

Comparison of US emergency department acute asthma care quality: 1997-2001 and 2011-2012

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Background: It remains unclear whether the quality of acute asthma care in US emergency departments (EDs) has improved over time.

Objectives: We investigated changes in concordance of ED asthma care with 2007 National Institutes of Health guidelines, identified ED characteristics predictive of concordance, and tested whether higher concordance was associated with lower risk of hospitalization.

Methods: We performed chart reviews in ED patients aged 18 to 54 years with asthma exacerbations in 48 EDs during 2 time periods: 1997-2001 (2 prior studies) and 2011-2012 (new study). Concordance with guideline recommendations was evaluated by using item-by-item quality measures and composite concordance scores at the patient and ED levels; these scores ranged from 0 to 100.

Results: The analytic cohort comprised 4039 patients (2119 from 1997-2001 vs 1920 from 2011-2012). Over these 16 years, emergency asthma care became more concordant with level A recommendations at both the patient and ED levels (both $P < .001$). By contrast, concordance with non-level

A recommendations (peak expiratory flow measurement and timeliness) decreased at both the patient (median score, 75 [interquartile range, 50-100] to 50 [interquartile range, 33-75], $P < .001$) and ED (mean score, 67 [SD, 7] to 50 [SD, 16], $P < .001$) levels. Multivariable analysis demonstrated ED concordance was lower in Southern and Western EDs compared with Midwestern EDs. After adjusting for severity, guideline-concordant care was associated with lower risk of hospitalization (odds ratio, 0.37; 95% CI, 0.26-0.53).

Conclusions: Between 1997 and 2012, we observed changes in the quality of emergency asthma care that differed by level of guideline recommendation and substantial interhospital and geographic variations. Greater concordance with guideline-recommended management might reduce unnecessary hospitalizations. (*J Allergy Clin Immunol* 2015;135:73-80.)

Key words: Acute asthma, emergency department, guideline, concordance, quality of care, hospitalization, regional variation, time trend

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Asthma remains an important public health burden in the United States. Asthma prevalence is at historically high levels, affecting 26 million persons in 2010.¹ There are 1.8 million emergency department (ED) visits and 440,000 hospitalizations for asthma,¹ with an estimated economic burden of \$56 billion annually.² In this context the US government has identified improving asthma care as a national objective in “Healthy People 2020” through “increasing the proportion of persons with current asthma who receive appropriate asthma care according to the guidelines.”³

Concordance of health care delivery with quality measures has improved over time in patients with several disease conditions, such as heart failure, acute myocardial infarction, and pneumonia.⁴⁻⁶ Compared with these emergency conditions, however, changes in the quality of emergency asthma care have attracted less attention. An analysis of survey data reported upward trends in the use of systemic corticosteroids and inhaled anticholinergic agents in the ED between 1993 and 2005.⁷ However, their inferences are limited because of selection bias, potential errors in data collection and coding, and unmeasured confounders (eg, severity). Additionally, this study did not address important aspects of emergency asthma care (eg, assessment of airflow limitation and timeliness measures). Therefore it remains unclear whether the quality of emergency asthma care increased or decreased over time, particularly after the publication of the 2007 National Institutes of Health (NIH) guidelines.

To address this knowledge gap, we analyzed data from 3 multicenter observational studies of patients with asthma exacerbation; 2 studies were conducted during 1997-2001, and the third was conducted during 2011-2012. Our study objectives were 3-fold: (1) to investigate changes in the concordance of asthma exacerbation management in the 48 EDs with recommendations in the NIH guidelines over these 16 years, (2) to identify ED characteristics associated with lower guideline concordance, and (3) to test whether higher concordance was associated with lower risk of hospitalization for asthma.

METHODS

Study design and setting

The present analysis combined data from 3 multicenter observational studies of adult ED patients with asthma exacerbation that were performed in 1997-2001 and 2011-2012 as part of the Multicenter Airway Research Collaboration (MARC). MARC is a part of the Emergency Medicine Network (EMNet), a collaboration of more than 225 EDs.⁸

From 1997 to 2001, EMNet conducted 2 observational studies of adult ED patients with asthma exacerbations (the MARC-2 and MARC-5 studies). These studies consisted of ED interviews to assess patients' characteristics and chart reviews to assess ED presentation, asthma management, and disposition. The design, setting, and methods of data collection used in the studies have been reported previously.^{9,10}

We recently completed the MARC-36 study, a multicenter chart review study that sought to characterize adult ED patients with asthma exacerbations and to determine the quality of their emergency care during 2011-2012. To better evaluate temporal changes in emergency asthma care, we recruited EDs by inviting the sites that had participated in the earlier MARC studies during 1997-2001. A total of 48 US EDs in 23 states completed the MARC-36 study (see [Table E1](#) and [Fig E1](#) in this article's Online Repository at www.jacionline.org); the 1997-2001 versus 2011-2012 comparison was based on the same 48 EDs during both time periods. In all of these studies, patients were managed at the discretion of the treating physician. The institutional review board of each participating center approved the studies.

Abbreviations used

ED:	Emergency department
EMNet:	Emergency Medicine Network
ICU:	Intensive care unit
IQR:	Interquartile range
MARC:	Multicenter Airway Research Collaboration
NIH:	National Institutes of Health
PEF:	Peak expiratory flow

Study participants

Using *International Classification of Diseases, Ninth Revision, Clinical Modification*, code 493.xx,¹¹ each site identified all visits with a primary ED or hospital discharge diagnosis of asthma during a 12-month period between January 1, 2011, and December 31, 2012 (ie, sites had a 24-month window from which to select the 12-month study period). Similar to the 1997-2001 studies, the inclusion criteria were ED visits made by adult patients aged 18 to 54 years and a history of physician-diagnosed asthma before the index ED visit. We excluded ED visits made by patients with a history of physician-diagnosed chronic obstructive pulmonary disease, transfer ED visits, repeat ED visits, or ED visits not prompted largely by an asthma exacerbation. In the case of repeat visits, only the first randomly sampled ED visit was included. Therefore each ED visit in the study represented a unique ED patient.

Data measurements

In the MARC-36 study onsite chart reviewers at each site reviewed 40 ED charts that were randomly selected by the EMNet Coordinating Center at Massachusetts General Hospital. All reviewers participated in a 1-hour Web conference training session, and then reviewers completed 2 practice charts, which were evaluated with a “criterion standard.” If a reviewer's accuracy was less than 80% per chart, the reviewer was retrained.

ED-level covariates. A key informant survey at each participating site was conducted to collect data on ED characteristics. Collected covariates included annual volume of ED visits, annual volume of asthma-related ED visits, affiliation with an emergency medicine residency program, urban-rural distinction, and region. Urban-rural distinctions were made according to the 2003 Urban Influences Codes.¹² Geographic regions were defined according to Census Bureau Boundaries.¹³

Patient-level covariates. In the MARC-36 study data abstraction was performed with a standardized form and included patients' demographics, past asthma history, current asthma medications, presentation, peak expiratory flow (PEF), asthma management in the ED or at discharge, and ED disposition. Severity of asthma exacerbation was classified according to the initial 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.¹⁴ This approach was used in earlier MARC studies.^{9,10,15,16}

Quality measures

Process measures. On the basis of common recommendations included in the 1997 and 2007 NIH guidelines¹⁷⁻¹⁹ and using methods similar to those in the National Emergency Department Safety Study,¹⁴ we derived *a priori* 9 explicit process measures. These process measures included 5 level A and 4 non-level A evidence-based measures (2 level B evidence-based treatments and 2 additional timeliness measures; see [Table E2](#) in this article's Online Repository at www.jacionline.org).

We summarized these 9 evidence-based process measures by using a patient composite concordance score, which was computed as the sum of guideline-concordant care provided from the patient's total number of eligible opportunities.²⁰ These scores were then averaged across patients at the ED level to obtain ED composite scores.¹⁴ These scores ranged from 0 to 100, with a score of 100 indicating perfect guideline concordance.²¹ To assess

whether the concordance varied by level of evidence, we calculated the scores for level A and non–level A guideline-recommended measures separately.

Outcome measures. The outcome of interest was hospitalization for asthma exacerbation, which was defined as hospital admission to an observation unit, inpatient unit, or intensive care unit (ICU).

Data analysis

Summary statistics at both the ED and patient levels were presented as means (with SDs), medians (with interquartile ranges [IQRs]), and proportions (with 95% CIs). At the patient level, the change in the item-by-item and overall concordance scores between the time periods were examined by using χ^2 tests or Wilcoxon-Mann-Whitney tests at the patient level. At the ED level, these changes were examined by using paired *t* tests to account for correlations within sites. Complete case analyses were used for these unadjusted analyses. Multiple imputation (using the multivariate normal model) was used for the multivariable regression analyses at both the ED and patient levels to account for the variables with significant missing data (see the [Methods](#) section in this article's Online Repository at www.jacionline.org).²²

ED-level analysis. Using the 2011-2012 data, we examined associations between ED characteristics and overall ED concordance scores by using multivariable linear regression, controlling for a predefined set of aggregate patient mix at the ED level (ie, age, sex, respiratory rate, oxygen saturation, and initial PEF at ED presentation). The missing values for the patient-level characteristics were multiply imputed and then summarized for each ED (see the [Methods](#) section in this article's Online Repository). In the sensitivity analysis, to examine the robustness of the findings, we also generated the ED-level composite concordance scores by using opportunity-based methods.²¹

Patient-level analysis. To examine the association of patients' composite concordance scores with the risk of hospitalization for asthma exacerbation in the 2011-2012 period, we constructed 2 regression models. First, we fitted an unadjusted model that included only the patient's composite score as the independent variable. Second, we fitted a 2-level mixed-effects model with binomial response by using random intercepts for EDs to account for the clustering of patients at the ED level. We adjusted for both patient-level variables (ie, age, sex, race/ethnicity, history of intubation for asthma, current use of systemic corticosteroids and inhaled corticosteroids, comorbidities, duration of symptoms, respiratory rate, oxygen saturation, and initial PEF at ED presentation) and ED-level variables (ie, annual ED visit volume, annual ED asthma volume, and region). For the models, only 4 level A evidence-based care treatments were used for computing the composite scores (ie, inhaled β -agonists, inhaled anticholinergic agents, and systemic corticosteroids and not receiving methylxanthines in the ED) to provide more weight to the treatments that have been shown to reduce asthma-related hospitalizations.^{14,19,23,24} The composite scores were treated as a dichotomous variable given the highly skewed distribution. Additionally, dichotomizing concordance into 100% concordance versus other concordance allowed us to examine how results differed using an all-or-none quality metric.^{14,25}

In the sensitivity analysis, to address potential reverse causations in the association between guideline concordance and risk of hospitalization (ie, critically ill patients were hospitalized quickly before receiving all of the recommended care in the ED), we repeated the hospitalization model, excluding patients hospitalized within 1 hour of ED arrival or those admitted directly to the ICU. Additionally, to address the effect of patients with a prolonged ED length of stay, we also repeated the model using a different definition of the outcome (ie, hospitalization or ED length of stay ≥ 360 minutes). All tests were 2-tailed, and a *P* value of less than .05 was regarded as statistically significant. Multiple imputation was performed with Stata 12.0 software (StataCorp, College Station, Tex); other analyses were performed with SAS 9.3 software (SAS Institute, Cary, NC).

RESULTS

ED and patient characteristics

The analytic cohort comprised 4039 adult patients: 2119 patients from 1997-2001 versus 1920 patients from 2011-2012.

All presented with an asthma exacerbation to one of the 48 participating EDs. Over these 16 years, participating EDs experienced a significant increase in annual volume of ED visits and a decrease in the number of asthma-related ED visits (both $P < .01$, [Table I](#)). The proportion of EDs affiliated with an emergency medicine residency program increased during the time periods ($P < .001$). Participating EDs are all urban but located in different regions across the United States.

ED patients with asthma exacerbations in more recent years were younger and less likely to be female, of non-Hispanic white race, of Hispanic ethnicity, and current smokers (all $P < .05$, [Table I](#)). Over the 2 time periods, chronic asthma burden decreased but remained high. For example, in the 2011-2012 period, 15% were hospitalized for asthma exacerbations in the past year, and 43% had visited the ED for asthma exacerbations. Likewise, use of long-term control medications increased over the time periods but remained underused in this population. For example, the proportion of asthmatic patients taking inhaled corticosteroids increased from 17% to 35% ($P < .001$). At ED presentation, according to the initial PEF results, 87% of patients were classified as having at least a moderate exacerbation in the 1997-2001 period and 80% in the 2011-2012 period ($P < .001$). After ED management, 21% of patients were hospitalized in the 1997-2001 period and 17% in the 2011-2012 period ($P < .001$).

Change in performance on quality measures

[Table II](#) summarizes the item-by-item guideline-recommended management and overall concordance scores according to the time period. At the patient level, the median overall concordance score decreased from 80 (IQR, 67-89) in the 1997-2001 period to 75 (IQR, 57-86; $P < .001$) in the 2011-2012 period. This decrease was driven by significant decreases in concordance with the non–level A recommendations (ie, use of PEF assessment and timeliness measures) from a median score of 75 (IQR, 50-100) to 50 (IQR, 33-75). By contrast, the concordance with the level A recommendations improved, with significant increases in use of inhaled anticholinergic agents and systemic corticosteroids in the ED and in provision of an oral corticosteroid prescription at ED discharge (all $P < .001$).

At the ED level, the overall concordance with the guideline recommendations also decreased, and its variation across EDs became larger over the 2 time periods, with a mean composite score of 75 (SD, 5) to 72 (SD, 8; $P = .02$). In the 2011-2012 period the best-performing ED had a score of 89, whereas the worst-performing ED had a score of 59. Similar to the findings at the patient level, this decrease in overall score was driven by significant decreases in concordance with the non–level A recommendations ([Fig 1](#)), such as PEF assessment (see [Fig E2](#) in this article's Online Repository at www.jacionline.org) and timeliness measures (see [Fig E3](#) in this article's Online Repository at www.jacionline.org), with larger variations in these measures across EDs (all $P < .001$). By contrast, the concordance with level A recommendations improved over these 16 years ([Fig 2](#)).

ED characteristics and ED-level guideline concordance

[Table III](#) shows ED characteristics associated with ED-level guideline concordance in the 2011-2012 period. After

TABLE I. ED and patient characteristics, according to time period

Characteristics	1997-2001	2011-2012	P value
ED characteristics	n = 48	n = 48	
No. of ED visits per year, median (IQR)	55,028 (42,557-800,43)	77,217 (52,957-99,428)	<.001
No. of ED visits for asthma per year, median (IQR)	1,388 (792-2,704)	689 (430-1,548)	.006
Residency affiliated	34 (71)	47 (98)	<.001
Census region			
Northeast		18 (38)	
Midwest		7 (15)	
South		11 (23)	
West		12 (25)	
Location			
Metropolitan		48 (100)	
Nonmetropolitan		0 (0)	
Patient characteristics	n = 2,119	n = 1,920	
Demographics			
Age (y), median (IQR)	37 (28-44)	34 (25-45)	.001
Female sex	1,325 (63)	1,140 (59)	.04
Race/ethnicity*			<.001
Non-Hispanic white	478 (23)	360 (19)	
Non-Hispanic black	1,010 (48)	985 (51)	
Hispanic ethnicity	562 (27)	364 (19)	
Asian	19 (1)	27 (1)	
Others	34 (2)	37 (2)	
Current smoker	741 (35)	627 (33)	<.001
Chronic asthma factors			
Admitted for asthma in past year	439 (21)	283 (15)	<.001
ED visit for asthma in past year	1,183 (54)	830 (43)	<.001
Ever intubated for asthma	334 (16)	230 (12)	<.001
Current use of oral corticosteroids	194 (9)	239 (12)	<.001
Current use of inhaled corticosteroids	366 (17)	672 (35)	<.001
Current use of long-acting β -agonist	187 (9)	470 (24)	<.001
Current use of leukotriene modifiers	18 (1)	208 (11)	<.001
Duration of symptoms*			.29
\leq 3 h before ED arrival	220 (10)	188 (10)	
>3 h	1,682 (79)	1,607 (84)	
ED presentation			
Initial respiratory rate (breaths/min), median (IQR)	22 (20-25)	20 (18-22)	<.001
Initial oxygen saturation (%), median (IQR)	96 (95-98)	98 (96-99)	<.001
Severity based on initial PEF [†]			<.001
Mild	183 (13)	159 (20)	
Moderate	510 (37)	312 (40)	
Severe	486 (35)	240 (31)	
Very severe	210 (15)	73 (9)	
Comorbid illnesses [‡]	184 (9)	266 (14)	<.001
ED length of stay (min), median (IQR)	185 (127-275)	188 (123-295)	.83
ED disposition			<.001
Sent home	1,642 (77)	1,570 (82)	
Admission (hospital ward/observation unit)	380 (18)	284 (15)	
ICU admission	56 (3)	31 (2)	
Other (eg, left against medical advice)	34 (2)	31 (2)	

Data were expressed as numbers (percentages) unless otherwise indicated.

*Percentages do not equal 100% because of missing data.

[†]Analyzed for 2,173 patients with initial PEF values available.

[‡]Including pneumonia, pneumothorax, congestive heart failure, arrhythmia, otitis, sinusitis, and others.

adjusting for aggregated patient mix, Southern EDs and Western EDs were less likely to deliver guideline-concordant care than Midwestern EDs. The sensitivity analysis using the opportunity-based method did not change the results materially.

Patient-level guideline concordance and risk of hospitalization

In the 2011-2012 period, approximately 80% of patients received care perfectly concordant with the 4 level A recommendations (Table IV). These patients had reduced risk of

TABLE II. Performance on quality measures at the patient and ED level, according to time period

Quality measure	Percentage of recommended care received* (95% CI)			Mean ED performance (SD)		
	1997-2001	2011-2012	P value	1997-2001	2011-2012	P value
Process of care						
Inhaled β-agonists in ED	100 (100-100)	99 (99-100)	<.001	100 (0)	99 (2)	.006
Inhaled anticholinergic agents in ED	42 (39-45)	80 (76-83)	<.001	42 (28)	78 (23)	<.001
Systemic corticosteroids in ED	73 (70-75)	82 (79-84)	<.001	74 (14)	81 (13)	.02
Methylxanthines not prescribed in ED	93 (92-94)	100 (100-100)	<.001	94 (6)	100 (0)	<.001
Prescribed oral corticosteroids at discharge	67 (64-70)	77 (74-80)	<.001	67 (20)	76 (18)	.01
Assessment of PEF	81 (79-82)	47 (45-49)	<.001	76 (19)	47 (32)	<.001
Timeliness measure						
Initial PEF ≤30 min of arrival	60 (58-63)	35 (32-38)	<.001	47 (23)	32 (23)	.001
Inhaled β-agonists ≤60 min of arrival	93 (92-94)	73 (71-74)	<.001	93 (6)	73 (18)	<.001
Systemic corticosteroid ≤75 min of arrival	46 (43-48)	44 (41-47)	.47	43 (16)	42 (20)	.93
Composite score						
Composite guideline concordance score (overall)	Patient level, median (IQR)		P value	ED level, mean (SD)		P value
Composite guideline concordance score (overall)	80 (67-89)		<.001	75 (5)		.02
Composite guideline concordance score (level A evidence)	100 (75-100)		<.001	84 (8)		<.001
Composite guideline concordance score (non-level A evidence)	75 (50-100)		<.001	67 (7)		<.001

*Denominators and numerators for each quality measure according to the time period are included in Table E3 in this article's Online Repository at www.jacionline.org.

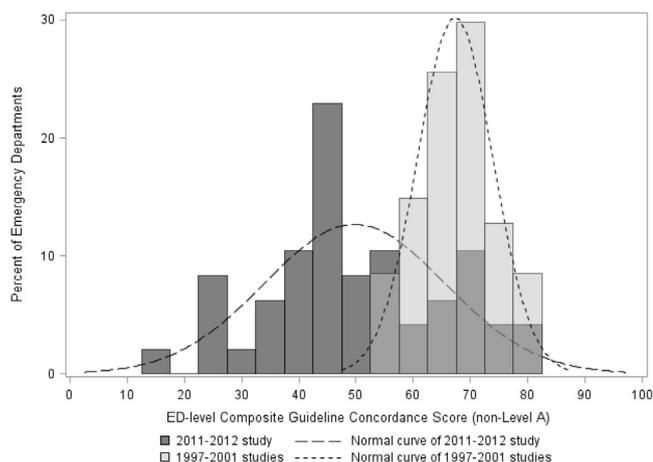


FIG 1. Distribution of composite guideline concordance with non-level A recommendations at the ED level according to time period. Compared with the 1997-2001 period, concordance with the non-level A recommendations was significantly lower in the 2011-2012 period (mean composite score, 67 vs 50; $P < .001$), with a larger variation in concordance (SD, 7 vs 16). The superimposed curves represent the normal curve based on each sample mean and SD.

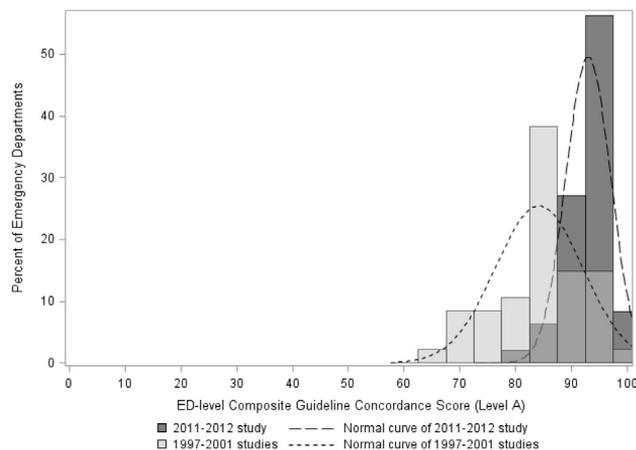


FIG 2. Distribution of composite guideline concordance with level A recommendations at the ED level according to time period. Compared with the 1997-2001 period, concordance with the level A recommendations was significantly higher in the 2011-2012 period (mean composite score, 84 vs 93; $P < .001$), with a smaller variation in concordance (SD, 8 vs 4). The superimposed curves represent the normal curve based on each sample mean and SD.

hospitalization compared with the others (14% vs 30%, $P < .001$). After adjusting for 14 patient- and ED-level characteristics, risk of hospitalization remained significantly lower in patients who received fully concordant care in the ED (odds ratio, 0.37; 95% CI, 0.26-0.53; $P < .001$). Likewise, in sensitivity analyses the significant association persisted with excluding patients admitted within 1 hour of ED presentation or admitted to the ICU and with using a different definition for the outcome (ie, hospitalization or prolonged ED length of stay; Table IV).

DISCUSSION

In this 48-center analysis based on 3 observational studies of 4039 adults with asthma exacerbation over 16 years, we observed changes in the quality of emergency asthma care that differed by

level of guideline recommendation. Although emergency care became highly concordant with level A guideline recommendations, the concordance with non-level A recommendations (ie, use of PEF measurement and timeliness measures) decreased. Additionally, the variations in these measures became larger across the EDs, with significant regional differences. Our data also demonstrated a strong association between quality of care and patient outcomes. More specifically, complete concordance with the NIH asthma guidelines was associated with a significantly reduced risk of hospitalization.

The extent to which guideline-recommended asthma care is provided in the real-world setting is of great interest to a variety of stakeholders. However, to date, changes in the quality of emergency care for asthma exacerbations have attracted less attention. In the present study we found significant improvement

TABLE III. Unadjusted and multivariable-adjusted predictors of higher ED composite guideline concordance score in 2011-2012 study

ED-level variable	Unadjusted β -coefficient (95% CI)	Multivariable-adjusted β -coefficient* (95% CI)	
		Model 1	Model 2†
Annual ED visits for asthma per 100-visit increase	0.17 (−0.05 to 0.38)	0.10 (−0.14 to 0.34)	0.11 (−0.13 to 0.35)
Annual ED visits per 1000-visit increase	0.02 (−0.05 to 0.08)	−0.01 (−0.08 to 0.06)	−0.01 (−0.09 to 0.06)
Census region			
Northeast	−4.33 (−10.5 to 1.83)	−5.47 (−13.6 to 2.61)	−5.62 (−13.6 to 2.41)
Midwest	Reference	Reference	Reference
South	−10.3 (−3.64 to −17.0)	−9.02 (−0.35 to −17.7)	−9.03 (−0.44 to −17.6)
West	−11.9 (−5.28 to −18.4)	−12.4 (−3.75 to −21.0)	−13.2 (−4.67 to −21.8)

Results in boldface are statistically significant.

*Model adjusted for all variables shown in the table and aggregated patient mix (age, sex, respiratory rate, oxygen saturation, and initial peak flow at ED presentation).

†Using the opportunity-based method.

TABLE IV. Unadjusted and multivariable associations of guideline-concordant care with hospitalization in the 2011-2012 study

Guideline-concordant care (all-or-none metric)	Percentage of asthmatic patients	Percentage of patients in the category admitted	Unadjusted OR (95% CI)	Adjusted OR (95% CI)		
				Model 1*	Model 2†	Model 3‡
Received all 4 types of guideline-recommended care when eligible§	83	14	0.39 (0.29-0.51)	0.37 (0.26-0.53)	0.36 (0.25-0.51)	0.49 (0.36-0.65)
Did not receive all 4 types of guideline-recommended care when eligible	17	30	Reference	Reference	Reference	Reference

OR, Odds ratio.

*Random-effects model adjusted for patient-level variables (age, sex, race/ethnicity, history of intubation for asthma, current use of systemic corticosteroids, current use of inhaled corticosteroids, comorbidities, duration of symptoms, respiratory rate, oxygen saturation, and initial peak flow at ED presentation) and ED-level variables (annual ED visit volume, annual ED asthma volume, and census region). Results were analyzed for 1885 patients who were discharged to home or hospitalized.

†Random-effects model excluding patients admitted within 1 hour of ED arrival or those admitted to the ICU (n = 1768).

‡Random-effects model using a different definition of the outcome (ie, hospitalization or ED length of stay ≥ 360 minutes [n = 1885]).

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

in the concordance with guideline recommendations that are based on stronger evidence (eg, use of inhaled anticholinergic agents in the ED and systemic corticosteroids in the ED and at discharge). This observed improvement was consistent with the previous analysis of the National Hospital Ambulatory Medical Care Survey⁷ and mirrored by the improvement in asthma care in the ambulatory²⁶ and pediatric inpatient²⁷ settings. Collectively, these findings reflect, at least in part, successful dissemination and implementation of the level A recommendations in the NIH guidelines over time.

The apparent improvement in concordance with level A recommendations contrasts sharply with the substantial decrease in concordance with the non-level A recommendations, with widening interhospital variations. In particular, we are struck by the decreasing use of PEF measurement in EDs over the study periods, although the NIH guidelines indicated that objective assessments of pulmonary function are central to asthma exacerbation diagnosis and risk stratification.¹⁹ Additionally, we demonstrated prolonged or sustained delays in delivery of asthma care in the ED. Reasons for these decreases in concordance with non-level A recommendations need to be elucidated. For example, our data demonstrated a substantial increase in overall patient volumes in EDs over the 16 years; these findings are in agreement with the nationwide studies demonstrating increasing ED volumes.^{28,29} Additionally, prior studies have found an association between ED crowding and decreased quality of care.^{30,31} Therefore it is plausible that this system-wide factor might have contributed to the decrease in concordance with guideline recommendations

that are based on weaker evidence. Our observations should facilitate further development of strategies for improving overcrowding in EDs. Furthermore, considering the successful implementation of the level A recommendations in the EDs, building more robust evidence on the non-level A recommendations (eg, PEF measurement and delivery of timely emergency asthma care), coupled with improved disseminations of these findings, could further improve care for ED patients with asthma exacerbations.

We were also struck by the wide variations in quality of emergency asthma care across the 48 EDs. The reasons for the observed practice variations are probably multifactorial. Our data identified that the variation in quality of care was partly explained by geographic region, even after adjusting for the other ED characteristics and patient mix, with Southern and Western EDs providing less guideline-concordant care than those in the Midwest. Parallel to these observations, the National Emergency Department Safety Study also showed a lower concordance with guideline recommendations in Southern EDs.¹⁴ However, the relationship between region and quality of emergency asthma care is complex. Geographic region is a surrogate marker for a number of patient, physician, institutional, and systems characteristics that affect quality of care but are difficult to quantify individually. We hope that our observations facilitate further investigation of any barriers to the delivery of high-quality asthma care in these underperforming EDs.

Process measures are designed to assess concordance with expected care and, when provided, should “maximize health

benefits to patients” and lead to improved clinical outcomes (eg, reduced risk of hospitalization).^{5,32} In the present study we demonstrated that complete delivery of the guideline-recommended asthma care (all or none) was associated with significantly lower risk of hospitalization. This association is encouraging and consistent with the results from our previous multicenter studies both in the United States and Japan.^{14,23}

With multiple studies arriving at a similar conclusion, despite differing populations and health care settings, we believe that there is very robust evidence to support level A management in all EDs.

Taken together, many hospitalizations and the associated health care spending could be avoided if the variations in asthma care were attenuated and best practices were implemented in underperforming EDs. Use of an all-or-none metric certainly raises the bar on performance for providers,¹⁴ and there might be potential resource disparities among sites that make it a challenge to implement some guideline recommendations. For patients with acute asthma, however, the level A recommendations are easily within reach (eg, prescribing systemic corticosteroids), and we believe that it is reasonable to expect a consistently high level of quality and performance in all US EDs. There is added urgency given that asthma is such a common public health problem.²³ Although improvement in the quality of emergency asthma care is ultimately the responsibility of the involved clinicians and hospitals, collective efforts with other stakeholders, such as community centers, professional organizations, and federal agencies, are warranted to overcome barriers to improving emergency asthma care nationally.

Potential limitations

Several study limitations should be noted. First, given the underuse of PEF measurement in this study, we might have underestimated the number of eligible patients who should receive anticholinergic agents or systemic corticosteroids in the ED. Accordingly, despite the high performance on these 2 measures, the smaller number of eligible patients using these measures carries less weight when calculating the overall concordance score, thereby underestimating the score.

Second, the study relied on medical record review for quality measure assessment; therefore some of the quality deficit might be due to underdocumentation. However, prior studies have demonstrated high agreement in ED asthma assessment and management between chart review and direct observation, with *k* coefficients ranging from 0.6 to 0.9.³³ Additionally, we used the identical approach to assess quality measures across studies, and this should mitigate any effect on the trend analysis.

Third, our study did not measure postdischarge care plans (eg, written discharge plans and follow-up care) and postdischarge outcomes (eg, revisits and readmissions). These important outcomes will be the focus of future research by the MARC investigators.

Fourth, as with any observational studies, the associations between higher concordance and lower risk of hospitalization does not necessarily prove causality and might be confounded by unmeasured factors, such as disease severity. However, we restricted the denominator of a quality measure to patients at risk for that measure to minimize potential confounding by severity and indication.³⁴ This approach has been used in prior studies of both acute and chronic asthma to adjust for this type of confounding.^{14,35-37}

Lastly, our study population consisted of adults who presented mainly to academic EDs. Therefore our inferences might not be

generalizable to children or asthma management in nonacademic EDs, where emergency asthma care might be better or worse than in our participating EDs. Nevertheless, we believe that our observations are highly relevant from a policy standpoint because these academic EDs train emergency medicine residents. Thus these institutions have a disproportionate effect on the quality of current and future emergency asthma care.

In summary, on the basis of observational studies of 4039 adults with asthma exacerbation in 48 US EDs, we found changes in quality of emergency asthma care that differed by level of guideline recommendation. The observed improvement in the concordance with level A guideline recommendations supports prior optimism that the quality of emergency asthma care can be improved and morbidity reduced. By contrast, the decreased concordance with non–level A recommendations and wide interhospital variations in quality of care present an important challenge. For researchers, these observations should facilitate further investigation to build more robust evidence on current non–level A recommendations. Finally, we found a strong association between fully concordant asthma care and reduced risk of hospitalization. Clinicians and policymakers will need to promote further adoption of level A recommendations and assist efforts to decrease the interhospital variations in quality of emergency asthma care to achieve better patient outcomes.

We thank the MARC-36 study hospitals and research personnel for their ongoing dedication to asthma research (see [Table E1](#) and [Fig E1](#) in this article’s Online Repository).

Clinical implications: We observed changes in quality of emergency asthma care that differed by level of guideline recommendation. Further improvements require adoption of level A recommendations and further research on non–level A recommendations.

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METHODS

Multiple imputation

In the patient- and ED-level models we conducted multiple imputation by using the multivariate normal imputation method for the variables with missing data. The proportion of missing values was small ($\leq 11\%$) for all variables, except for PEF data. The proportion of missing values for PEF was 59% if we only use the sample from the 2011-2012 period but decreased to 46% if we use the data from both the 1997-2001 and 2011-2012 study periods. Therefore we used data from both study periods to impute the missing values. Because the proportion of missing values was relatively large for PEF, we created 100 multiply imputed data sets by using the multivariate normal imputation method developed by Rubin and colleagues.^{E1,E2}

We first imputed missing values including the ED indicator in the imputation model as fixed effects and then constructed hierarchic models treating the ED indicator as random effects.^{E3} We dropped the first 200 simulations as a burn-in and used every 100 simulations as thinning. Incomplete variables were imputed by using the variables predictive of either missing values or missingness and all of the variables included in our analysis models (age; sex; race/ethnicity; primary insurance; smoking history; primary care physician status; history of intubation for asthma; number of ED visits for asthma in the previous year; current use of systemic corticosteroids, inhaled corticosteroids, long-acting β -agonist inhalers, and leukotriene modifiers; comorbidities; duration of the current asthma exacerbation before the ED presentation; respiratory rate and oxygen saturation at ED presentation; administration of systemic corticosteroids, anticholinergic agents, and subcutaneous epinephrine in the ED; ED disposition; log-transformed ED length of stay; ED identifiers; annual ED visit volume; annual ED asthma volume; census region; and patient-level composite scores). Our data had less than 2% missingness in the outcome variable (ie, hospitalization) of the patient-

level regression models. We included this outcome variable in the imputation model and then excluded any cases with imputed values for the outcome variables from the final models, according to the approach by von Hippel.^{E4} These estimates and their standard errors were combined by using Rubin's combination methods.^{E1}

We created 100 multiply imputed data sets to account for the relatively large proportion of missingness of the PEF variable. As long as the missing-at-random assumption holds, the missing PEF values would not bias the estimates or affect the estimated SEs. Alternatively, patients with missing PEF data might have had asthma too severe to undergo PEF measurements in the ED. In this case, with predicting the missingness of PEF by using the markers of acute asthma severity (eg, respiratory rate and oxygen saturation at ED presentation, administration of inhaled anticholinergic agents and subcutaneous epinephrine in the ED, ED length of stay, and disposition), the unobserved PEF values are no longer relevant to the missingness of this variable (ie, the missing at random assumption holds). Multiple imputation was conducted at the patient level and then aggregated for the ED-level analyses. All analyses with multiple imputation were performed with Stata 12.0 software (StataCorp).

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FIG E1. Location of the 48 participating sites in MARC-36.

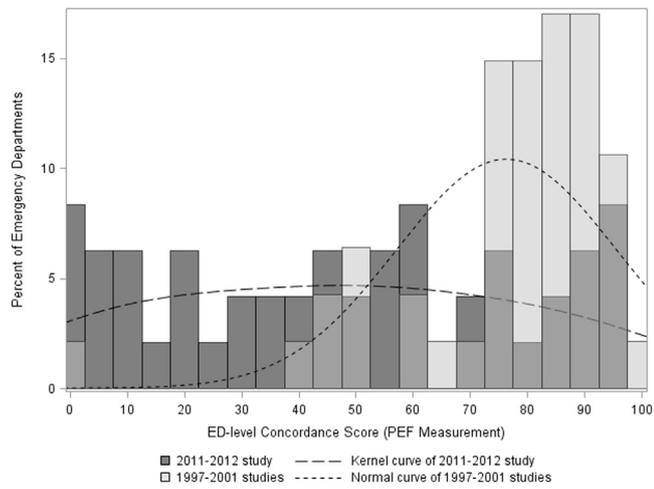


FIG E2. Distribution of concordance with PEF assessment at the ED level according to the study period. Compared with the 1997-2001 period, concordance with PEF assessment was significantly lower in the 2011-2012 period (mean composite score, 76 vs 47; $P < .001$), with a larger variation in concordance (SD, 19 vs 32).

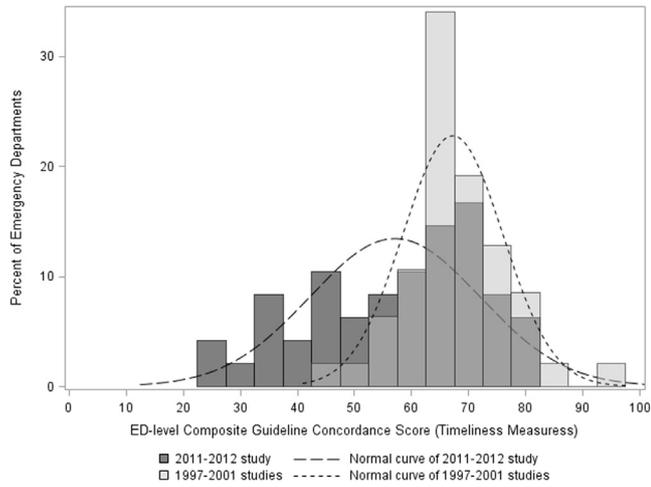


FIG E3. Distribution of guideline concordance with 3 timeliness measures at the ED level according to the study period. Compared with the 1997-2001 period, concordance with the 3 timeliness measures (PEF measurements, inhaled β -agonists in the ED, and systemic corticosteroids in the ED) was significantly lower in the 2011-2012 period (mean composite score, 67 vs 57; $P < .001$), with a larger variation in concordance (SD, 9 vs 15).

TABLE E1. Site investigators at the 48 participating sites in MARC-36

Akron City Hospital	Kirk A. Stiffler, MD, MPH
Albert Einstein Medical Center	Stewart O. Sanford, MD
Allegheny General Hospital	Joseph Montibeller, MD
Baystate Medical Center	Howard A. Smithline, MD, MS
Ben Taub General Hospital	Michael G. Gonzalez, MD
Beth Israel Deaconess Medical Center	Nathan Shapiro, MD
Brigham and Women's Hospital	Daniel J. Pallin, MD, MPH
Brooklyn Hospital Center	Mark J. Leber, MD, MPH
Buffalo General Hospital	Jeanne M. Basior, MD
Carolinas Medical Center	D. Matthew Sullivan, MD
Christiana Hospital	John T. Powell, MD
Cooper Medical School of Rowan University	Brigitte M. Baumann, MD, MSCE
Detroit Receiving Hospital	Claire Pearson, MD, MPH
East Carolina University, Vidant Medical Center	John E. Gough, MD
Hartford Hospital	Michael J. Drescher, MD
Hennepin County Medical Center	Richard O. Gray, MD
Henry Ford Hospital	Richard M. Nowak, MD, MBA
John H. Stroger Jr Hospital of Cook County	Rashid F. Kysia, MD, MPH
Lincoln Medical and Mental Health Center	Muhammad Waseem, MD, MS
Long Island Jewish Medical Center	Robert A. Silverman, MD
Maricopa Medical Center	Frank LoVecchio, MD
Massachusetts General Hospital	Eva Tovar Hirashima, MD, MPH
Mercy Hospital of Philadelphia	Patrick Shen, MD
MetroHealth Medical Center	Rita K. Cydulka, MD, MS
Mount Sinai St Luke's and Mount Sinai Roosevelt Hospitals	Daniel J. Egan, MD
New York Methodist Hospital	Theodore J. Gaeta, DO, MPH
New York Presbyterian Hospital/Weill Cornell Medical Center	Sunday Clark, ScD, MPH
Newark Beth Israel Medical Center	Eric J. Wasserman, MD
Oregon Health & Science University Hospital	Stephanie Nonas, MD
Palmetto Health Richland	Joseph S. Myslinski, MD
Sentara Norfolk General Hospital	Francis L. Counselman, MD
Shands Hospital at the University of Florida	J. Adrian Tyndall, MD, MPH
St Barnabas Hospital	Blanca Grand, DO
Stanford University Medical Center	Nancy E. Wang, MD
Temple University Hospital	Megan Healy, MD
Thomas Jefferson University Hospital	Bernard L. Lopez, MD, MS
Truman Medical Center Hospital	P. Charles Inboriboon, MD, MPH
University of Arkansas for Medical Sciences	Talmage M. Holmes, PhD, MPH
University of California Davis Medical Center	Suzanne S. Teuber, MD
University of California Irvine Medical Center	Mark I. Langdorf, MD, MHPE
University of California San Diego Medical Center	Brian Snyder, MD
University of California San Francisco Medical Center	Christopher Fee, MD
University of Maryland Medical Center	Veronica Pei, MD
University of Oklahoma School of Community Medicine – Hillcrest Medical Center	Annette O. Arthur, PharmD
University of New Mexico Health Sciences Center	Cameron Crandall, MD, PhD
University of Texas Health Science Center at San Antonio	Dan Mosely, MD
University of Texas Southwestern Medical Center–Parkland Memorial Hospital	Ava E. Pierce, MD
York Hospital	Ronald S. Benenson, MD

TABLE E2. Description of quality measures for acute asthma care

Measure	Numerator	Denominator	Level of evidence according to NAEPP EPR-3
Process measure			
Treatment with inhaled β -agonists in the ED	Inhaled β -agonist given in the ED	Patients presenting to the ED with an asthma exacerbation	A
Treatment with inhaled anticholinergic agents in the ED	Inhaled anticholinergic agents given in the ED	Patients presenting to the ED with a severe asthma exacerbation, which is defined as any of the following criteria: (1) admitted to the observation unit, hospital, or ICU; (2) PEF <200 L/min for women and <250 L/min for men Exclusion: mildest exacerbations (oxygen saturation = 100% and RR <18)	A
Treatment with systemic corticosteroids in the ED	Systemic corticosteroids given in the ED	Patients presenting to the ED with a moderate-to-severe asthma exacerbation, which is defined as any of the following criteria: (1) using any type of corticosteroids at the time of the ED visit; (2) admitted to the observation unit, hospital, or ICU; (3) PEF <300 L/min for women and <400 L/min for men Exclusion: mildest exacerbations (oxygen saturation = 100% and RR <18)	A
Treatment with methylxanthines in the ED	Not given methylxanthines in the ED	Patients presenting to the ED with an asthma exacerbation	A
Treatment with oral corticosteroids at discharge	Oral corticosteroids given in the ED	Asthmatic patients who meet the criteria to receive systemic corticosteroids in the ED (see above) and are discharged home	A
Assessment of airflow limitation	At least 1 PEF measured in the ED	Patients presenting to the ED with an asthma exacerbation Exclusion: respiratory extremis (oxygen saturation <90% or RR \geq 30)	B
Timeliness measure			
Assessment of airflow limitation	Initial PEF checked within 30 min of arrival	Patients who presented to the ED with an asthma exacerbation and with \geq 1 PEF measured Exclusion: respiratory extremis (oxygen saturation <90% or RR \geq 30)	B
Treatment with inhaled β -agonists in the ED	Inhaled β -agonists given within 60 min of arrival	Patients who present to the ED with an asthma exacerbation and are given β -agonists	—
Treatment with systemic corticosteroids in the ED	Systemic corticosteroids given within 75 min of ED arrival	ED asthmatic patients who meet the criteria to receive systemic corticosteroids (see above)	—

NAEPP EPR3, National Asthma Education and Prevention Program Expert Panel Report 3; RR, respiratory rate.

TABLE E3. Performance on quality measures at the patient level according to time period

Quality measure	1997-2001		2011-2012	
	No. of patients eligible	No. of times care was delivered	No. of patients eligible	No. of times care was delivered
Process of care				
Inhaled β -agonists in ED	2119	2119	1920	1904
Inhaled anticholinergic agents in ED	970	404	558	445
Systemic corticosteroids in ED	1521	1105	1202	981
Methylxanthines not prescribed in ED	2119	1968	1920	1920
Prescribed oral corticosteroids at discharge	1063	715	863	666
Assessment of PEF	1893	1527	1824	860
Timeliness measure				
Initial PEF ≤ 30 min of arrival	1527	923	860	300
Inhaled β -agonists ≤ 60 min of arrival	2119	1966	1904	1381
Systemic corticosteroid ≤ 75 min of arrival	1521	692	1202	530