Change in Frequency of Invasive and Noninvasive Respiratory Support in Critically Ill Pediatric Subjects

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BACKGROUND: Noninvasive respiratory support has become more popular in the pediatric population and may prevent or replace invasive procedures, such as endotracheal intubation, in certain circumstances. The objective was to examine the frequency of invasive and noninvasive respiratory support from 2009 to 2017 in critically ill pediatric patients and to determine patient-related factors associated with invasive support using the Virtual Pediatric Systems, LLC database. METHODS: This was an analysis of prospectively collected data on admissions with respiratory support from 17 pediatric ICUs from 2009 to 2017 reported within the Virtual Pediatric Systems database. We determined the frequency of invasive and noninvasive respiratory support over the study period by measuring the number of admissions with either invasive or noninvasive support within a given year divided by the total number of pediatric ICU admissions with respiratory support during the same year. Factors associated with invasive support were examined in univariate and multivariate regressions. RESULTS: A total of 69,262 cases of respiratory support were included. There was a decrease in the rate of invasive support over the study period from 66.9% to 48.5% (*P* value for test of trend < .001) and an increase in the rate of noninvasive support from 28.7% to 57.7% (*P* value for test of trend < .001). Trauma cases and subjects < 1 month old were more likely to receive invasive support. Cases occurring in later years and subjects with Black or Hispanic race were less likely to receive invasive support. CONCLUSIONS: From 2009 to 2017, the frequency of admissions with invasive respiratory support decreased, and those with noninvasive respiratory support increased. By 2017, the frequency of noninvasive respiratory support was greater than that of invasive respiratory support.
Key words: airway management; noninvasive ventilation; endotracheal intubation; critical care; respiratory failure; pediatric intensive care units. [Respir Care 2021;66(8):1247–1253.

Introduction

Endotracheal intubations in pediatric ICUs are associated with frequent adverse events. First-pass success can be as low as 62%, with adverse event rates as high as 20%, including severe desaturation as high as 13%.[1-3] Peri-intubation cardiac arrest in pediatric ICU patients ranges from 1.7% to 7% of intubations, with a peri-intubation mortality rate as high as 1.6%.[4,5] Factors associated with peri-intubation arrest include multiple attempts, desaturation, hemodynamic instability, and a history of difficult airway or cardiac disease.[4-8] While some peri-intubation interventions, such as choice of induction agent and apneic oxygenation, have been shown to

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reduce peri-intubation adverse events,[9,10] noninvasive respiratory support has emerged as an increasingly more common therapy for critically ill pediatric patients requiring respiratory support that may reduce the need for intubation.[11]

Widespread use of noninvasive respiratory support has led to a decline in the frequency of endotracheal intubation in both adults and neonates, but it is unknown how it has affected the rate of intubation and other forms of invasive respiratory support in the pediatric ICU demographic.[12,13] Noninvasive respiratory support has been advocated as a first-line treatment in critically ill pediatric patients requiring respiratory support given its potential benefits over intubation, including a decreased need for sedation and a shorter pediatric ICU stay.[14-16] Given the potential tradeoff between invasive and noninvasive support, the objective of this study was to examine the frequency of invasive and noninvasive respiratory support from 2009 to 2017 in critically ill pediatric patients using a large, prospectively collected dataset.

QUICK LOOK

Current knowledge

The frequency of invasive respiratory support is decreasing in adults and neonates, and the use of noninvasive respiratory support is increasing. However, the frequency of invasive and noninvasive respiratory support among critically ill pediatric patients is unknown.

What this paper contributes to our knowledge

From 2009 to 2017, the frequency of invasive respiratory support decreased in critically ill pediatric subjects, while noninvasive respiratory support increased. The frequency of noninvasive respiratory support has overcome invasive support in this population.

Methods

Study Design

The study was approved by the institutional review board at Saint Vincent Health Center in Erie, Pennsylvania. Data were queried from a prospectively collected data set maintained by the Virtual Pediatric Systems, LLC database, from January 1, 2009 to December 31, 2017. These dates were chosen as a uniform web-based application process was used for data entry starting January 1, 2009. The Virtual Pediatric Systems database collects data from pediatric ICUs across the world, but primarily from the United States and has been described previously.[17] Briefly, participating pediatric ICUs submit data pertaining to patients admitted to the units including patient demographics (eg, age, weight, sex, race), interventions performed during the admission (eg, type of invasive or noninvasive respiratory support), and mortality. Data are prospectively entered by trained individuals at each site.

Study Population, Definitions, and Outcomes

We collected data on all pediatric ICU admissions with reported respiratory support during the study period. For this study, invasive respiratory support was limited to intubation and laryngeal mask airways; other methods, such as jet ventilation, were excluded because they are not considered a definitive airway and occur extremely infrequently. Noninvasive support included CPAP, bi-level positive airway pressure, and high-flow nasal cannula (HFNC).

Variables indicating the use of invasive and noninvasive respiratory support during an admission were created, and the annual usage of invasive and noninvasive procedures was assessed for each pediatric ICU. Pediatric ICUs were excluded if they did not commit to reporting all noninvasive procedures, if their invasive rate was > 90% of their combined invasive and noninvasive volume per year for any given year over the study period, if they had an annual admission count < 10 per year, or if they did not report data during each year of the study period. Our data included

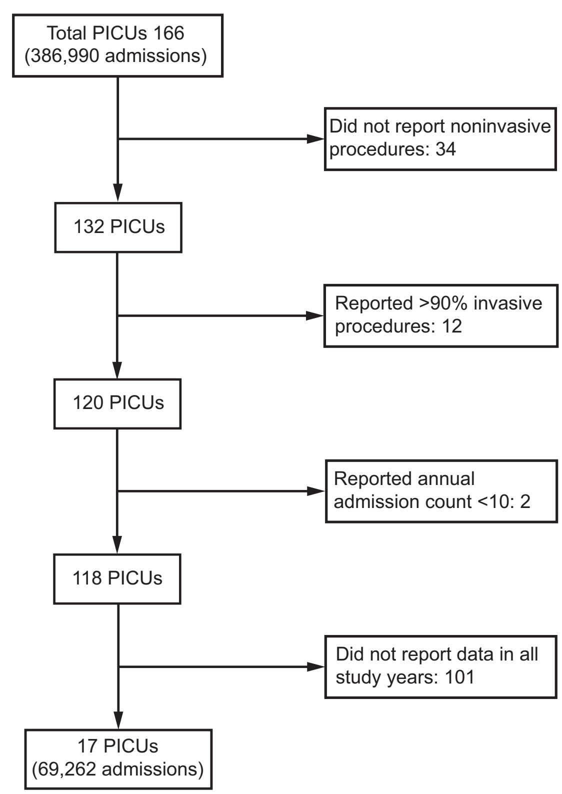

Fig. 1. Flow chart. PICU = pediatric ICU.

Table 1. Subject Demographics by Year

	2009 (n = 5,294)	2010 (n = 6,895)	2011 (n = 7,234)	2012 (n = 7,623)	2013 (n = 8,039)	2014 (n = 8,019)	2015 (n = 8,408)	2016 (n = 8,606)	2017 (n = 9,144)
Method									
Noninvasive	28.7	31.1	34	41.8	48.8	49.9	52.8	55.9	57.7
Invasive	66.9	67.4	65	62	61.1	57.4	54.3	51.6	48.5
Device									
Endotracheal intubation	66.9	67.4	65.0	62.0	61.1	57.4	54.2	51.6	48.5
CPAP	5.7	5.1	5.1	5.3	5.8	6.6	7.3	9.0	9.7
High-flow nasal cannula	24.1	27.2	30.7	34.9	36.9	37.7	40.1	43.1	45.1
BPAP	0	0	0	5.0	14.0	15.2	16.4	17.5	18.4
Laryngeal mask airway	0.06	0.07	0.10	0.08	0.09	0.06	0.06	0.03	0.07
Age									
< 1 month	6.95	6.57	7.0	6.8	6.9	6.2	5.5	5.6	5.6
1–23 months	39.08	39.2	38.6	38.4	38.4	38.7	39.43	40.0	42.5
2–5 y	17.3	17.7	18.7	18.7	18.6	18.6	19.0	18.9	17.4
6–12 y	17.5	16.3	16.5	17.3	17.0	17.5	17.3	17.6	16.1
13–18 y	16.0	17.4	16.6	16.0	16.5	16.3	16.2	15.00	15.2
> 18 y	3.2	2.8	2.6	2.6	2.65	2.7	2.6	2.8	3.0
Sex									
Female	44.1	44.6	44.2	43.2	43.8	44.3	44.1	43.4	43.9
Race									
White	45.0	45.8	47.9	46.4	46.8	48.4	45.4	46.3	44.4
Black	16.7	17.8	17.9	18.6	18.5	17.5	19.9	18.4	20.5
Hispanic	15.6	16.1	14.9	14.23	14.2	13.7	14.3	13.9	12.9
Other	7.8	7.4	7.2	8.3	8.5	8.1	9.4	9.8	10.6
Unknown	14.9	12.9	12.0	12.4	12.1	12.1	11.0	11.6	11.6
Trauma	8.03	8.73	7.4	8.00	6.7	6.4	6.2	6.3	6.3
Died	7.4	6.54	6.2	6.4	5.6	5.8	5.2	5.1	5.2
PIM2									
Mean	–3.7	–3.8	–3.8	–3.8	–3.9	–4.0	–4.2	–4.3	–4.3
Median	–3.5	–3.5	–3.6	–3.6	–3.9	–4.2	–4.4	–4.5	–4.5
25th percentile	–4.7	–4.7	–4.8	–4.8	–4.8	–4.9	–5.0	–5.1	–5.2
75th percentile	–3.0	–3.1	–3.1	–3.1	–3.2	–3.2	–3.3	–3.3	–3.3
PRISM3									
Mean	5.4	5.4	5.2	5.3	4.9	4.7	4.4	4.1	4.1
Median	3	3	3	3	3	3	3	2	2
25th percentile	0	0	0	0	0	0	0	0	0
75th percentile	8	8	7	8	7	7	6	6	6

Data are presented as percentages unless otherwise noted. The chi-square test, used for linear trends, resulted in $P < .001$ for all included variables except for laryngeal mask airway ($P = .39$) and sex ($P = .47$).
BPAP = bi-level positive airway pressure
PIM2 = Pediatric Index of Mortality 2
PRISM3 = Pediatric Risk of Mortality III

a total of 17 pediatric ICUs with 69,262 admissions receiving any respiratory support, invasive or noninvasive, over the 9-y period (Fig. 1).

We determined the frequency of respiratory support admissions with invasive and noninvasive interventions and trended them over the study period. This was defined as the number of admissions in a given year with ≥ 1 invasive or noninvasive interventions reported, respectively, during that admission divided by the total number of admissions with respiratory support. Our secondary objective was to determine the association between invasive support and age, sex, race, trauma, and mortality.

Statistical Analysis

Data were collected and summarized over each year. The frequencies of invasive and noninvasive respiratory support were calculated as the number of admissions with invasive or noninvasive interventions divided by the total number of admissions with respiratory support for the year, and these frequencies are presented as percentage values.

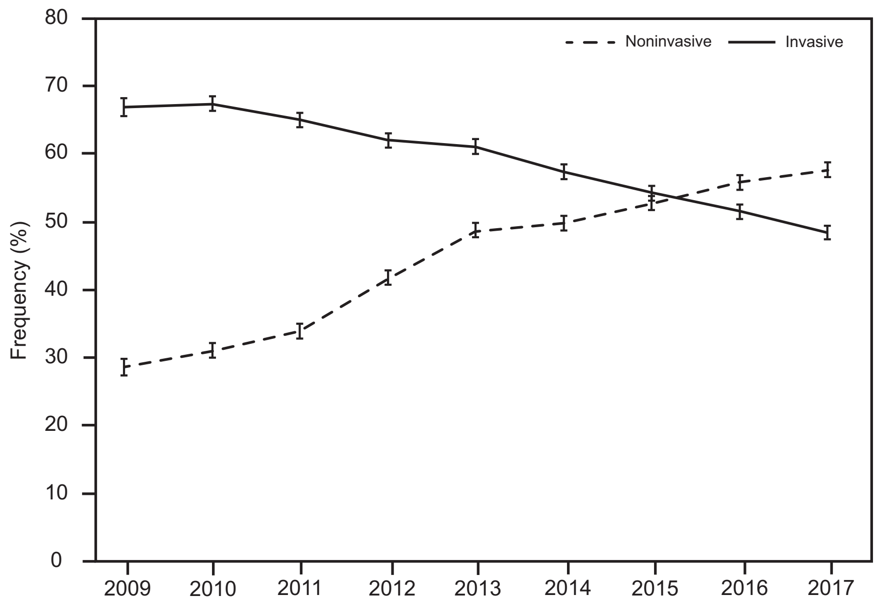

Fig. 2. Change in frequency of invasive and noninvasive respiratory support over the study period, with 95% CIs around the annual point estimates.

Admissions with both invasive and noninvasive support were counted twice, ie, they were included in the count for both invasive and noninvasive. Data were then graphed and evaluated with the chi-square test for linear trend. Unadjusted risk ratios for invasive support were calculated for the variables mentioned above with 95% CIs. Adjusted analyses (adjusted risk ratios) were corrected for Pediatric Index of Mortality 2 (PIM2) and Pediatric Risk of Mortality III (PRISM3) severity of illness scores, which are collected in the Virtual Pediatric Systems database.

Results

The most common form of invasive support was consistently intubation in all study years, while the most common form of noninvasive support was consistently HFNC in all study years. There was a decrease in the rate of invasive support over the study period from 66.9% to 48.5% (*P* value test of trend $< .001$) and an increase in the rate of noninvasive support from 28.7% to 57.7% (*P* value test of trend $< .001$). Table 1 describes the distribution of procedures, subject demographics, mortality, and risk scores over the study period. The relative frequency of invasive and noninvasive support changed during the course of the study period (Fig. 2). By the end of the study period, noninvasive interventions occurred more frequently than invasive interventions.

Various factors were associated with invasive respiratory support in unadjusted analyses (Table 2). Approximately 80% of subjects < 1 month old received invasive support. Children of all successive age categories were less likely to receive invasive support compared to subjects < 1 month old. Compared to white subjects, Black (0.87 [95% CI 0.86–0.88]) and Hispanic (0.95 [95% CI 0.94–0.96]) subjects were less likely to receive invasive support. Trauma admissions and individuals with higher PIM2 or PRISM3 scores were more likely to receive invasive support. Admissions in more recent years were less likely to receive invasive support.

Factors associated with invasive support were similar in adjusted analyses (Tables 3 and 4). Black and Hispanic patients were less likely to receive invasive support. Similarly, admissions in more recent years and subjects $>$ 1 month old were less likely to receive invasive support. Trauma admissions and higher PIM2 and PRISM3 scores remained independent predictors of invasive support. PIM2 and PRISM3 scores were evaluated in separate multivariable models.

Discussion

This is the largest study of prospectively collected data evaluating the frequencies of invasive and noninvasive support in critically ill pediatric subjects. We found an inverse relationship between the frequency of invasive and noninvasive support over time with a decrease in the rate of invasive support and an increase in the rate of noninvasive support. As of 2017, the frequency of noninvasive support, mostly HFNC, is greater than the frequency of invasive support, almost exclusively intubation. However, the etiology of this trend remains unclear.

The change in frequency of invasive and noninvasive respiratory support of critically ill pediatric subjects is likely

Table 2. Unadjusted Risk Ratios for Invasive Respiratory Support

	Unadjusted Risk Ratio (95% CI)	Invasive Rate of Reference (IQR)
Age		
< 1 month	Reference	80.17 (79.58–8.77)
1–23 months	0.66 (0.65–0.66)	
2–5 y	0.62 (0.61–0.63)	
6–12 y	0.66 (0.66–0.67)	
13–18 y	0.78 (0.77–0.78)	
> 18 y	0.58 (0.57–0.60)	
Sex		
Female	Reference	55.59 (55.30–55.88)
Male	0.99 (0.98–1.00)	
Race		
White	Reference	56.15 (55.85–56.45)
Black	0.87 (0.86–0.88)	
Hispanic	0.95 (0.94–0.96)	
Other	1.02 (1.01–1.04)	
Unknown	1.07 (1.06–1.08)	
Trauma		
No	Reference	52.83 (52.63–53.03)
Yes	1.78 (1.77–1.79)	
Admission Year		
2009	Reference	65.22 (64.4–66.04)
2010	1.01 (1.00–1.03)	
2011	0.97 (0.95–0.98)	
2012	0.96 (0.94–0.97)	
2013	0.94 (0.92–0.95)	
2014	0.88 (0.87–0.89)	
2015	0.78 (0.77–0.79)	
2016	0.75 (0.73–0.76)	
2017	0.71 (0.70–0.72)	
PIM2 score	1.18 (1.17–1.18)	
PRISM3 score	1.03 (1.03–1.03)	

IQR = interquartile range
PIM2 = Pediatric Index of Mortality 2
PRISM3 = Pediatric Risk of Mortality III

Table 3. Risk Ratios for Invasive Respiratory Support Adjusted by PIM2

	Adjusted Risk Ratio (95% CI)
Admission Year	
2009	Reference
2010	1.02 (1.00– 1.05)
2011	0.99 (0.97–1.02)
2012	0.94 (0.92–0.97)
2013	0.95 (0.93–0.98)
2014	0.91 (0.89–0.94)
2015	0.89 (0.86–0.91)
2016	0.85 (0.83–0.88)
2017	0.80 (0.78–0.82)
Age	
< 1 month	Reference
1–23 months	0.79 (0.78–0.81)
2–5 y	0.72 (0.71–0.74)
6–12 y	0.73 (0.72–0.75)
13–18 y	0.80 (0.78–0.81)
> 18 y	0.60 (0.57–0.64)
Sex	
Female	Reference
Male	1.00 (0.99–1.01)
Race	
White	Reference
Black	0.94 (0.92–0.95)
Hispanic	0.97 (0.95–0.99)
Other	1.07 (1.05–1.09)
Unknown	1.02 (1.00–1.04)
Trauma	
No	Reference
Yes	1.34 (1.33–1.36)
PIM2 score	1.16 (1.15–1.16)

PIM2 = Pediatric Index of Mortality 2

multifactorial. Noninvasive support may help avoid intubation in some pediatric patients.[14,16,18,19] However, the changes in the frequency of invasive and noninvasive support we observed were largely driven by increased use of noninvasive interventions, particularly HFNC (Table 1). Equipoise still exists regarding the impact HFNC has on intubation rates in pediatric patients compared to conventional oxygen therapy and other forms of noninvasive support.[20-22] Therefore, it is uncertain to what degree the increased proportion of noninvasive support is due to replacing intubation or increased access to noninvasive interventions, particularly HFNC.

Demographic changes over the study period may have contributed to the reduced frequency of invasive support as well. There was a decrease over the study period in the proportion of subjects < 1 month old and trauma cases, which we found to be factors associated with invasive support. This would be consistent with prior literature associating younger age and trauma with intubation.[23-25] However, the proportion of Black subjects increased, which was inversely associated with invasive support. The etiology of this association is unclear and likely multifactorial; although Black patients are more susceptible to critical illness, the prevalence of certain comorbidities such as asthma may deter clinicians from performing invasive interventions.[26,27] In addition, overall mortality decreased over the study period, likely reducing the frequency of invasive support necessary for critical conditions such as cardiac arrest. Lastly, mean PIM2 and PRISM3 scores decreased over the study period, signifying a possible increase in lower-acuity admissions to the pediatric ICUs or a practice pattern of admitting patients on HFNC to a pediatric ICU rather than a general care floor (Table 1).

Table 4. Risk Ratios for Invasive Respiratory Support Adjusted by PRISM3

	Adjusted Risk Ratio (95% CI)
Admission Year	
2009	Reference
2010	1.01 (0.98–1.03)
2011	0.98 (0.96–1.01)
2012	0.93 (0.91–0.95)
2013	0.93 (0.91–0.95)
2014	0.88 (0.86–0.91)
2015	0.85 (0.82–0.87)
2016	0.81 (0.79–0.83)
2017	0.76 (0.74–0.78)
Age	
< 1 month	Reference
1–23 months	0.78 (0.76–0.79)
2–5 y	0.72 (0.70–0.74)
6–12 y	0.72 (0.71–0.74)
13–18 y	0.77 (0.76–0.79)
> 18 y	
Sex	
Female	Reference
Male	1.00 (0.99–1.01)
Race	
White	Reference
Black	0.93 (0.91–0.94)
Hispanic	0.97 (0.96–0.99)
Other	1.07 (1.04–1.09)
Unknown	1.03 (1.01–1.04)
Trauma	
No	Reference
Yes	1.49 (1.47–1.51)
PRISM3 score	1.03 (1.03–1.03)

PRISM3 = Pediatric Risk of Mortality III

Nevertheless, these data are consistent with prior literature suggesting an overall increased use of noninvasive respiratory support.[11] Although new noninvasive modalities may contribute to this trend, first-line use of noninvasive respiratory support has been associated with a reduction in mortality, length of ventilation, length of pediatric ICU stay, and an increase in ventilator-free days.[15,28] In addition, critically ill pediatric patients overall who fail noninvasive respiratory support requiring intubation do not have greater peri-intubation adverse effects compared to patients who are primarily intubated.[29-31] However, an increased frequency of noninvasive respiratory support has also been associated with increased noninvasive failure rates.[11] Risk factors for noninvasive ventilation failure in pediatric patients include apnea, prematurity, pneumonia, bacterial co-infection, younger age, ARDS, high oxygen requirements, and history of intubation and cardiac disease.[14,25,32] Therefore, further research is needed to identify which critically ill pediatric patients would benefit from a primary invasive strategy versus a trial of noninvasive support.

Limitations

Our study had several limitations. First, we analyzed admissions with respiratory support and associated variables but not a temporal course for each admission. This creates ambiguity around the sequence of respiratory support procedures, such as which noninvasive interventions failed more often and resulted in invasive support. This may also have falsely elevated the frequency of invasive support by failing to capture patients who were tried on noninvasive support in the emergency department and either recovered prior to pediatric ICU admission or were intubated prior to admission to a pediatric ICU. In addition, 149 of 166 pediatric ICUs in the database were excluded using criteria indicating unreliable reporting of noninvasive data (Fig. 1). This was meant to limit biased data, but it may also limit the generalizability of the findings as internal procedures of each pediatric ICU may affect invasive and noninvasive support rates. Finally, our data lacked several confounding factors that may have explained a choice of invasive over noninvasive interventions including apnea, prematurity, bacterial co-infection, comorbidities, or ARDS.[14,25,32]

Conclusions

In this large, multicenter cohort of subjects admitted to pediatric ICUs requiring respiratory support, the frequency of invasive support decreased, while the frequency of noninvasive support increased. The frequency of noninvasive respiratory support is now greater than that of invasive support in critically ill pediatric patients in this cohort.

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