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Missed opportunities to transition from nebulizers to inhalers during hospitalization for acute asthma: A multicenter observational study

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ABSTRACT

Objective: Hospitalizations for acute asthma are thought to be highly preventable through the use of efficacious medications, though many patients have poor metered-dose inhaler (MDI) techniques, thus lessening these medications' real-world effectiveness. Teaching MDI techniques during hospitalization may therefore lead to improved outcomes. However, MDIs may be underutilized to deliver short-acting β -agonists (SABAs) in the inpatient setting, despite equivalent efficacy to nebulizer delivery. We sought to characterize delivery methods of SABAs among hospitalized patients with acute asthma to understand if there are missed opportunities for self-management education. **Methods:** In this secondary analysis of a cross-sectional 25-center chart review study of children and adults (ages 2–54 years) hospitalized for acute asthma across 18 states (2012–2013), we studied SABA therapy delivery methods during hospitalization and receipt of action plans and follow-up visits. Unadjusted associations were analyzed using chi-square, Fisher's exact, or Kruskal–Wallis tests. **Measurements and main results:** Of 987 patients, 44% received only nebulizer-SABA (children 32% vs. adults 53%; $p < 0.001$) during hospitalization, and 55% (children 68% vs. adults 47%; $p < 0.001$) received any MDI-SABA during hospitalization. Children receiving only nebulizer- vs. MDI-SABA were significantly less likely to receive individualized action plans ($p < 0.001$). Compared to children, adults were overall less likely to receive written plans (47% vs. 78%, $p < 0.001$) or to have a follow-up appointment (38% vs. 59%, $p < 0.001$) at discharge. **Conclusions:** Opportunities exist to increase the delivery of MDI-SABA during hospitalization, particularly for adult inpatients with asthma. Further studies are needed to determine if increased use of MDI-delivered therapies improves patient education and outcomes.

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Acute asthma; asthma exacerbation; hospitalization; metered-dose inhaler; nebulizer; short-acting β -agonist; practice variation

Abbreviations

ED	emergency department
EMNet	Emergency Medicine Network
ICS	inhaled corticosteroids
MDI	metered-dose inhaler
SABA	short-acting β -agonist

Introduction

Nearly 500,000 children and adults are hospitalized annually in the United States for asthma [1]. Hospitalizations for acute asthma are thought to be highly preventable through the use of efficacious medications to prevent and treat asthma symptoms [2]. Many of these medications are delivered directly to the lungs through either respiratory inhaler devices or nebulizer machines. Inhalers are often preferred for patient use as they are more portable

and less cumbersome than nebulizers, however, many patients have poor inhaler techniques [3–5]. Metered-dose inhalers (MDIs) have equal efficacy with nebulizers for the delivery of short-acting β -agonists (SABAs) [6–11], but may be underutilized among hospitalized patients [12]. This underutilization may lead to missing an opportunity to provide critical self-management education [13], as improved MDI technique has been shown to decrease acute care utilization [5]. Children and adults are encouraged to use of inhalers to deliver SABAs, if they are able to use them, because inhalers are more portable than nebulizers [14]. However, some patients or their families prefer nebulizers due to perceptions that they work better [15]. Further, the value of care may be diminished, as nebulizer treatments are costly [10,16], and \$5–7 billion of approximately \$25 billion spent annually on respiratory inhalers is lost due to inhaler misuse [17].

Therefore, more appropriate use of MDIs to deliver SABA medication to inpatients may raise the value of care

provided through cost-saving and improved outpatient self-management. Studies show that conversion from nebulizer-delivered SABA (nebulizer-SABA) to MDI-delivered SABA (MDI-SABA) improves hospital resource utilization for both children and adults, and provides an opportunity to teach critical self-management skills [12]. There are few data, though, on how many hospitalized patients are provided with MDI-SABA during their hospitalization, and therefore the scope of this missed opportunity is unknown.

To address this knowledge gap, we analyzed the data from a 25-center observational study of patients hospitalized with acute asthma to investigate the delivery methods of SABA therapy. Our central hypothesis was that evidence-based use of MDIs to deliver SABAs is underutilized in the inpatient setting. Our primary analysis was to evaluate nebulizer-SABA versus MDI-SABA delivery methods during hospitalization. Secondary analyses included SABA delivery methods by age, as well as receipt of action plans and follow-up visits after discharge.

Methods

This is a secondary analysis of data from a multicenter chart review study characterizing children and adults hospitalized for acute asthma, as part of the 37th Multicenter Airway Research Collaboration (MARC-37) [Appendix Table E1]. The study was coordinated by the Emergency Medicine Network (EMNet), a collaboration of 235 participating hospitals [18]. The design, setting, and methods of data collection used in the study have been reported previously [19].

Table E1. Site investigators at the 25 participating sites in MARC-37.

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
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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

Briefly, we recruited 25 hospitals across 18 US states. Using a principal discharge diagnosis of asthma (ICD-9-CM 493.x), we identified all hospitalizations for acute asthma during 2012–2013, among patients aged 2–54 years [20] with a history of physician-diagnosed asthma. Hospitalized patients were excluded if: they had a physician diagnosis of chronic obstructive pulmonary disease or cystic fibrosis, if a substantial reason for admission was not their asthma exacerbation, if they had been transferred from another hospital, or if the same individual had repeat hospitalizations during the one-year study period [19]. Chart abstraction was done after successfully completing training that included an online lecture, test practice charts, and certification upon reaching the criterion standard [19]. Charts were randomly selected by the EMNet Coordinating Center at Massachusetts General Hospital and chart abstractors reviewed 40 of these randomly-selected patients' medical records in an approach that was used in the prior 1999–2000 UHC study [20,21]. Using a standardized electronic form [Appendix], investigators abstracted data, including patients' demographics, asthma history, presentation, and asthma management in the emergency department or clinic, inpatient asthma management, and discharge medications or plan. The institutional review board of each participating center approved the study.

For the purpose of this analysis, we classified patients into children aged 2–17 years and adults aged 18–54 years and into three mutually exclusive groups based on the methods used to deliver inhaled SABA during inpatient course: nebulization-only, MDI-only, and both to analyze differences by demographic characteristics and asthma history, presentation and in-hospital management, and post-hospitalization management. We tested unadjusted associations of the methods to deliver SABA with patient characteristics and clinical course for children (aged 2–17 years) and adults (aged 18–54 years) separately, using chi-square, Fisher's exact, or Kruskal–Wallis tests. We also constructed multivariable models to examine factors associated with the SABA delivery methods. First, to make the data interpretation more meaningful, the delivery methods were dichotomized into any MDI use and nebulizer-only. Next, for children and adults separately, we fitted a multivariable logistic regression model including age, sex, race/ethnicity, markers for socioeconomic status (health insurance, quartiles for household income), markers of chronic asthma severity (history of intubation and hospitalization for asthma in the preceding year), and current medications (oral corticosteroids and ICS), which were chosen based on potential clinical significance and *a priori* knowledge. We also used generalized estimating equations to account for potential clustering of patients within hospitals. All analyses were performed with SAS

Table 1. Demographic characteristics and asthma history of patients hospitalized for asthma exacerbation, according to methods to deliver inhaled short-acting β -agonists.

Patient characteristics	Children aged 2–17 years (<i>n</i> = 385)				Adults aged 18–54 years (<i>n</i> = 602)			
	Nebulization-only <i>n</i> = 122 (32%)	MDI-only <i>n</i> = 50 (13%)	Both <i>n</i> = 213 (55%)	<i>p</i> -value	Nebulization-only <i>n</i> = 322 (53%)	MDI-only <i>n</i> = 17 (3%)	Both <i>n</i> = 263 (44%)	<i>p</i> -value
Demographics								
Age				0.73				0.06
2–4 years	50 (41)	16 (32)	80 (38)		—	—	—	—
5–11 years	59 (48)	26 (52)	102 (48)		—	—	—	—
12–17 years	13 (11)	8 (16)	31 (15)		—	—	—	—
18–29 years	—	—	—	—	71 (22)	2 (12)	69 (26)	
30–39 years	—	—	—	—	95 (30)	2 (12)	84 (32)	
40–54 years	—	—	—	—	156 (48)	13 (76)	110 (42)	
Female sex	58 (48)	23 (46)	64 (30)	0.003	219 (68)	12 (71)	151 (57)	0.03
Race/ethnicity				0.02				0.47
Non-Hispanic white	45 (37)	9 (18)	72 (34)		79 (25)	2 (12)	53 (20)	
Non-Hispanic black	56 (46)	28 (56)	76 (36)		170 (53)	13 (76)	141 (54)	
Hispanic ethnicity	12 (10)	9 (18)	47 (22)		46 (14)	2 (12)	43 (16)	
Others	6 (5)	3 (6)	9 (4)		10 (3)	0 (0)	12 (5)	
Health insurance				0.58				0.76
Private	45 (37)	18 (36)	81 (38)		75 (23)	4 (23)	68 (26)	
Public	54 (44)	30 (60)	121 (57)		134 (42)	9 (53)	110 (42)	
No insurance	7 (6)	2 (4)	7 (3)		95 (30)	4 (24)	66 (25)	
Estimated median household income (\$), median (IQR)	38,792 (30,572–48,544)	38,630 (31,175–54,598)	44,700 (36,696–56,820)	<0.001	38,403 (30,340–52,336)	44,752 (36,412–44,889)	40,910 (31,239–51,118)	0.46
Having primary care physician	117 (96)	47 (94)	200 (94)	0.82	200 (62)	14 (82)	179 (68)	0.17
Chronic asthma factors								
Current smoker	1 (1)	0 (0)	1 (<1)	0.79	115 (36)	6 (35)	93 (35)	0.99
Exposure to passive smoke in home	38 (31)	16 (32)	48 (23)	0.20	36 (11)	1 (6)	33 (13)	0.71
Ever intubated for asthma	3 (2)	3 (6)	8 (4)	0.53	81 (25)	5 (29)	66 (25)	0.93
ED visit for asthma in past 12 months	57 (47)	27 (54)	106 (50)	0.69	188 (58)	6 (35)	140 (53)	0.38
Hospitalization for asthma in past 12 months	44 (36)	19 (38)	71 (33)	0.60	121 (38)	3 (18)	102 (39)	0.21
Chronic asthma management								
Current asthma medications								
Current use of oral corticosteroids	18 (15)	13 (26)	56 (26)	0.04	88 (27)	8 (47)	76 (29)	0.21
Current use of ICS	69 (57)	31 (62)	123 (58)	0.80	153 (48)	16 (94)	152 (58)	<0.001
Current use of ICS/LABA	15 (12)	16 (32)	32 (15)	0.005	111 (34)	14 (82)	101 (38)	<0.001
Current use of leukotriene modifiers	29 (24)	14 (28)	52 (24)	0.84	69 (21)	6 (35)	40 (15)	0.049
Seen by asthma specialist in past 12 months	33 (27)	17 (34)	50 (23)	0.41	59 (18)	2 (12)	34 (13)	0.48

Notes. ED, emergency department; ICS, inhaled corticosteroids; IQR, interquartile range; LABA, long-acting β -agonist; MDI, metered-dose inhaler.

Data were presented as *n* (%) unless otherwise indicated.

*Percentages are not equal 100 because of missing data.

°The use of oral corticosteroids at the presentation to pre-hospitalization visit (e.g., ED, clinic).

9.4 (SAS Institute, Cary, NC). All tests were two-tailed, and $p < 0.05$ was regarded as statistically significant.

Results

We identified 1,000 children and adults hospitalized for acute asthma. Of these, 987 (99%) had data on the methods used to deliver SABA during their hospitalization, and were included in the current analysis. Among the 987 patients analyzed for this sub-study, 39% (385/987) were children aged 2–17 years, and 61% (602/987) were adults aged 18–54 years; 53% were female, and 26% were non-Hispanic white. Public insurance was more common than private insurance (46% vs. 29%) (Table 1).

Of the 987 patients receiving SABA, 44% received only nebulizer-SABA; however, this was lower for children versus adults (32% vs. 53%, $p < 0.001$). About half of the patients (48%) received both nebulizer-SABA and MDI-SABA; this was higher among children versus adults (55% vs. 43%, $p < 0.001$). The proportion of patients who just received MDI-SABA during their hospitalization was low at 7%, but more likely among children versus adults (13% vs. 3%, $p < 0.001$). Factors associated with any MDI-SABA use included male gender and use of oral corticosteroids among children (Table 2) and male gender and household income among adults (Table 3). The vast majority of patients received nebulizer-SABA during their hospitalization. This was true across

Table 2. Multivariable logistic regression model for factors associated with any mdi use in children hospitalized for asthma exacerbation.

	Children aged 2-17 years	
	Odds ratio (95% CI)	p-Value
Age		
2-4 years	1 [reference]	—
5-11 years	1.49 (0.76-2.92)	0.25
12-17 years	1.09 (0.76-1.57)	0.63
Female sex	0.67 (0.47-0.95)	0.02
Race/ethnicity		
Non-Hispanic white	1 [reference]	—
Non-Hispanic black	1.03 (0.51-2.10)	0.93
Hispanic	1.22 (0.57-2.63)	0.60
Others	0.72 (0.27-1.92)	0.51
Health insurance		
Private	1 [reference]	—
Public	1.04 (0.59-1.85)	0.89
No insurance	0.56 (0.21-1.50)	0.25
Quartiles for median household income		
1 (lowest)	0.76 (0.42-1.36)	0.35
2	1.14 (0.66-1.99)	0.63
3	1.37 (0.68-2.73)	0.38
4 (highest)	1 [reference]	—
Ever intubated for asthma	0.77 (0.40-1.52)	0.46
Hospitalization for asthma in past 12 months	0.86 (0.60-1.23)	0.40
Current use of oral corticosteroids	1.62 (1.08-2.44)	0.02
Current use of ICS	0.85 (0.62-1.17)	0.32

Notes. CI, confidence interval; ICS, inhaled corticosteroids.

*Any metered-dose inhaler (MDI) use during hospitalization.

*Logistic regression models with the generalized estimating equation to account for patient clustering within hospitals.

sub-populations, though children (87%, 335/385) were slightly less likely than adults (97%, 585/602, $p < 0.001$), to receive nebulizer-SABA treatment (Table 1). Over half (55%) of all patients received MDI-SABA during hospitalization, again greater for children than adults (68%

vs. 47%, $p < 0.001$). Further, among the 25 hospitals participating in the study, there was a wide range of exposure to MDI-SABA, from 13% to 92% of participants using any MDI-SABA during their inpatient course (Figure 1).

Table 3. Multivariable logistic regression model for factors associated with any metered-dose inhaler use in adults hospitalized for asthma exacerbation.

Variables	Adults aged 18-54 years	
	Odds Ratio (95% CI)	p-Value
Age		
18-29 years	1 [reference]	—
30-39 years	0.77 (0.52-1.14)	0.19
40-54 years	0.78 (0.48-1.28)	0.33
Female sex	0.76 (0.58-1.00)	0.048
Race/ethnicity		
Non-Hispanic white	1 [reference]	—
Non-Hispanic black	1.24 (0.90-1.71)	0.18
Hispanic	1.39 (0.90-2.15)	0.13
Others	1.09 (0.32-3.71)	0.89
Health insurance		
Private	1 [reference]	—
Public	0.98 (0.71-1.35)	0.89
No insurance	0.81 (0.51-1.27)	0.36
Quartiles for median household income		
1 (lowest)	1.80 (1.07-3.04)	0.03
2	2.13 (1.01-4.49)	0.05
3	2.06 (1.20-3.53)	0.01
4 (highest)	1 [reference]	—
Ever intubated for asthma	0.91 (0.62-1.32)	0.60
Hospitalization for asthma in past 12 months	0.93 (0.67-1.29)	0.67
Current use of oral corticosteroids	0.91 (0.61-1.35)	0.63
Current use of ICS	1.19 (0.88-1.61)	0.26

Notes. CI, confidence interval; ICS, inhaled corticosteroids.

*Any metered-dose inhaler (MDI) use during hospitalization.

*Logistic regression models with the generalized estimating equation to account for patient clustering within hospitals.

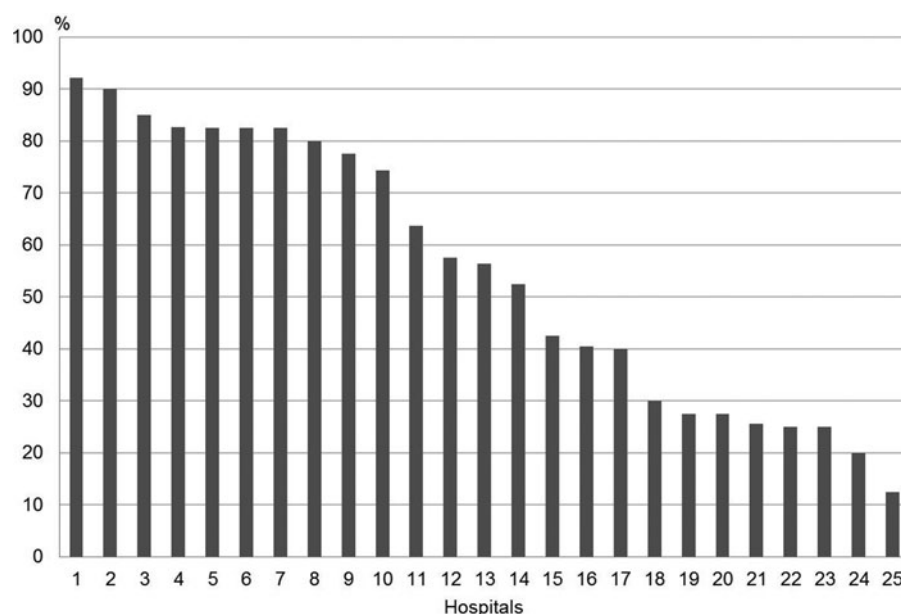


Figure 1. Variability in proportion of patients who used any MDI during inpatient course at the 25 participating hospitals. The proportion of patients who received SABA by using MDI-only or both nebulization and MDI during their inpatient course ranged from 13% at one hospital to 92% at one hospital (median 56%, IQR, 28–83%).

Among the presentation and in-hospital management of children hospitalized for an asthma exacerbation, those receiving only nebulizer-SABA had longer length of stay (LOS; 3 vs. 2 days, $p < 0.001$), presented with higher initial respiratory rate and lower initial oxygen saturation, had higher pre-hospitalization acute-use of inhaled anti-cholinergics, and were more likely to be initially admitted to the ICU (p -values < 0.05); adults, however were only more likely to be initially admitted to the ICU (p -value < 0.001) (Table 4).

When looking at post-hospitalization management, differences between SABA delivery methods existed: children receiving only nebulizer-SABA were significantly less likely than those who received any MDI-SABA, to receive individualized action plans ($p < 0.001$). Interestingly, for adults, those receiving both MDI-SABA and nebulizer-SABA were the most likely to receive action plans ($p = 0.008$). Notably, compared to children, adults were overall less likely to receive written plans (47% vs. 78%, $p < 0.001$). Additionally, compared to children, adults were less likely to have a follow-up appointment (38% vs. 59%, $p < 0.001$), with those receiving only nebulizer-SABA being more likely for both children and adults ($p = 0.08$ and $p < 0.001$) (Table 5).

Discussion

In this study of 987 children and adults hospitalized in 25 US hospitals for acute asthma, there is evidence to support our central hypothesis, as we found that almost half of all patients did not receive any MDI-SABA during

hospitalization, while this differed greatly across sites. The vast majority of patients did receive nebulizer-SABA during their hospitalization, though children were more likely than adults to receive only MDI-SABA. Children were significantly more likely than adults to receive MDI-SABA during hospitalization; about two-thirds of children and less than half of adults received MDI-SABA. Self-management opportunities were missed with respect to providing individualized action plans among pediatric patients receiving only nebulizer-SABA, yet were heightened with respect to follow-up appointments among adults receiving only nebulizer-SABA.

The geographic locations of the study hospitals ranged from the East Coast to the West Coast. There was 7-fold variation in the use of MDI-SABA across these 25 hospitals ranging from 13% to 92% of hospitalized patients receiving any MDI-SABA during hospitalization. Therefore, improvements can be made to increase the delivery of MDI-SABA among inpatients to facilitate opportunities for critical self-management education for effective MDI technique. While this is true for all patients, adult patients and patients at some US hospitals may have the most potential to increase use of MDI-SABA delivery during hospitalization for acute asthma.

Work done in one Midwest setting found that 86% of hospitalized adults with asthma or Chronic Obstructive Lung Disease (COPD) initially misused their MDI-SABAs but could be taught the correct inhaler technique [4]. Time for teaching this technique in hospital settings has been found to be just under 6.5 minutes [22]. The hospital setting is an ideal opportunity to teach and

Table 4. Presentation and in-hospital management of patients hospitalized for asthma exacerbation, according to methods to deliver inhaled short-acting β -agonists.

Variables	Children aged 2–17 years (<i>n</i> = 385)				Adults aged 18–54 years (<i>n</i> = 602)			
	Nebulization-only <i>n</i> = 122 (32%)	MDI-only <i>n</i> = 50 (13%)	Both <i>n</i> = 213 (55%)	<i>p</i> -Value	Nebulization-only <i>n</i> = 322 (53%)	MDI-only <i>n</i> = 17 (3%)	Both <i>n</i> = 263 (44%)	<i>p</i> -Value
Presentation and ED/clinic course								
Duration of symptoms ≤24 hours	35 (29)	10 (20)	55 (26)	0.50	76 (24)	3 (18)	75 (29)	0.34
Vital signs								
Initial respiratory rate (breaths/min), median (IQR)	37 (30–44)	30 (24–40)	32 (24–42)	0.005	22 (20–28)	24 (20–32)	23 (20–28)	0.87
Initial oxygen saturation (%), median (IQR)	93 (90–95)	94 (90–97)	94 (91–97)	0.02	95 (93–98)	96 (93–99)	95 (92–98)	0.84
Initial PEF (L/min)*, median (IQR)	—	—	—	—	178 (140–243)	500	200 (150–278)	0.06
Concomitant medical disorders	24 (20)	15 (30)	41 (19)	0.20	106 (33)	6 (35)	70 (27)	0.24
Acute asthma treatment								
Systemic corticosteroids	107 (88)	43 (86)	196 (92)	0.35	288 (89)	17 (100)	234 (89)	0.40
Inhaled anticholinergics	68 (56)	34 (68)	153 (72)	0.01	207 (64)	14 (82)	178 (68)	0.25
Non-invasive positive pressure ventilation	3 (2)	1 (2)	4 (2)	0.94	30 (9)	2 (12)	17 (6)	0.39
Intubation	1 (1)	0 (0)	2 (1)	0.79	10 (3)	0 (0)	7 (3)	0.74
Inpatient course								
Initial admission location				<0.001				<0.001
ED observation unit	2 (2)	0 (0)	6 (3)		32 (13)	0 (0)	67 (25)	
Hospital ward	73 (60)	39 (78)	138 (65)		203 (63)	14 (82)	151 (47)	
Stepdown unit	3 (2)	7 (14)	6 (3)		24 (7)	1 (6)	14 (5)	
ICU	44 (36)	4 (8)	63 (30)		53 (16)	2 (12)	31 (12)	
Acute asthma treatment								
Systemic corticosteroids	118 (97)	50 (100)	205 (96)	0.39	312 (97)	16 (94)	241 (92)	0.02
Non-invasive positive pressure ventilation	6 (5)	2 (4)	4 (2)	0.28	20 (6)	1 (6)	7 (3)	0.12
Intubation	2 (2)	0 (0)	1 (<1)	0.40	17 (5)	0 (0)	9 (3)	0.54
Hospital length-of-stay (d), median (IQR)	3 (2–4)	2 (2–3)	2 (0–3)	<0.001	3 (2–4)	3 (2–4)	0 (0–3)	<0.001
Disposition				—				0.047
Sent home	122 (100)	50 (100)	213 (100)		313 (97)	16 (94)	247 (94)	
Died in the hospital	0 (0)	0 (0)	0 (0)		4 (1)	0 (0)	0 (0)	
Other	0 (0)	0 (0)	0 (0)		5 (2)	1 (6)	16 (6)	

Notes. ED, emergency department; ICU, intensive care unit; IQR, interquartile range; PEF, peak expiratory flow; MDI, metered-dose inhaler.

Data were presented as *n* (%) unless otherwise indicated.

*Analyzed for 193 adults with initial PEF available. Only 1 patient in the MDI-only group underwent PEF measurement in the ED.

† Defined by pneumonia, congestive heart failure, pneumothorax, arrhythmia, and others.

‡ Include patients who were transferred to another facility and those who left against medical advice.

Table 5. Post-hospitalization management for patients hospitalized for asthma exacerbation, according to methods to deliver inhaled short-acting β -agonists.

Variables	Children aged 2–17 years (<i>n</i> = 385)				Adults aged 18–54 years (<i>n</i> = 602)			
	Nebulization-only	MDI-only	Both	<i>p</i> -Value	Nebulization-only	MDI-only	Both	<i>p</i> -Value
Discharge medications								
Oral corticosteroids	111 (91)	50 (100)	196 (92)	0.10	291 (93)	12 (75)	216 (87)	0.01
ICS [†]	101 (83)	48 (96)	188 (88)	0.052	241 (77)	15 (94)	193 (78)	0.28
Leukotriene modifier	8 (7)	7 (14)	32 (15)	0.07	83 (27)	4 (25)	54 (22)	0.45
Discharge medications if not receiving a controller medications before the index hospitalization [‡]								
Oral corticosteroids	43 (86)	18 (100)	77 (91)	0.23	140 (92)	1 (100)	90 (87)	0.43
ICS [†]	36 (72)	16 (89)	61 (72)	0.30	94 (62)	1 (100)	62 (60)	0.70
Leukotriene modifier	6 (12)	1 (6)	8 (9)	0.72	18 (12)	0 (0)	13 (13)	0.92
Received individualized written asthma action plan	72 (59)	48 (96)	180 (85)	<0.001	138 (44)	6 (38)	140 (57)	0.008
Follow-up appointment made before discharge	83 (68)	32 (64)	113 (53)	0.08	155 (50)	4 (25)	71 (29)	<0.001

Notes. ICS, inhaled corticosteroids; MDI, metered-dose inhaler.

Data were presented as *n* (%) unless otherwise indicated.

*Analyzed for 385 children and 576 adults who were sent home.

† Includes ICS and ICS/long-acting β -agonist.

‡ Analyzed for 153 children and 256 adults who were not treated with ICS, ICS/inhaled long-acting β -agonist, or leukotriene modifiers prior at the time of the index hospitalization.

transition patients to MDIs, and these efforts may even be cost-saving. In a study done on the West Coast, Moriates et al. [13] found that harnessing the ‘teachable moment’ by instructing inpatients on how to use MDIs was a feasible and important reason to increase the use of MDIs in the inpatient setting. Further, they found that decreasing inappropriate nebulizer use resulted in a \$250,000 annual cost savings per inpatient ward [13]. Cost savings were also found in other studies comparing nebulizer-SABA to MDI-SABA with savings of more than \$200,000 upwards of \$300,000 annually [12, 23–24]. However, in the current study, almost half of all the patients, more than half of the adult patients, and up to 77% of patients at some hospitals, received only nebulizer-SABA. Further, children with only nebulizer-SABA had longer LOS. Therefore, increased use of MDI-SABA may be both patient-centered and cost-saving.

Beyond these opportunities to increase delivery of MDI-SABA when appropriate, the variation seen in practice by patient age or hospital location is important to understand. With regard to the substantial differences in MDI-SABA use based on patients’ age, it is important to note that inpatient education programs are more prevalent among pediatric versus adult patient populations [25], perhaps leading to increased use of opportunities to provide and teach MDI use during hospitalization. Further, geographical variation is a commonly recognized phenomenon that affects costs, morbidity, mortality, and use of procedures or services [26–28]. With regard to geographic variation for asthma, variations in the prevalence of asthma symptoms have been found in New Zealand [26] and the United Kingdom [27], and rates of hospitalization and mortality are known to vary across the United States [28]. Further exploration into SABA delivery method variation across the United States is warranted. The implications of these findings are that MDI-SABA is still underutilized, with an even greater opportunity for improvement among adult patients and at some US hospitals. Further work should evaluate mechanisms of why MDI-SABA is underused, and develop interventions to increase its appropriate use to enhance hospital-based self-management education and possibly decrease costs.

When trying to understand why nebulizer-only delivery methods were used for SABA therapy, the most common factors appeared to be related to actual or perceived disease severity of the exacerbation at presentation and throughout hospitalization. For instance, among children who received only nebulizer-SABA, they were more likely to present with unstable vitals including respiratory rate and oxygenation to the pediatric intensive care unit (PICU); among adults, severity of illness also appeared influential, with a higher proportion presenting initially

to the ICU. Severity of illness should necessarily dictate the mode of SABA delivery, as even ventilated patients can receive SABA-MDI safely [29,30]. Further, it is important to evaluate why there were substantial differences in the results based on patient age. Inpatient asthma-related education programs are likely more prevalent among the pediatric versus adult patient populations, perhaps leading to increased opportunity to provide and teach MDI use during hospitalization. This may have been demonstrated in our study since children were both more likely to receive MDI-SABA and more likely to receive written action plans and discharge appointments when compared with adults. The relationship of MDI-SABA use in the hospital with self-management and discharge tools, such as action plans and follow-up appointments needs further study. In addition to determining if interventions can improve the appropriate use of MDI-SABA in hospital settings, it is important to note that patient preference may impact the use of MDI-SABA upon discharge [15]. Further, some patients may not have the dexterity, cognitive ability, or skill level required to use MDI-SABA [15,28]. However, these factors should be evaluated and the appropriate delivery method should be prescribed [15,31], taught, and encouraged for each patient.

While this study is among the first to delineate the use of MDI-SABA among hospitalized children and adults, potential limitations exist. First, this was a cross-sectional study, therefore, only associations and not causal mechanisms, could be determined. Second, although less than half of the patients received MDI-SABA during hospitalization, it was beyond the scope of this study to determine if non-MDI use was appropriate. For instance, young children may have difficulty using MDI-SABA and adults with poor cognition and/or problems with dexterity may have required only nebulizer-SABA [3,32]. Further, this study was unable to ascertain if teaching was provided during administration of MDI-SABA, nor were details available regarding timing of switching from nebulizer-SABA to MDI-SABA and use of valved holding chambers. Future work should study how often missed opportunities exist for appropriate provision of MDI-SABA with and without teaching. In addition, the generalizability of these findings may be limited as the majority of study sites were university hospitals. Finally, there was a wide age range, and the impact of MDI-SABA use among the different age cohorts could impact outcomes differently and interventions to address this problem may need to be tailored accordingly. More work is needed to understand which settings, populations, and geographic regions (including outside the United States) would benefit most from changing practice based on these results.

In summary, using a multi-site observational study dataset, we found that over half of the inpatients received MDI-SABA, though there is significant room for improvement, particularly among the adult hospitalized patient population and at many hospitals across the United States. Although our study could not determine if inhaler education was provided during hospitalization, we did find that children who did not receive MDI-SABA were less likely to receive action plans, and adults were less likely to receive action plans or follow-up appointments. These results underscore missed opportunities for hospital-based self-management education, and particularly for children, a potential link by SABA delivery method. Our data facilitate further investigation into opportunities to improve assessments of, and interventions to, improve guideline-directed care of assessing and teaching MDI technique during hospitalization, and whether these interventions lead to improved health outcomes and are cost effective.

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Declaration of interest

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