactual definitions of indirect effects). Direct and indirect effects were averaged over all patients.

In the MARC-37 study, the overall target sample size was set as 1,000 patients hospitalized for acute asthma. We anticipated that approximately 60% of these 1,000 patients would receive perfectly concordant asthma care in the ED;⁶ this target sample size provided a 95% confidence interval (CI) of 7 percentage points (57%–63%), which is tight enough band to draw inferences from the results. All tests were two-tailed, and $p < 0.05$ was regarded as statistically significant; analyses were implemented with SAS 9.4 (SAS Institute).

RESULTS

The MARC-37 study enrolled 1,000 patients hospitalized for acute asthma from 25 hospitals during 2012–2013. From these, we excluded 122 patients who received initial prehospitalization management in the non-ED setting, 20 patients who left the hospital against medical advice, and four patients who died during the hospital course. After these exclusions, our final sample comprised 854 ED patients subsequently hospitalized for acute asthma. Of the 854 patients in the analytic cohort, 65% were adults and 55% were female. Additionally, 62% of patients received care perfectly concordant with the four level A recommendations in the ED and 38% did not. The mean hospital LOS was 2.3 days in the patients who received perfectly concordant ED care and 2.8 days in those who did not.

Patient Characteristics and Hospital Course

Table 1 summarizes the patient demographics, chronic asthma factors, and chronic treatments by guideline concordance in the ED. Patients who received perfectly concordant ED asthma care were more likely to be male and non-Hispanic black and have markers of chronic asthma severity (ED visits and hospitalizations for acute asthma in the preceding year), compared to those who did not (all $p < 0.05$).

Table 2 summarizes acute asthma presentation and in-hospital (ED and inpatient) course by guideline concordance in the ED. Most of the asthma presentation (e.g., vital signs), initial hospitalization location, and inpatient asthma management did not differ across the groups. However, among the patients who did not receive perfectly concordant ED asthma care, only 14% received inhaled anticholinergics and 77% received systemic corticosteroids in the ED. By contrast, those who received perfectly concordant ED care had a slightly longer ED LOS compared to the others (median = 305 minutes vs. 263 minutes, $p = 0.01$).

Associations Between Quality of ED Asthma Care and Hospital LOS

In the negative binomial model accounting for patient clustering within hospitals, patients who received perfectly concordant ED care had a significantly shorter hospital LOS (−18%, 95% CI = −29% to −5%, $p = 0.006$; Table 3), compared to the others. Likewise, after adjusting for 11 potential confounders and inpatient concordance with asthma medication regimen, perfectly concordant ED asthma care was independently associated with a shorter hospital LOS (−17%, 95% CI = −27% to −5%, $p = 0.006$).

In the sensitivity analyses (Table 3), the adjusted association persisted with exclusion of patients admitted within 1 hour of ED presentation or admitted directly to the intensive care unit and in the adult stratum. With the decrease in statistical power ($n = 299$), children who received perfectly concordant ED asthma care had a nonsignificantly shorter hospital LOS (−13%, 95% CI = −29% to 7%, $p = 0.18$).

In the mediation analysis, the test for ED-inpatient quality of care interaction was significant ($p < 0.001$). With allowing for this interaction, the direct effect of

Table 1
Characteristics of Patients Hospitalized for Acute Asthma, According to Quality of Asthma Care in the ED

Patient characteristics	Perfectly Concordant ED Care* (n = 532)	Imperfectly Concordant ED Care (n = 322)	p-value
Demographics			
Age (y)			
2–4	70 (13)	41 (13)	0.59
5–11	100 (19)	46 (14)	
12–17	27 (5)	15 (5)	
18–29	78 (15)	50 (16)	
30–39	105 (20)	65 (20)	
40–54	152 (29)	105 (33)	0.01
Female sex	274 (52)	194 (60)	
Race/ethnicity†			0.03
Non-Hispanic white	114 (21)	96 (30)	
Non-Hispanic black	291 (55)	148 (46)	
Hispanic ethnicity	86 (16)	52 (16)	
Others	21 (4)	10 (3)	
Health insurance†			0.43
Private	146 (27)	96 (30)	
Public	249 (47)	145 (45)	
No insurance	110 (21)	55 (17)	
Estimated median household income (\$), median (IQR)	39,438 (30,572–51,698)	40,910 (31,039–54,022)	0.13
Having primary care physician	401 (75)	233 (73)	0.66
Current smoker	123 (23)	77 (24)	0.80
Chronic asthma factors			
Ever intubated for asthma	89 (17)	61 (19)	0.18
ED visit for asthma in past 12 months	316 (59)	149 (46)	0.02
Hospitalization for asthma in past 12 months	215 (40)	100 (31)	<0.001
Chronic asthma management			
Current asthma medications			
Current use of oral corticosteroids	134 (25)	87 (27)	0.55
Current use of ICS	307 (58)	168 (52)	0.11
Current use of ICS/LABA	162 (30)	96 (30)	0.83
Current use of leukotriene modifiers	121 (23)	63 (20)	0.25
Seen by asthma specialist in past 12 months	86 (16)	76 (24)	0.001

Data are presented as n (%) unless otherwise indicated.

ICS = inhaled corticosteroids; IQR = interquartile range; LABA = long-acting β -agonist.

*The elements of care represented four level A guideline-recommended treatments in ED: inhaled β -agonists, inhaled anticholinergic agents, and systemic corticosteroids and not receiving methylxanthines.

†Percentages are not equal 100 because of missing data.

perfectly concordant ED asthma care on hospital LOS was similar to that in the primary analysis (−16%, 95% CI = −27% to −5%, $p = 0.005$; Table 3). By contrast, the indirect effect was not significant, indicating that the effect of guideline-concordant ED asthma care on hospital LOS was mediated through pathways other than inpatient asthma care.

DISCUSSION

In this 25-center study of 854 ED patients subsequently hospitalized for acute asthma, we found that approximately 60% of patients received ED acute asthma care perfectly concordant with the four level A recommendations in the NIH asthma guidelines. We also found that these patients had a significantly shorter hospital LOS and that this association operates principally through pathways other than quality of inpatient asthma care. To our knowledge, this is the first study to examine the impact of guideline-concordant care in the ED on acute outcomes in patients hospitalized for acute asthma.

Process measures are designed to examine concordance with expected care and, when provided, should

lead to improved health outcomes.⁵ However, previous studies of process–outcome link in the quality of ED acute asthma care have reported inconsistent associations with acute outcomes.^{6–10} For example, a retrospective analysis of Canadian ED-based data reported that the hospitalization rate of children treated in the EDs with standardized protocols was no different from the rate of children in EDs without these protocols.¹⁰ By contrast, two previous U.S.-based multicenter studies of ED patients demonstrated that adults with complete delivery of the guideline-recommended acute asthma care (i.e., the four process measures used in the current study) had a reduced risk of hospitalization.^{6,7} Reasons for the apparent inconsistency across studies include differences in study design, setting, patient populations, and process measures. Furthermore, the Canadian study that found no significant association did not investigate the concordance at the patient level.¹⁰ In contrast, the validity of the current findings is supported by using a similar study design and process measures as used in the two previous U.S.-based studies. Our data build on these prior investigations and extend them by demonstrating the association with

Table 2
ED and Inpatient Management of Adults Hospitalized for Acute Asthma, According to Quality of Asthma Care in the ED

Variables	Perfectly Concordant ED Care* (<i>n</i> = 532)	Imperfectly Concordant ED Care (<i>n</i> = 322)	p-value
Presentation and ED course			
Vital signs			
Initial respiratory rate (breaths/min), median (IQR)	25 (21–32)	26 (20–32)	0.38
Initial oxygen saturation (%), median (IQR)	95 (92–98)	95 (91–98)	0.96
Initial PEF (L/min), median (IQR)	200 (140–250)	160 (130–220)	0.21
Concomitant medical disorders†	139 (24)	96 (30)	0.07
Acute asthma treatment			
Inhaled short-acting β -agonist*	532 (100)	303 (95)	<0.001
Inhaled anticholinergics*	532 (100)	46 (14)	<0.001
Systemic corticosteroids*	532 (100)	249 (77)	<0.001
Systemic methylxanthines*	0 (0)	3 (1)	0.05
Noninvasive positive pressure ventilation	30 (6)	23 (7)	0.38
Intubation	9 (2)	9 (3)	0.28
ED LOS (min), median (IQR)	305 (191–452)	263 (145–436)	0.01
Inpatient course			
Initial hospitalization location			
ED observation unit	67 (13)	41 (13)	0.21
Hospital ward	319 (60)	209 (65)	
Stepdown unit	31 (6)	17 (5)	
ICU	115 (22)	55 (17)	
Acute asthma treatment			
Inhaled short-acting β -agonist	532 (100)	322 (100)	—
Systemic corticosteroids	509 (96)	306 (95)	0.66
Inhaled anticholinergics	313 (59)	115 (36)	<0.001
Systemic methylxanthines	3 (1)	1 (0.3)	0.60
Noninvasive positive pressure ventilation	28 (5)	8 (3)	0.05
Intubation	15 (3)	12 (4)	0.46
Hospital LOS (d), median (IQR)	2 (1–3)	2 (1–4)	0.02
Data are presented as <i>n</i> (%) unless otherwise indicated.			
ICU = intensive care unit; IQR = interquartile range; LOS = length of stay; PEF = peak expiratory flow.			
*The elements of care represented four level A guideline-recommended treatments in the ED: inhaled β -agonists, inhaled anticholinergic agents, and systemic corticosteroids and not receiving methylxanthines.			
†Pneumonia, bronchiolitis, congestive heart failure, and others.			

another acute asthma outcome (i.e., hospital LOS) among ED patients subsequently hospitalized for acute asthma. Taken together, several rigorously designed studies have arrived at similar conclusions, despite some inconsistencies in the literature. Collectively, we believe that there is sufficient support to using the four process measures as a performance metric in ED patients with acute asthma.

The potential mechanisms linking guideline-concordant asthma care in the ED and subsequent hospital LOS are complex. One might surmise that the observed association is confounded or mediated by the quality of inpatient asthma care. However, in this study, the association remained significant even after adjusting for perfect inpatient compliance with the medication regimen. Additionally, the mediation analysis indicated that the effect of guideline-concordant ED care on hospital LOS was mediated through pathways other than inpatient care. Alternatively, there may be a causal relationship—that is, high-quality asthma care in the ED decreases hospital LOS. Indeed, the literature has well documented the efficacy of early administration of systemic corticosteroids in the ED—one of the four process measures used in the study—on resolution of airway obstruction.²² Systemic corticosteroids are known to accelerate the rate of improvement in airway edema, cellular infiltration, and mucus hypersecretion.²³ Despite

the accumulated evidence, our data also demonstrated that approximately 40% of the study population did not receive emergency asthma care that was fully concordant with the evidence-based guideline recommendations.¹⁷ Our observations should facilitate further investigation of barriers to the delivery of evidence-based emergency care to this asthma population with high morbidity.

LIMITATIONS

Our study has several potential limitations. First, the study derived process measures from medical record review; therefore, an error in data measurement and collection is possible. Although we did not measure the interobserver agreement in this study, the literature demonstrated a high agreement in ED asthma management between retrospective chart abstraction and direct observation, with kappa coefficients of 0.7–0.8.²⁴ In addition, we also rigorously trained chart abstractors at each site and used a previously applied standardized data collection system with uniform definitions.^{6,7} Second, as with any observational study, the association of guideline concordance in the ED with a shorter hospital LOS might be explained, at least partly, by unmeasured confounders, such as reasonable exceptions to the guidelines (e.g., someone with supraventricular

Table 3
Associations of Perfectly Concordant (Versus Imperfectly Concordant) Acute Asthma Care in the ED With Hospital LOS

Models	% Change in Hospital LOS (95% CI)	p-value
Primary analysis		
Unadjusted model*	−18% (−29% to −5%)	0.006
Adjusted model†	−17% (−27% to −5%)	0.006
Sensitivity analyses		
Subgroup analysis‡	−26% (−35% to −15%)	<0.001
Stratified analysis‡		
Children (2–17 y)	−13% (−29% to 7%)	0.18
Adults (18–54 y)	−19% (−31% to −4%)	0.01
Mediation analyses§		
Direct effect	−16% (−27% to −5%)	0.005
Indirect effect	2% (−2% to 6%)	0.86

LOS = length of stay.

*Negative binomial model only accounted for clustering of patients within hospitals by using generalized estimating equations ($n = 854$).

†Negative binomial model adjusted for the 11 patient-level characteristics (age, sex, race/ethnicity, primary health insurance, hospitalization for asthma in the preceding year, current use of oral and inhaled corticosteroids, respiratory rate, oxygen saturation and peak expiratory flow [in adults] at ED presentation, and comorbidities) and quality of inpatient acute asthma care, while using generalized estimating equations to account for clustering of patients within hospitals ($n = 854$). Full multivariable model included in Data Supplement S2 (available as supporting information in the online version of this paper). The results of the adjusted associations between each of recommendation items and hospital LOS included in Data Supplement S3 (available as supporting information in the online version of this paper).

‡Multivariable negative binomial model excluded patients hospitalized within 60 minutes of ED arrival or those admitted directly to the intensive care unit ($n = 647$).

§Mediation analysis fit negative binomial models with 1,000 bootstrap samples.

tachycardia from beta-agonist overuse, medication intolerances), complex patient population with atypical presentations, and institutional variability in hospital discharge criteria. However, the significant association persisted even after accounting for potential clustering within hospitals. Third, one may surmise that the observed 17% reduction in hospital LOS is not meaningful. However, the public health burden of asthma-related hospitalizations is substantial (373,000 hospitalizations with \$2 billion direct cost each year).² Therefore, a 17% decline would be substantial in stressed healthcare systems, although the potential saving achieved by quality improvement effort in the ED would likely be less than 17%. Our inference should be relevant to many stakeholders, such as policymakers, quality agencies, hospitals, and patients. Fourth, we investigated only ED patients who were subsequently hospitalized for acute asthma. Therefore, those who were treated and released at the ED, or their post-ED discharge outcomes (e.g., return ED visits, rehospitalization), were not assessed. Nevertheless, our study focused on the population with the highest morbidity and health care utilization. Finally, our sample consisted of urban, academic EDs and hospitals; therefore, our inferences might be less generalizable to other settings

(e.g., rural or suburban, nonacademic medical centers). Although it might be tempting to dismiss the broader applicability of our inferences, the observed association between higher guideline concordance in the ED and shorter hospital LOS persisted across several different analytic assumptions. There are also plausible biologic mechanisms to support our inferences. Although formal validation of the study in other settings is warranted, we believe that the observed relationships are likely to be present in different practice settings.

CONCLUSIONS

Based on a 25-center observational study of 854 ED patients who were subsequently hospitalized for acute asthma, we found that adults who received emergency asthma care that was fully concordant with level A guideline recommendations had a significantly shorter hospital length of stay, compared those who received suboptimal ED asthma care. Our analysis demonstrated that this association operates principally through pathways other than the quality of inpatient asthma care. For policymakers, our observations lend significant support to the use of these process measures as a performance metric in ED patients with acute asthma. Finally, we also observed that many patients received suboptimal acute asthma care in the ED before their hospitalization. This finding should encourage clinicians and researchers to promote further adoption of evidence-based guidelines and thereby achieve better patient outcomes.

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Supporting Information

The following supporting information is available in the online version of this paper:

Data Supplement S1. Site Investigators at the 25 Participating Sites.

Data Supplement S2. Multivariable Associations of Perfectly-concordant Acute Asthma Care in the Emergency Department with Hospital Length-of-stay.

Data Supplement S3. Associations of Guideline-concordant Acute Asthma Care in the Emergency Department with Hospital Length-of-stay.

Data Supplement S1. Site Investigators at the 25 Participating Sites

Brigham and Women's Hospital	Jason Ahn, MD, MPA
Denver Health Medical Center	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	Samantha J. Stoll, MD
Oregon Health & Science University Hospital	Stephanie Nonas, MD
University Health System – San Antonio	Roberto Villarreal, MD
University Hospital Case Medical Center	Barry Brenner, MD, PhD
University of Arizona Medical Center	Mark A. Brown, MD
University of Arkansas for Medical Sciences	Carly Snipes, MD
University of California Davis Medical Center	Suzanne S. Teuber, MD
University of California Irvine Medical Center	Ravi C. Gutta, MD
University of Chicago Medical Center	Valerie Press, MD, MPH
University of Colorado Hospital	Nee-Kofi Mould-Millman, MD
University of Maryland Medical Center	Veronica Pei, MD, MPH, MEd
University of Kentucky	Mehdi Khosravi, MD
University of Missouri Hospitals & Clinics	Jonathan Heidt, MD
University of Utah Medical Center	Scott Youngquist, MD, MS
University of Wisconsin Hospital and Clinics	Sima K. Ramratnam, MD, MPH
University of Texas Medical Branch – Galveston	William Calhoun, MD
Vidant Medical Center/East Carolina University	John E. Gough, MD
Virginia Commonwealth University	Taruna Aurora, MD
Wake Forest Baptist Medical Center	Wendy C. Moore, MD

Data Supplement S2. Multivariable Associations of Perfectly-concordant Acute Asthma Care in the Emergency Department with Hospital Length-of-stay

Variable	% change in hospital LOS (95% CI)	P-value
Primary exposure		
Received perfectly-concordant ED asthma care*	-17% (-27% to -5%)	0.006
Covariates		
Age		
2-4 years	Reference	—
5-11 years	12% (-2% to 28%)	0.08
12-17 years	27% (2% to 59%)	0.03
18-29 years	28% (1% to 62%)	0.04
30-39 years	37% (11% to 69%)	0.004
40-54 years	46% (23% to 71%)	<0.001
Female sex	11% (0.2% to 23%)	0.045
Race/ethnicity		
Non-Hispanic white	Reference	—
Non-Hispanic black	-8% (22% to 7%)	0.27
Hispanic ethnicity	-18% (-39% to 10%)	0.18
Others	-27% (-54% to 16%)	0.18
Health insurance		
Private	Reference	—
Public	-1% (-22% to 25%)	0.92
No insurance	-0.2% (-18% to 21%)	0.98
Hospitalization for asthma in past 12 months	12% (-4% to 30%)	0.16
Current use of oral corticosteroids	6% (-10% to 25%)	0.50
Current use of inhaled corticosteroids	8% (-4% to 22%)	0.20
Respiratory distress†	8% (-4% to 22%)	0.21
Severity based on initial peak expiratory flow‡		
Mild	Reference	—
Moderate	20% (-23% to 88%)	0.41
Severe	13% (-20% to 59%)	0.49
Very severe	45% (-3% to 116%)	0.07
Comorbidity§	22% (2% to 45%)	0.03
Received perfectly-concordant inpatient asthma care	-11% (-24% to 3%)	0.10

CI, confidence interval; ED, emergency department; LOS, length-of-stay

* The elements of care represented 4 level-A guideline-recommended treatments in the ED: inhaled β -agonists, inhaled anticholinergic agents, and systemic corticosteroids and not receiving methylxanthines.

† Oxygen saturation less than 90% or respiratory rate greater than 30/minute in children aged <6 years; oxygen saturation less than 90% or respiratory rate greater than 20/minute in children aged >6 years and adults.

‡ Severity of asthma exacerbation was classified according to the initial peak expiratory flow (PEF) at ED presentation as follows: mild, 400 L/min or greater for men and 300 L/min or greater for women; moderate, 250 to 399 L/min for men and 200 to 299 L/min for women; severe, 150 to 249 L/min for men and 120 to 199 L/min for women; and very severe, less than 150 L/min for men and less than 120 L/min for women. A dummy variable was used for missingness in PEF (e.g., children).

§ Pneumonia, bronchiolitis, congestive heart failure and others.

|| The elements of care represented 4 level-A guideline-recommended treatments in hospital: use of inhaled β -agonists and systemic corticosteroids, non-use of inhaled anticholinergics and methylxanthines during inpatient course.

Data Supplement S3. Associations of Guideline-concordant Acute Asthma Care in the Emergency Department with Hospital Length-of-stay

Multivariable model*	% change in hospital LOS (95% CI)	P-value
Overall		
Perfect concordance to the 4 level-A guideline-recommended treatments in the ED	−17% (−27% to −5%)	0.006
Item-by-item		
Inhaled β -agonists	−38% (−66% to 11%)	0.11
Inhaled anticholinergic agents	−11% (−22% to 1%)	0.07
Systemic corticosteroids	−16% (−34% to 7%)	0.16
Not receiving methylxanthines	−20% (−31% to 18%)	0.45

Abbreviations: CI, confidence interval; LOS, length-of-stay

* Negative binomial model adjusted for the 11 patient-level characteristics (age, sex, race/ethnicity, primary health insurance, hospitalization for asthma in the preceding year, current use of oral and inhaled corticosteroids, respiratory rate, oxygen saturation and peak expiratory flow at ED presentation, and comorbidities) and quality of inpatient acute asthma care, while using generalized estimating equations to account for clustering of patients within hospitals.

Data Supplement S1. Site Investigators at the 25 Participating Sites

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