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Changes in the Use of Invasive and Noninvasive Mechanical Ventilation in Pediatric Asthma
2009–2019

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Abstract

Rationale: Despite lower overall hospitalization rates for asthma in recent years, there has been an increase in the number of pediatric patients receiving intensive care management in the United States.

Objectives: To investigate how the use of invasive and noninvasive mechanical ventilation for asthma has changed in the context of an evolving cohort of critically ill pediatric patients with asthma.

Methods: We analyzed children admitted to intensive care units for asthma from 2009 through 2019 in the Virtual Pediatric Systems database. Regression analyses were used to evaluate how respiratory support interventions, mortality, and patient characteristics have changed over time. Odds ratios were calculated to determine how patient characteristics were associated with respiratory support needs. Stratified analyses were performed to determine how changing practice patterns may have differed between patient subgroups.

Results: There were 67,614 admissions for 56,727 patients analyzed. Intubation occurred in 4.6% of admissions and decreased from 6.9% to 3.4% over time ($P < 0.001$), whereas noninvasive ventilation as the maximal respiratory support increased from 8.9% to 20.0% ($P < 0.001$). Over time, the cohort shifted to include more 2- to 6-year-olds and patients of Asian/Pacific Islander or Hispanic race/ethnicity. Although intubation decreased and noninvasive ventilation increased in all subgroups, the changes were most pronounced in the youngest patients and slightly less pronounced for obese patients.

Conclusions: In pediatric asthma, use of intubation has halved, whereas use of noninvasive ventilation has more than doubled. This change in practice appears partially related to a younger patient cohort, although other factors merit exploration.

Keywords: critical care outcomes; respiratory insufficiency; noninvasive ventilation; healthcare disparities

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Although pediatric asthma diagnoses increased significantly in the late 20th century, recent data demonstrate a decrease in overall prevalence since 2006, with a most recent estimate of 8% prevalence in U.S. children aged 0–17 years (1). Despite a concordant decrease in the overall incidence of asthma hospitalizations, several studies have demonstrated an increasing proportion of admissions to pediatric intensive care units (PICUs) (2, 3).

The reasons for increased critical care use for pediatric asthma remain unclear. For one, changing patient demography, such as lower age at asthma diagnosis and increased rates of pediatric obesity, may favor management in a dedicated pediatric critical care unit (4–7). Another factor may be an increase in the overall availability of PICU beds commensurate with a decrease in pediatric inpatient beds (8). In addition, the expansion and adaptation of high-flow nasal cannula (HFNC) and noninvasive ventilation (NIV) to the pediatric population may have facilitated a change in practice preference as new support modalities increase in availability (9–14). Exacerbation of racial, socioeconomic, and regional disparities that are known to affect asthma outcomes may also contribute to greater critical care use (15–18).

In this study, we aimed to investigate how the characteristics and support of critically ill children with asthma have changed over time. We aimed to specifically test whether changes in asthma cohort composition might be associated with changes in critical care support, including invasive ventilation and NIV. We hypothesized that patients with asthma requiring PICU care are younger than in years past, with a demographic composition that otherwise reflects national changes. On the basis of our local institution's data, we also suspected trends toward increased use of HFNC and NIV and decreased invasive mechanical ventilation (IMV) and mortality rates.

Methods

Design

This was a retrospective multicenter cohort analysis using data from 161 PICUs contributing to the Virtual Pediatric Systems (VPS) database (Virtual Pediatric Systems, LLC). VPS is a clinical database dedicated to standardized data sharing among PICUs and is used to track outcomes, measure quality, and conduct research. VPS neither endorsed nor restricted our interpretation of these data. Trained VPS analysts collected patient data, including demographics, diagnoses, and critical care interventions, from PICU admission through PICU discharge or death. This study was deemed exempt from review by the Institutional Review Board, as all patient data were deidentified.

Study Population

The VPS database was queried for patients between 2 and 18 years of age admitted to North American PICUs between January 1, 2009, and December 31, 2019, with diagnoses of "asthma with acute exacerbation," "asthma with status asthmaticus," or "cough variant asthma." To focus our assessment specifically on patients admitted primarily for asthma, patients with complex or other severe chronic comorbid medical conditions, including other chronic respiratory diseases such as bronchopulmonary dysplasia and cystic fibrosis, were excluded from analysis (for excluded diagnoses, *see* Table E1 in the data supplement).

Outcomes

The primary outcome was endotracheal intubation with IMV. Those who never received IMV were further classified as having required NIV as maximal respiratory support (NIV_{max}; continuous or bilevel positive airway pressure), HFNC as maximal respiratory support ($HFNC_{max}$), or nasal cannula or less (including regular nasal cannula, face-mask oxygen, blow-by, etc.). VPS collects data on the need for IMV for all admissions and NIV and/or HFNC for a subset of admissions; admissions for which data on NIV and/or HFNC use were not collected were excluded from analyses of NIV and/or HFNC use. PICU mortality was assessed as a secondary outcome.

Predictors

For each PICU admission, patient demographics, anthropometrics, origin before PICU admission, readmission status (indicating more than one lifetime PICU admission), Pediatric Risk of Mortality III (PRISM III) score, admission and discharge year, and diagnoses were collected (19, 20). VPS categorically defines age as 2–6 years, 6–12 years, or 12–18 years. Other demographic data included sex, race, and ethnicity (categorically defined in a single variable as White, Black, Hispanic, Asian/Pacific Islander, other, or unknown on the basis of patient and/or family self-identification). PRISM III scores served as estimates of admission illness severity (19, 20).

Anthropometrics

Height and weight at PICU admission were used to calculate body mass index (BMI) and determine weight categories (underweight, normal, overweight, obese). Pediatric BMI norms vary considerably with age and sex because of normal growth and development, and thus BMI percentile for age, rather than absolute BMI value, is typically used for establishing pediatric weight classes.
We used a modified BMI categorization, defining cutoffs of percentile for age group to accommodate the categorical reporting of age in our data (21). Cutoff points for the BMI categories were determined from the Centers for Disease Control and Prevention BMI-for-age growth charts by calculating a mean of the yearly cutoff points for the underweight, overweight, and obese BMI categories for boys and girls across the age ranges provided by VPS (*see* Figure E1) (22).

Statistical Analysis

All statistical analyses were performed using R statistical software (R Core Team). Population norms were described with means and standard deviations for normally distributed variables and medians with interquartile ranges for skewed distributions. Changes in the use of IMV, NIV_{max}, and $HFNC_{max}$ over time were assessed using generalized estimating equation (GEE) regression models with discharge year as a linear predictor variable. GEE models used a logistic link function clustered by patient to account for multiple admissions of the same patient. To determine factors associated with mechanical ventilation, we performed multivariable GEE predictive modeling assessing mechanical ventilation by age, sex, race/ethnicity, weight classification, and PRISM III score. Changes in each of the patient characteristics over time were then assessed using discharge year as a linear predictor variable. Next, to determine whether the odds of mechanical ventilation changed over time within patient characteristic subgroups, we performed analyses stratified by patient characteristic, using GEE models to associate admission year with odds of respiratory support modality within each subgroup. Last, to determine whether the change in odds of

mechanical ventilation over time differed among subgroups, we used GEE models to associate use of mechanical ventilation with both year and patient subgroup, accounting for an interaction term between the two. PICU mortality was then assessed in a multivariable GEE model adjusting for patient age, sex, race/ethnicity, weight classification, and PRISM III score.

Results

Patient and Admission Characteristics

There were 56,727 patients accounting for 67,614 admissions who met the inclusion/exclusion criteria (Figure 1). Patient characteristics linked with each ICU admission are listed in Table 1. Notable cohort characteristics include a predominance of male patients (59.5% of admissions) and Black patients (38.5% of admissions). Of note, 13.5% of patients had two or more admissions during the study period, such that 20% of all admissions were considered readmissions. As readmissions of the same patient could confound subsequent analyses, we tested for factors associated with readmission status and identified that Black patients had the highest odds of readmission (odds ratio [OR], 1.76; 95% confidence interval [CI], 1.67–1.84; $P < 0.001$ compared with non-Hispanic White patients), and obese patients had higher odds of readmission compared with normal-weight patients (OR, 1.15; 95% CI, 1.08–1.23; $P < 0.001$; *see* Table E2). Subsequent analyses were performed with patient-level clustering to account for the effects of multiple admissions of the same patient.

Use of Mechanical Ventilation

IMV occurred in 3,123 admissions (4.6%). There was a significant downward trend in IMV use over the study period (adjusted OR [aOR], 0.95 per year; 95% CI, 0.94–0.96; $P < 0.001$; Figure 2). IMV occurred in 6.9% of admissions in 2009 compared with 3.4% of admissions in 2019. Of the IMV admissions, 2,305 subjects (73.8%) were intubated before arriving at the PICU. Of those, 2,118 (91.9%) were admissions from emergency departments. HFNC or NIV

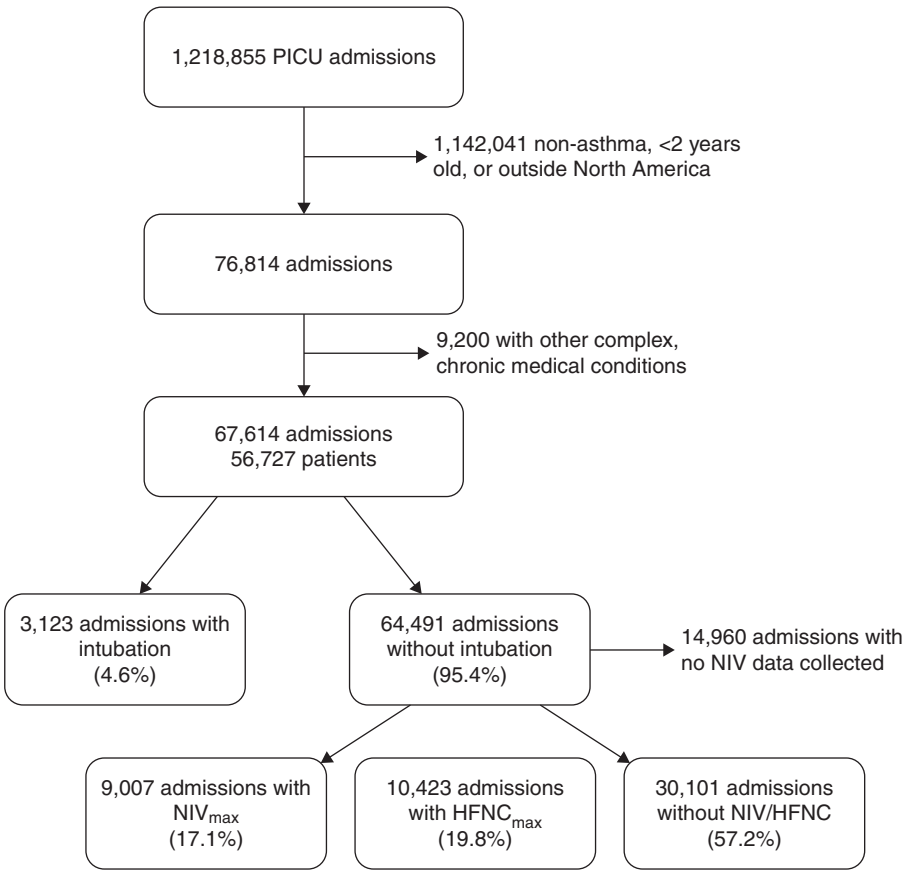

Figure 1. Inclusion/exclusion flow diagram. In total, 67,614 PICU admissions were identified corresponding to 56,727 unique patients. HFNC = high-flow nasal cannula; $HFNC_{max}$ = high-flow nasal cannula as maximal respiratory support; NIV = noninvasive ventilation; NIV_{max} = noninvasive ventilation as maximal respiratory support; PICU = pediatric intensive care unit.

Table 1. Pediatric intensive care unit characteristics of children with asthma (67,614 total admissions)

	Admissions [*n* (%)]
Age	
2–6 yr	28,603 (42.3)
6–12 yr	27,446 (40.6)
12–18 yr	11,565 (17.1)
Sex	
Female	27,369 (40.5)
Male	40,245 (59.5)
Race/ethnicity	
White	16,943 (25.1)
Black	26,056 (38.5)
Hispanic	8,712 (12.9)
Asian/PI	1,591 (2.4)
Other	3,123 (4.6)
Unknown	11,189 (16.6)
Readmission status	
No	54,096 (80.0)
Yes	13,518 (20.0)
Patient origin	
ED	56,299 (83.3)
OR	203 (0.3)
Clinic	319 (0.5)
Ward	9,530 (14.1)
Intermediate care unit	851 (1.3)
Other ICU	265 (0.4)
Home	71 (0.1)
Other	76 (0.1)
BMI category*	
Underweight	4,107 (12.3)
Normal	17,253 (51.5)
Overweight	4,401 (13.1)
Obese	7,754 (23.1)
PRISM III score	
0–2	43,650 (64.6)
3–5	14,510 (21.5)
6–10	5,236 (7.7)
>10	1,294 (1.9)
Unknown	2,924 (4.3)
Maximum respiratory support	
Intubation	3,123 (4.6)
No intubation	64,491 (95.4)
NIV	9,007 (17.1)
HFNC	10,423 (19.8)
NC/less	30,101 (57.2)
Unknown	14,960 (23.2)

Definition of abbreviations: BMI = body mass index; ED = emergency department; HFNC = high-flow nasal cannula; ICU = intensive care unit; NC = nasal cannula; NIV = noninvasive ventilation; OR = operating room; PI = Pacific Islander; PRISM III = Pediatric Risk of Mortality III.
*BMI data were missing from 34,099 admissions.

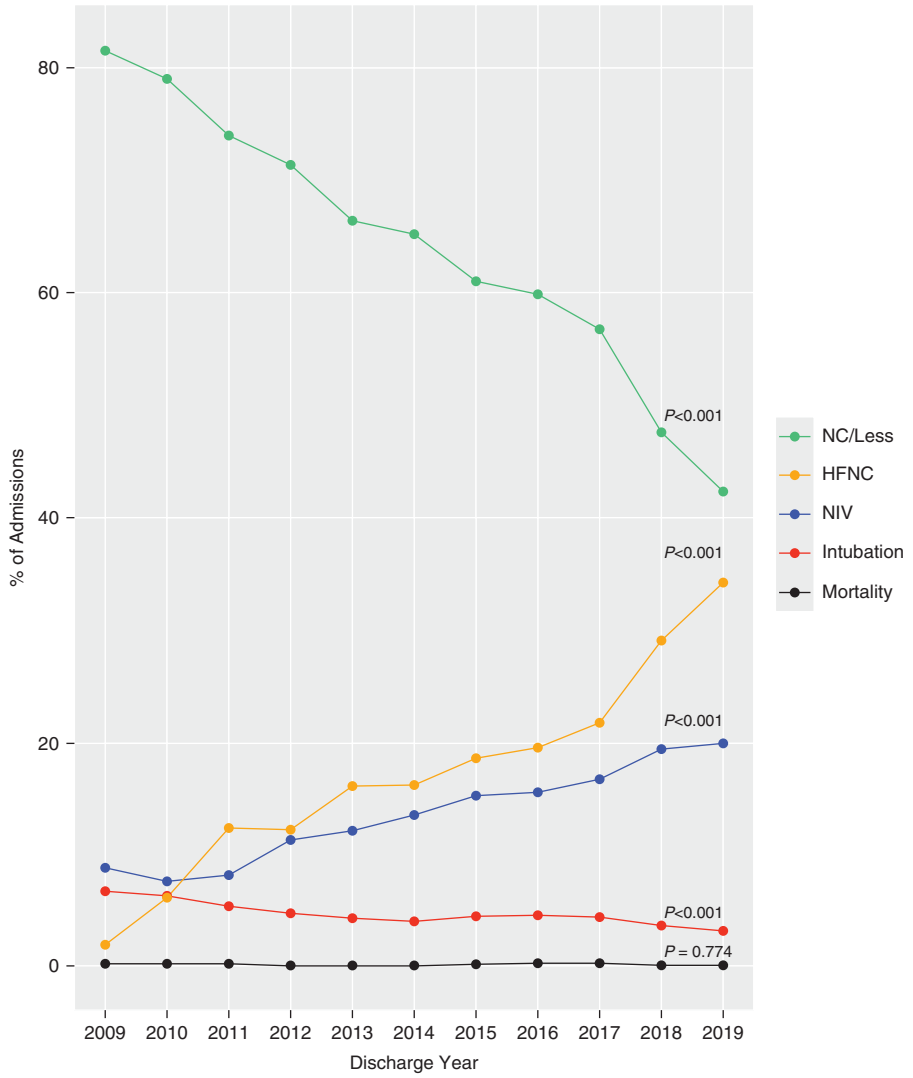

Figure 2. Changes in respiratory support modalities over time. Trends in the maximal respiratory support required and mortality rates during PICU admissions per year. *P* values represent results of regression analyses associating support modality/mortality with year of PICU admission. HFNC = high-flow nasal cannula; NC = nasal cannula; NIV = noninvasive ventilation; PICU = pediatric intensive care unit.

preceded intubation in 427 (55.5%) of the 770 admissions during which intubation occurred in the PICU and HFNC and NIV data were collected. NIV without escalation to intubation (NIV_{max}) was the maximal support required in 17.1% of admissions for which NIV data were reported (9,007 of 52,654 admissions). The odds of NIV_{max} significantly increased over the study period (aOR, 1.16 per year; 95% CI, 1.15–1.17; $P < 0.001$; Figure 2). In 2009, NIV was the maximal support in 8.9% of admissions, compared with 20.0% of admissions in 2019. HFNC was the maximal support required in 19.8% of admissions and similarly increased significantly throughout the years (aOR, 1.22 per year; 95% CI, 1.21–1.23; $P < 0.001$; Figure 2).

Factors Associated with Mechanical Ventilation

The 6- to 12-year age group had the highest odds of requiring IMV (Figure 3; *see* Table E3). Older patients were more likely to require NIV_{max} than younger patients, whereas the 2- to 6-year age group was most likely to require $HFNC_{max}$. Male patients were more likely to require IMV, and female patients were more likely to require NIV_{max} or $HFNC_{max}$. Black and Hispanic patients were less likely to require IMV, whereas Black and other race patients were more likely to require NIV_{max} (relative to White patients). $HFNC_{max}$ was more common among Asian/Pacific Islander and Hispanic patients and less common among Black patients. Weight classification was not associated with IMV, but obese patients were more likely to require NIV_{max}, and underweight patients were more likely to require $HFNC_{max}$.

Changes in Cohort Composition over Time

We hypothesized that changes in cohort composition could underlie the observed changes in mechanical ventilation over time. To test whether cohort traits changed over time, we first performed GEE regression analyses to test for associations between patient characteristics and admission year. Regression analyses revealed a trend toward an increase in the cohort proportion of admissions by female relative to male patients over time ($P = 0.06$; Table 2). Relative to 6- to 12-year-old patients, 2- to 6-year-olds had more admissions over time ($P = 0.007$), whereas the rates of admissions of 12- to 18-year-olds were stable. Admissions of Asian or Pacific Islander, Hispanic, and other race/ethnicity patients increased relative to White patients over the study duration ($P < 0.001$), whereas there was no change in the percentage of Black patients. The rate of missing race and ethnicity data decreased. BMI categorizations did not change over time, aside from an increasing rate of missing data. The proportion of patients with higher PRISM III scores decreased with each subsequent year.

Effect of Changing Cohort Characteristics on Mechanical Ventilation

Given the observed changes in relevant patient characteristics over time, we next assessed to what extent the decreasing rates of IMV and increasing rates of NIV_{max} and $HFNC_{max}$ may have been related to changes in patient characteristics. In stratified analyses, IMV decreased and both NIV_{max} and $HFNC_{max}$ increased over time within all age groups ($P < 0.01$), but IMV decreased and both NIV_{max} and $HFNC_{max}$ increased the most for 2- to 6-year-olds (interaction $P < 0.1$; Table 3). IMV decreased and both NIV_{max} and $HFNC_{max}$ increased over time for both male and female patients ($P < 0.001$), but IMV decreased to a greater extent for female patients (interaction $P < 0.1$), whereas NIV_{max} and $HFNC_{max}$

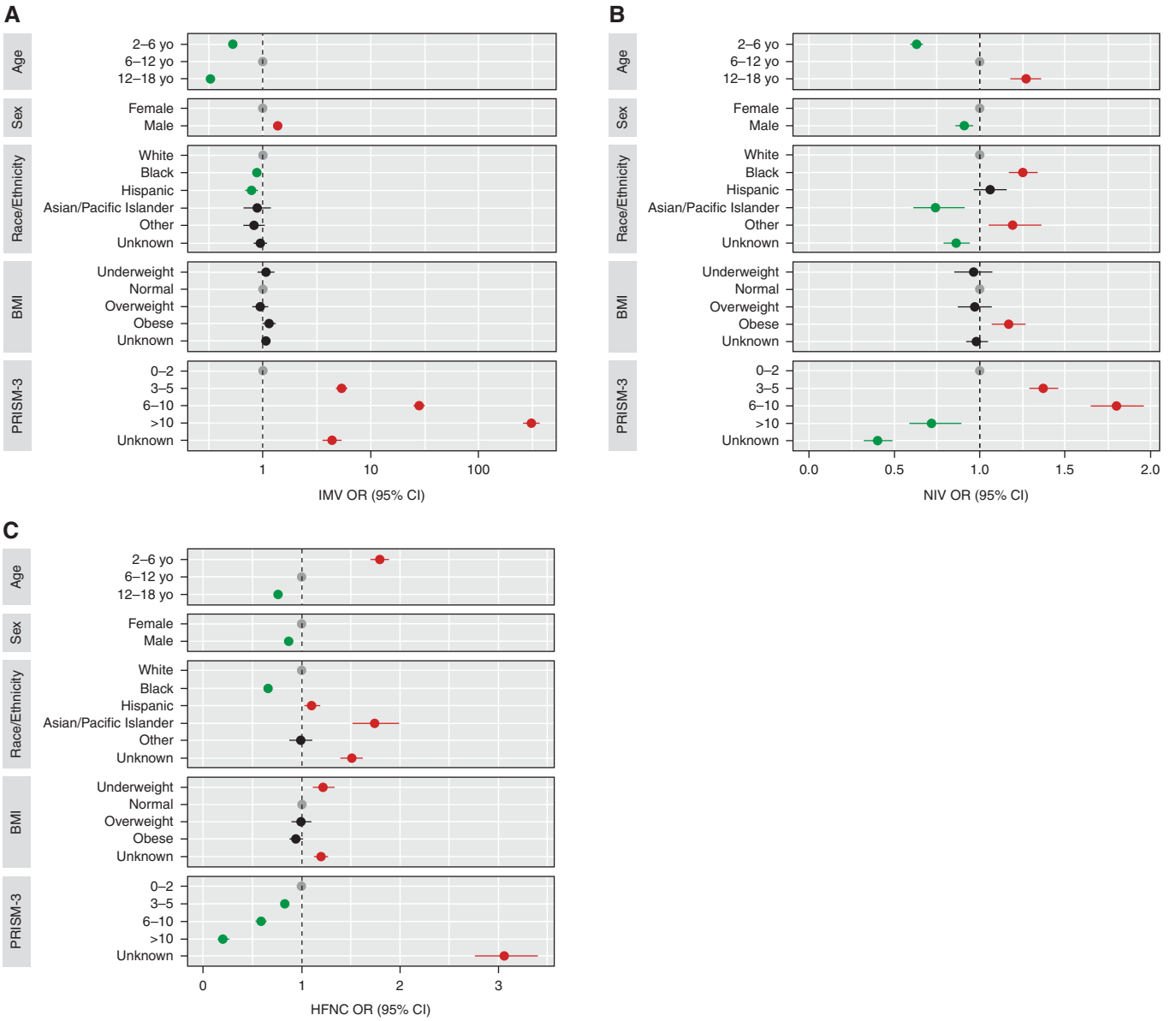

Figure 3. Factors associated with respiratory support modality in pediatric asthma. ORs determined by multivariable regression analyses associating maximal respiratory support requirement with patient characteristic are demonstrated for the use of IMV (*A*), noninvasive ventilation (NIV) (*B*), and high-flow nasal cannula (HFNC) (*C*). Intubation odds were higher in male patients and patients with higher Pediatric Risk of Mortality III (PRISM III) scores and lower in patients 2–6 years old, 12–18 years old, and of Black or Hispanic race/ethnicity. Odds of NIV as maximal respiratory support were higher for patients 12–18 years old, patients of Black or other race/ethnicity, obese patients, and patients with PRISM III scores of 3–10 and lower for patients 2–6 years old, male patients, patients of Asian/Pacific Islander or unknown race/ethnicity, and patients with PRISM III scores >10. Odds of HFNC as maximal respiratory support were higher in patients 2–6 years old; those of Hispanic, Asian/Pacific Islander, or unknown race/ethnicity; and underweight patients or those with unknown BMI. Odds of HFNC as maximal respiratory support were lower in patients 12–18 years old, male patients, Black patients, and patients with higher PRISM III scores. BMI = body mass index; CI = confidence interval; IMV = invasive mechanical ventilation; OR = odds ratio.

increased similarly among male and female patients. All racial and ethnic groups demonstrated decreasing odds of IMV and increased odds of both NIV_{max} and $HFNC_{max}$ over time ($P < 0.05$), but the decrease in IMV and increase in $HFNC_{max}$ were significantly more pronounced for Hispanic patients (interaction $P < 0.1$), whereas increases in NIV_{max} were similar across racial and ethnic groups. IMV decreased significantly over time in all weight classification groups except overweight (OR, 0.95; 95% CI, 0.91–1.00, $P = 0.05$) and obese (OR, 0.97; 95% CI, 0.93–1.00; $P = 0.08$) patients. Relative to obese patients, normal-weight patients had a greater decline in the use of IMV (interaction $P < 0.1$). Both NIV_{max} and $HFNC_{max}$ increased for all weight classification groups ($P < 0.001$) at similar rates. IMV odds decreased over time in patients with PRISM III scores <10 but at

Table 2. Changes in characteristics of pediatric intensive care unit children with asthma from 2009 to 2019

	Relative Change in Characteristic per Year	
	OR (95% CI)	***P* Value**
Age		
2–6 yr	1.08 (1.02–1.13)	0.007
6–12 yr	Reference	Reference
12–18 yr	1.04 (0.96–1.12)	0.33
Sex		
Female	Reference	Reference
Male	0.95 (0.91–1.00)	0.06
Race/ethnicity		
White	Reference	Reference
Black	0.98 (0.92–1.04)	0.55
Hispanic	1.52 (1.40–1.65)	<0.001
Asian/PI	2.54 (2.19–2.96)	<0.001
Other	1.42 (1.26–1.60)	<0.001
Unknown	0.62 (0.57–0.67)	<0.001
BMI category		
Underweight	1.00 (0.90–1.10)	0.92
Normal	Reference	Reference
Overweight	1.00 (0.91–1.11)	0.97
Obese	1.04 (0.96–1.14)	0.33
Unknown	1.28 (1.21–1.36)	<0.001
PRISM III score		
0–2	Reference	Reference
3–5	0.90 (0.85–0.95)	<0.001
6–10	0.70 (0.54–0.76)	<0.001
>10	0.56 (0.48–0.67)	<0.001
Unknown	0.66 (0.58–0.75)	<0.001

Definition of abbreviations: BMI = body mass index; CI = confidence interval; OR = odds ratio; PI = Pacific Islander; PRISM III = Pediatric Risk of Mortality III.
Among age groups, 2- to 6-year-olds increased over time relative to 6- to 12-year-olds. Among race/ethnicity groups, Hispanic, Asian/PI, and other increased over time relative to White, whereas those with unknown race decreased over time. Relative to patients with the lowest PRISM III scores of 0–2, patients with higher PRISM III scores decreased over time.

a slower rate for patients with scores of 6–10, and the odds increased over time for patients with scores >10. NIV_{max} odds increased over time for all PRISM III score groups except for patients with scores >10, and $HFNC_{max}$ increased similarly across all groups.

We note that other factors may influence the use of mechanical ventilation in pediatric asthma over time. As such, in a multivariable GEE model, we found that IMV decreased and both $HFNC_{max}$ and NIV_{max} increased over time, even after adjusting for patient age, sex, race/ethnicity, and weight classification ($P < 0.001$ and $P < 0.001$, respectively).

Mortality

There were 240 deaths total in our cohort (0.35% of asthma PICU admissions). Deaths occurred 97.9% of the time in intubated patients ($n = 235$ of 240). After controlling for age, sex, race/ethnicity, weight class, and PRISM III score, the lowest odds of mortality were seen in patients 2–6 years old (aOR, 0.26 compared with 6–12 years; 95% CI, 0.17–0.39; $P < 0.001$; *see* Table E4). There were no associations between race/ethnicity, sex, or weight class and mortality. Mortality rates ranged from 0.27% to 0.46% per year and did not significantly differ over the time frame ($P = 0.603$; Figure 2).

Discussion

Our findings highlight a significant decrease in the use of IMV and commensurate increases in the rates of both NIV_{max} and $HFNC_{max}$ for critically ill children with asthma. These trends were most pronounced in the 2- to 6-year age group, which saw both an increase in relative cohort composition and relatively greater changes in the approach to respiratory support over time. The vast majority of patients who received IMV were already intubated upon PICU admission and arrived from emergency departments. Overall, these findings demonstrate meaningful patterns and shifts in practice within critical care.

Compared with older patients, the youngest patients in our cohort had the most significant decrease in the rate of IMV use and increase in the rates of HFNC and NIV without need for intubation from 2009 to 2019. This raises questions about how the efficacy of different respiratory support strategies may differ for our youngest patients and also highlights how advances in respiratory support technology, particularly NIV, may differentially affect patients of different ages. The array of NIV tools available in the PICU has never been larger (23). The development of pediatric-specific masks has expanded significantly in recent years, which directly influences the ability to provide high-level noninvasive support in younger children (24). Some institutions are even exploring the use of custom-fitted, three-dimensionally printed masks for use in pediatric patients requiring NIV, a practice that has the potential to become a standard of practice in hospitals with sufficient resources (25). There are also increasing data on the efficiency of delivering aerosolized medications such as albuterol through noninvasive ventilator interfaces, which further helps support their use in status asthmaticus (26). Last, there is a growing body of evidence to support the safe use of relatively low risk sedation protocols, such as dexmedetomidine as a single continuous infusion, to improve adherence to and efficacy of NIV (27, 28). Further investigation into how these and other factors influence the efficacy of NIV use at different ages is warranted to help guide how our approach to respiratory support in asthma will continue to develop.

Although obesity was not associated with the need for IMV in our overall cohort, we found that obesity was associated with a greater rate of ICU readmission and that the odds of intubation decreased over time to a lesser degree for obese patients compared with patients of other BMI classification groups. Obesity can affect respiratory outcomes in a number of ways, including the mechanical effects of truncal adiposity on the functional residual capacity and expansion/recoil of lungs, heightened degrees of systemic inflammation and concentrations of inflammatory biomarkers related to obesity, and differences in the pharmacokinetics and pharmacodynamics of respiratory

Table 3. Odds of maximal respiratory support over time

	Change in IMV per Year			Change in NIV_{max} per Year; OR (95% CI)			Change in $HFNC_{max}$ per year; OR (95% CI)		
	OR (95% CI)	*P* Value	*P* Value for Interaction Term	OR (95% CI)	*P* Value	*P* Value for Interaction Term	OR (95% CI)	*P* Value	*P* Value for Interaction Term
Age									
2–6 yr	0.93 (0.91–0.95)	<0.001	0.099	1.15 (1.13–1.17)	<0.001	0.005	1.24 (1.23–1.26)	<0.001	<0.001
6–12 yr	0.95 (0.93–0.97)	<0.001	Reference	1.11 (1.10–1.13)	<0.001	Reference	1.18 (1.17–1.20)	<0.001	Reference
12–18 yr	0.96 (0.94–0.99)	0.004	0.331	1.09 (1.07–1.11)	<0.001	0.11	1.21 (1.18–1.24)	<0.001	0.15
Sex									
Female	0.93 (0.91–0.95)	<0.001	0.086	1.12 (1.10–1.13)	<0.001	0.37	1.21 (1.20–1.23)	<0.001	0.78
Male	0.95 (0.94–0.97)	<0.001	Reference	1.11 (1.10–1.12)	<0.001	Reference	1.22 (1.20–1.23)	<0.001	Reference
Race/ethnicity									
White	0.95 (0.92–0.97)	<0.001	Reference	1.13 (1.11–1.15)	<0.001	Reference	1.22 (1.20–1.24)	<0.001	Reference
Black	0.94 (0.92–0.96)	<0.001	0.77	1.13 (1.11–1.15)	<0.001	0.97	1.20 (1.18–1.22)	<0.001	0.21
Hispanic	0.90 (0.87–0.93)	<0.001	0.019	1.11 (1.08–1.13)	<0.001	0.20	1.28 (1.25–1.31)	<0.001	0.002
Asian/PI	0.87 (0.79–0.96)	0.006	0.11	1.09 (1.00–1.19)	0.042	0.49	1.27 (1.21–1.34)	<0.001	0.12
Other	0.92 (0.87–0.97)	0.002	0.30	1.12 (1.07–1.17)	<0.001	0.65	1.16 (1.11–1.21)	<0.001	0.28
Unknown	1.00 (0.98–1.03)	0.76	0.002	1.06 (1.03–1.09)	<0.001	<0.001	1.19 (1.17–1.22)	<0.001	0.11
BMI category									
Underweight	0.92 (0.88–0.97)	<0.001	0.63	1.15 (1.11–1.19)	<0.001	0.61	1.20 (1.16–1.23)	<0.001	0.57
Normal	0.93 (0.91–0.96)	<0.001	Reference	1.14 (1.12–1.16)	<0.001	Reference	1.21 (1.19–1.23)	<0.001	Reference
Overweight	0.95 (0.91–1.00)	0.05	0.43	1.13 (1.10–1.17)	<0.001	0.88	1.19 (1.15–1.23)	<0.001	0.40
Obese	0.97 (0.93–1.00)	0.08	0.098	1.11 (1.08–1.14)	<0.001	0.11	1.19 (1.16–1.22)	<0.001	0.23
Unknown	0.95 (0.93–0.97)	<0.001	0.32	1.10 (1.08–1.11)	<0.001	0.003	1.23 (1.21–1.24)	<0.001	0.17
PRISM III score									
0–2	0.93 (0.90–0.96)	<0.001	Reference	1.12 (1.11–1.14)	<0.001	Reference	1.22 (1.21–1.24)	<0.001	Reference
3–5	0.93 (0.91–0.95)	<0.001	0.91	1.10 (1.08–1.12)	<0.001	0.066	1.23 (1.21–1.26)	<0.001	0.45
6–10	0.98 (0.95–1,00)	0.047	0.010	1.12 (1.09–1.15)	<0.001	0.96	1.26 (1.21–1.31)	<0.001	0.16
>10	1.06 (1.02–1.10)	0.006	<0.001	1.02 (0.95–1.09)	0.63	0.003	1.30 (1.14–1.48)	<0.001	0.38
Unknown	1.04 (0.97–1.10)	0.25	0.002	1.46 (1.30–1.63)	<0.001	<0.001	1.06 (1.03–1.10)	<0.001	<0.001

Definition of abbreviations: BMI = body mass index; CI = confidence interval; $HFNC_{max}$ = high-flow nasal cannula as maximal respiratory support; IMV = invasive mechanical ventilation; NIV_{max} = noninvasive ventilation as maximal respiratory support; OR = odds ratio; PI = Pacific Islander; PRISM III = Pediatric Risk of Mortality III.

Intubation, NIV_{max}, and $HFNC_{max}$ ORs per year are demonstrated within each patient characteristic subgroup. Interaction terms (discharge year × patient characteristic) were used to determine if changes in respiratory support odds per year were different between patient characteristic groups, relative to a reference trait. All age groups had decreasing odds of intubation and increasing odds of NIV_{max} and $HFNC_{max}$ over time, but 2- to 6-year-olds had a greater decrease in intubation and increases in NIV_{max} and $HFNC_{max}$ per year. Both female and male patients showed decreases in intubation and increases in NIV_{max} and $HFNC_{max}$ over time, but female patients had a greater decrease in intubation over time. All racial/ethnic groups had decreases in intubation and increases in NIV_{max} and $HFNC_{max}$ over time, but the decrease in intubation and increase in $HFNC_{max}$ were greatest for Hispanic patients. Among weight groups, all groups had decreases in intubation and increases in NIV_{max} and $HFNC_{max}$ over time, but the decrease in intubation was less pronounced for overweight and obese patients. IMV decreased over time for patients with PRISM III scores <10 but did so less for patients with scores of 6–10. IMV increased over time for patients with PRISM III scores >10. NIV_{max} and $HFNC_{max}$ increased over time for all PRISM III score groups, but NIV_{max} increased to a lesser extent for scores of 3–5 and >10.

medications (6, 7). Our findings suggest a greater hesitancy to avoid intubation for obese patients with severe asthma, perhaps because of these well-described effects of obesity on respiratory outcomes. Although it was not associated with the major outcomes of need for IMV and mortality in the present study, providers should continue to weigh obesity as an important clinical variable when making decisions about the respiratory support of patients with asthma.

We identified several interesting findings related to patient race and ethnicity in our cohort. Black patients were vastly overrepresented in our study, constituting 38.5% of all admissions. According to 2020 U.S. census data, only 14.2% of the population identifies as Black or African American (29). Although a number of prior studies have demonstrated similar findings of increased asthma prevalence, hospital admissions, and asthma-related morbidities in Black patients, few have shown such an outsized burden of ICU admission as we see in this cohort (15, 16, 30–36). Our findings appear to be driven primarily by a significantly higher readmission rate among Black patients, who had 76% higher odds of being readmitted compared with non-Hispanic White patients. Interestingly, despite the disproportionately high rates of PICU admissions for Black patients as well as the rising rates of PICU admissions noted for Hispanic patients, we found lower odds of intubation in Black and Hispanic patients compared with non-Hispanic White children in our cohort. A handful of prior studies have similarly demonstrated that racial disparities may manifest differently once an asthma exacerbation reaches the degree of severity necessitating ICU care (17, 18, 37–45). Although it is known that Black and Hispanic children have higher asthma prevalence, emergency department use, hospitalization and readmission rates, and overall rates of mortality, at least one other study has also demonstrated lower odds of intubation for Hispanic compared with non-Hispanic White children (17). The reasons behind such findings are unclear, and our data are unfortunately limited in their scope to explore any further. Future investigation into the factors that contribute to these differences in adverse outcomes between racial and ethnic groups is warranted, and we must continue to develop strategies to help mitigate the disparities that exist in pediatric asthma.

Strengths and Limitations

There were several limitations to this study. We acknowledge that decisions regarding respiratory support strategies are not objective and do not follow agreed-on guidelines. Hence, these patterns may reflect more of a behavioral trend and preference evolution over time. The VPS database contains mostly discharge-level data without detailed clinical information beyond what is captured in diagnosis codes. The database also does not include data on complications or deaths that occur outside the PICU. Race and ethnicity are not mandatory fields in VPS and were collected in 83.45% of admissions, similar to the rate of missing data in other large, multicenter data sets (17). VPS collects race and ethnicity as a single variable, limiting our categorization of race/ethnicity used in our analyses. We were also limited in our analyses of BMI data because of data collection methods and missing data. Age was collected as a categorical variable, which precluded our ability to calculate BMI percentile for age and categorize by the standard pediatric definitions of underweight, overweight, and obese. Given this, we defined BMI categories as outlined above to best categorize our anthropometric data. The proportion of patients categorized as obese via this schema is similar to that reported for pediatric patients admitted for other etiologies of respiratory failure (46). Last, we did not have details regarding the patients' asthma classifications or histories, outpatient treatment, or pulmonary function test results to correlate with PICU outcomes.

Conclusions

In critically ill children with asthma, the use of intubation has halved, whereas the use of NIV has more than doubled. This change in practice appears partially related to an increasingly younger patient cohort, although other factors merit exploration. Ongoing investigation into the optimal use of mechanical ventilation, particularly in young children with asthma, is needed. Despite the significant changes in the approach to management, mortality from pediatric asthma remains stably low. ■

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