

Declining Procedures in Pediatric Critical Care Medicine Using a National Database

OBJECTIVES: To investigate the change in rate of invasive procedures (endotracheal intubation, central venous catheters, arterial catheters, and peripheral inserted central venous catheters) performed in PICUs per admission over time. Secondly, to investigate the change in type of respiratory support over time.

DESIGN: Retrospective study of prospectively collected data using the Virtual Pediatric Systems (VPS; LLC, Los Angeles, CA) database.

SETTING: North American PICUs.

PATIENTS: Patients admitted from January 2009 to December 2017.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: There were 902,624 admissions from 161 PICUs included in the analysis. Since 2009, there has been a decrease in rate of endotracheal intubations, central venous catheters placed, and arterial catheters placed and an increase in the rate of peripheral inserted central venous catheter insertion per admission over time after controlling for severity of illness and unit level effects. As compared to 2009, the incident rate ratio for 2017 for endotracheal intubation was 0.90 (95% CI, 0.83–0.98; $p = 0.017$), for central venous line placement 0.69 (0.63–0.74; $p < 0.001$), for arterial catheter insertion 0.85 (0.79–0.92; $p < 0.001$), and for peripheral inserted central venous catheter placement 1.14 (1.03–1.26; $p = 0.013$). Over this time period, in a subgroup with available data, there was a decrease in the rate of invasive mechanical ventilation and an increase in the rate of noninvasive respiratory support (bilevel positive airway pressure/continuous positive airway pressure and high-flow nasal oxygen) per admission.

CONCLUSIONS: Over 9 years across multiple North American PICUs, the rate of endotracheal intubations, central catheter, and arterial catheter insertions per admission has decreased. The use of invasive mechanical ventilation has decreased with an increase in noninvasive respiratory support. These data support efforts to improve exposure to invasive procedures in training and structured systems to evaluate continued competency.

KEY WORDS: central venous catheterization; critical care; intubation; medical education; pediatrics; peripheral arterial catheterization

Pediatric Critical Care Medicine (PCCM) intensivists need initially to learn and subsequently to maintain the skills necessary to provide both airway support and vascular access to critically ill patients. In a recent single-center study, we demonstrated a decline over time in the number of arterial catheter and central venous catheter (CVC) placed by pediatric critical care fellows during their training (1). It is possible there has been a

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decline in the rate of procedures performed in PICUs, in general, over time, due to an increase in noninvasive ventilation and use of peripherally inserted central catheters (PICCs). There is concern that performing fewer procedures over time may translate into decreased competency of physicians and in turn greater risk for patients.

Through reviewing the procedures performed in PICUs using a national database, we sought to assess our hypothesis that over time, invasive procedures performed in PICUs across North America have decreased. Our primary outcome was the change in the rate of invasive procedures performed per admission.

PATIENTS AND METHODS

The study was approved by our local institutional review board (Children's Hospital Los Angeles CHLA-18-00125). We performed a retrospective analysis of prospectively collected data using the Virtual Pediatric Systems (VPS; LLC, Los Angeles, CA) database from January 2009 to December 2017. Data from years that an ICU did not submit Pediatric Risk of Mortality (PRISM) III scores were excluded.

Data abstracted included the total number of admissions, procedures, types of respiratory support, and mean PRISM III scores per ICU per calendar year. All procedures recorded were noted to be placed in PICU and not present at admission.

To address the effect of change in procedures relative to concurring changes in the PICU workforce, we also extracted data from publications by the American Board of Pediatrics Physician Workforce.

Outcomes

Our primary outcome was the change in the rate of procedures per admission. Procedures included the following: endotracheal intubations, insertion of CVC, arterial catheters, and PICC. In a subgroup with respiratory support data available, we investigated the rate of use of types of respiratory support per admission including conventional mechanical ventilation (CMV), high-frequency oscillatory ventilation (HFOV), noninvasive respiratory support with pressure as bilevel positive airway pressure (BiPAP) and continuous positive airway pressure (CPAP), and noninvasive respiratory support without pressure as high-flow nasal oxygen (HFNO).

Statistical Analysis

Data are expressed as total counts, percentages, and medians (interquartile range). We used a line graph to demonstrate the change in percentage of procedures performed per admission over time. Count data were evaluated and found to be overdispersed with a variance much greater than mean value. Therefore, the data fit a negative binomial regression model. For multivariable analysis, we used a multilevel mixed effects negative binomial regression model adjusting for number of admissions and controlling for unit level effects. We present the incidence rate ratio (IRR) for the procedures performed as predicted from the regression model. Initial evaluation of data showed a change in the severity of illness measured with PRISM III over time. The multivariable analysis was repeated controlling for number of admissions, unit level effects, and mean value of PRISM III per unit per year. Year was treated as a categorical value modeled with the reference year of 2009.

RESULTS

In the VPS dataset there were 932,500 admissions from January 2009 to December 2017. After excluding admissions without unit specific yearly PRISM III data, there were 902,624 admissions available for analysis (**Table 1**). The number of contributing PICUs was greater than 100 for most of the years analyzed, and the median number of admissions per ICU per year was 842 (IQR, 433–1,387). Admissions per unit increased over time (2009 median 692 [IQR, 326–1,101], 2017 median 980 [IQR, 490–1,473]), and median PRISM per year decreased (2009 median 0.026 [IQR, 0.019–0.034], 2017 median 0.020 [IQR, 0.016–0.026]) (**Table 1**).

Rate of Procedures

Over the 9 years of the study, there was a decline in the percentage of intubations, CVC insertion, and arterial catheter insertion per admission, whereas percentage of PICC insertions per admission remained constant (**Table 1** and **Fig. 1**). In multivariable modeling, the IRR of intubations, CVC insertion, and arterial catheter insertion decreased, and the IRR of PICC insertion increased from 2009 to 2017 after controlling for unit level severity of illness per year

TABLE 1.
Admission, Pediatric Risk of Mortality III, Number of ICUs, and Procedural Data

Year	Admissions, <i>n</i>	No. of ICUs	Pediatric Risk of Mortality III, Median (IQR)	Intubations, %, Median (IQR)	Arterial Catheter, %, Median (IQR)	Central Venous Catheter, %, Median (IQR)	Peripherally Inserted Central Catheter, %, Median (IQR)
2009	59,543	76	0.026 (0.019–0.034)	10.4 (7.0–14.1)	10.6 (7.8–14.4)	11.5 (7.1–15.5)	5.9 (3.4–9.3)
2010	72,803	91	0.027 (0.020–0.037)	12.1 (8.1–16.1)	11.5 (7.8–17.8)	11.5 (7.6–16.4)	6.4 (2.9–10.9)
2011	89,650	92	0.026 (0.019–0.033)	10.4 (7.6–14.5)	10.7 (6.9–14.4)	10.2 (7.3–14.5)	6.4 (3.0–9.4)
2012	100,005	101	0.024 (0.018–0.033)	10.3 (6.8–16.2)	9.4 (6.4–15.7)	10.0 (6.4–14.1)	6.5 (3.2–10.5)
2013	105,611	108	0.022 (0.018–0.029)	10.0 (6.9–15.5)	9.4 (5.9–14.0)	9.1 (6.0–13.0)	6.4 (3.6–11.1)
2014	114,918	113	0.020 (0.017–0.028)	9.8 (6.3–14.7)	9.0 (6.1–12.9)	8.6 (5.8–12.2)	6.0 (3.8–10.5)
2015	122,490	115	0.022 (0.017–0.027)	10.0 (5.8–13.5)	9.0 (5.7–12.8)	8.1 (5.5–12.4)	6.0 (3.9–10.2)
2016	121,571	113	0.021 (0.016–0.025)	8.7 (5.3–12.6)	8.4 (4.4–12.2)	7.6 (4.5–11.2)	5.8 (3.3–9.7)
2017	116,033	106	0.020 (0.016–0.026)	8.7 (5.7–11.8)	8.7 (4.3–11.5)	7.5 (4.3–10.1)	5.2 (3.0–8.9)

IQR = interquartile range.

(PRISM III) as well as unit level effects (Table 2). These results were consistent when PRISM III was not included in the modeling (Supplemental Table 1, Supplemental Digital Content 1, <http://links.lww.com/CCX/A521>).

Rate of Respiratory Interventions

Over the 9 years of the study, in a subgroup with available data, there has been a decline in the percentage of admissions receiving CMV and HFOV (Table 3 and Fig. 2). In multivariable modeling, the IRR decreased from 2009 to 2017 for CMV and HFOV after controlling for initial severity of illness (PRISM III) as well as unit level effects (Table 4). In multivariable modeling, the IRR increased for noninvasive ventilation with either BiPAP/CPAP or HFNO from 2009 to 2017 after controlling for initial severity of illness (PRISM III) and unit level effects (Table 4). These results were consistent when PRISM III was not included in modeling

(Supplemental Table 2, Supplemental Digital Content 1, <http://links.lww.com/CCX/A522>).

Changes in PICU Workforce

From the American Board of Pediatrics Physician Workforce Data in 2009, there were 371 total fellows and 1,654 board-certified faculty less than 70 years old. By 2017, this increased 42% to 527 fellows and 35% to 2,234 faculty, a net increase of 36% (2, 3). Using a subset of our data for units that contributed to the dataset in both 2009 and 2017, although admissions increased by 63%, the net increase in procedures was less (intubations 50.4%, arterial catheters 35.4%, and CVC 7.3%) except for PICC catheters which increased by 94.7%.

DISCUSSION

Our study shows that over 9 years in North American PICUs, there has been a significant decrease in the

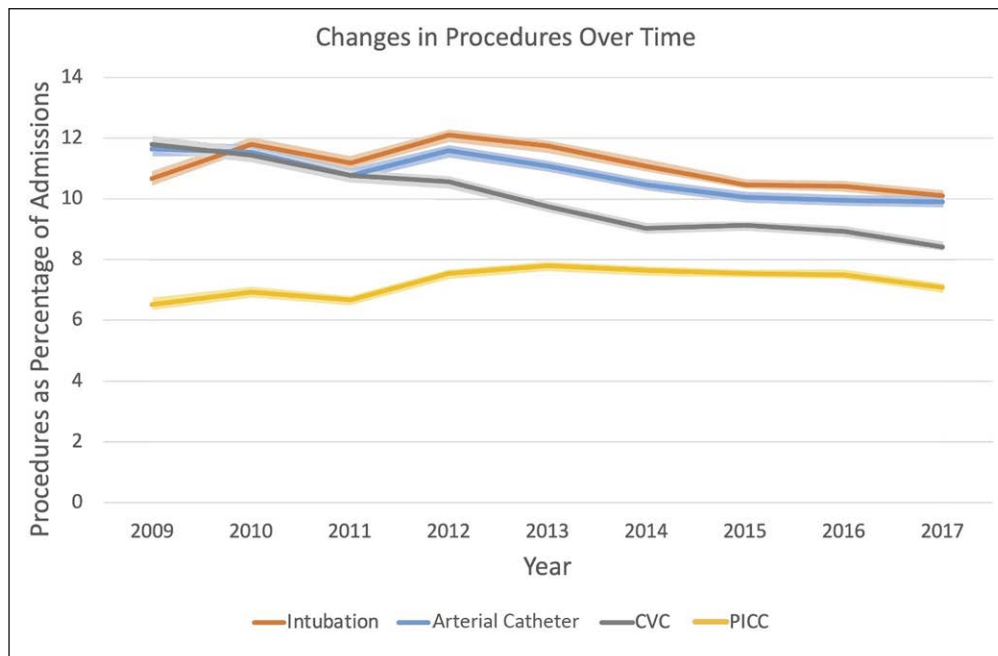


Figure 1. Change in procedures over the years 2009 to 2017. Data are shown as procedures performed as a percentage (solid line with 95% CI shaded) for all admissions that year. Included are intubation, arterial catheter placement, central venous catheter (CVC) placement, and peripherally inserted central catheter (PICC) placement.

rate of invasive procedures (endotracheal intubations, CVC insertions, and arterial catheter insertions) per admission. In the same time period, use of invasive ventilation has decreased, and noninvasive methods of respiratory support have increased. The decreasing intubations may reflect the change in practice patterns with rising noninvasive ventilation (4, 5). It is possible that the decline in arterial catheter placement reflects an acceptance of pulse oximetry and capnometry in the management of pediatric respiratory failure.

We believe our study has serious implications for the field of PCCM. There has been a decrease over time in the number procedures performed by residents (6, 7) well as by PCCM fellows (1). We have now demonstrated a decrease over time in procedures per admission for a large cohort of pediatric critical care units in the United States and Canada. Decreased opportunity to perform procedures may result in a delay in trainees achieving competency. Decreased procedures may also affect whether PCCM faculty are maintaining competency.

There has been an increase in the number of admissions to these PICUs over the 9 years of the study, so there is an overall larger number of total procedures, although procedures per admission has decreased. However, there has also been an increase in the number

of providers (trainees and faculty) in PCCM as indicated by the ABP Physician Workforce Data (2, 3). Further, this analysis does not include the likely increasing contribution of nurse practitioners, physician assistants, and airway rapid response team involvement in PICU procedures (8, 9). Although total procedures have increased, as providers have also increased, physicians may not have the same opportunity to perform invasive procedures that they did previously, most notably for CVC placement.

To address the concern regarding decreasing competence for intubations, there is a distinct benefit to first attempt tracheal intubation success. Increasing intubation attempts are associated with desaturation (10), and increased desaturations or increased tracheal intubation associated events are associated with longer length of mechanical ventilation and longer PICU stay (11). Stinson et al (12) showed that failure of first attempt intubation was independently associated with progression of acute respiratory compromise to cardiopulmonary arrest after controlling for confounding variables. The number of intubations needed in training to achieve high first attempt success varies greatly (26–76) between studies (13–15) as well as between individuals, so it is difficult to set one benchmark for training. Unfortunately for trainees in 2020, the emergence of the global pandemic caused by severe acute respiratory syndrome coronavirus 2 has likely further reduced their practical experience with intubation. The potential for aerosolization of the virus during endotracheal intubation may place the intubating physician at greater risk. This has increased the need for first attempt tracheal intubation success. Trainees may be less frequently allowed to intubate patients that are positive for coronavirus disease 2019 or when the patient status is unknown awaiting testing. The

TABLE 2.**Invasive Procedures (Intubations, Central Venous Catheter Placement, Arterial Catheter Placement, and Peripherally Inserted Central Catheter Placement) Over Time**

Year	Model No. 1		Model No. 2		Model No. 3		Model No. 4	
	Intubations		Central Venous Line		Arterial Catheter		Peripherally Inserted Central Catheter	
	IRR	<i>p</i>	IRR	<i>p</i>	IRR	<i>p</i>	IRR	<i>p</i>
2009	Reference		Reference		Reference		Reference	
2010	1.05 (0.96–1.14)	0.290	0.93 (0.86–1.01)	0.097	1.00 (0.92–1.08)	0.978	1.10 (0.99–1.22)	0.077
2011	0.97 (0.89–1.06)	0.542	0.87 (0.80–0.94)	0.001	0.92 (0.85–0.99)	0.033	1.04 (0.94–1.16)	0.395
2012	0.96 (0.88–1.04)	0.334	0.80 (0.74–0.86)	< 0.001	0.89 (0.83–0.96)	0.002	1.09 (0.99–1.21)	0.077
2013	0.95 (0.87–1.03)	0.235	0.77 (0.71–0.83)	< 0.001	0.86 (0.80–0.93)	< 0.001	1.17 (1.06–1.29)	0.002
2014	0.91 (0.83–0.99)	0.021	0.71 (0.66–0.77)	< 0.001	0.84 (0.78–0.91)	< 0.001	1.19 (1.07–1.31)	0.001
2015	0.92 (0.85–1.00)	0.051	0.74 (0.68–0.81)	< 0.001	0.87 (0.80–0.93)	< 0.001	1.21 (1.09–1.33)	< 0.001
2016	0.91 (0.83–0.99)	0.025	0.71 (0.66–0.78)	< 0.001	0.85 (0.79–0.92)	< 0.001	1.21 (1.09–1.33)	< 0.001
2017	0.90 (0.83–0.98)	0.017	0.69 (0.63–0.74)	< 0.001	0.85 (0.79–0.92)	< 0.001	1.14 (1.03–1.26)	0.013

IRR = incidence rate ratio.

Data are analyzed using multilevel mixed effects negative binomial regression model controlling for mean value of Pediatric Risk of Mortality III per unit per year for each individual outcome. Year is treated as a categorical value in the model, and the baseline value is 2009. The model controls for unit level effects addressing the issue that observations in the same ICU are correlated because they share common cluster-level random effects.

Committee on Occupational Health from the ASA has recommended “During laryngoscopy and intubation: ...Designate the most experienced anesthesia professional available to perform intubation, if possible” (16). How long this problem will remain and impact trainees is unknowable.

With the increasing number of trainees and declining number of intubations, we must consider how to fill this gap. There is some suggestion that simulation may improve skills (17, 18). There has also been a commitment to this type of education as the majority of PCCM fellowships incorporate simulation training in their curricula (19). Despite studies demonstrating benefit and the ubiquity in fellowships, there is

still concern that simulation training does not always translate to clinical improvement (20). Assessment of performance following simulation training is very good for procedures that have an anticipated progression or a checklist that can be followed. However, it is more difficult to assess whether the procedure was done well or smoothly and how well it would be performed in a difficult clinical situation.

Studies thus far have addressed only the development of procedural competency of PCCM trainees. The maintenance of competency among PCCM faculty needs to be considered in future studies and an ongoing conversation within the field. There are survey data from Pediatric Emergency Medicine Medical

TABLE 3.
Admission, number of ICUs and respiratory support data.

Year	No. of ICUs Overall	CMV, No. of Units	CMV, Median (IQR)	HFOV, No. of Units	HFOV, Median (IQR)	BiPAP/CPAP, No. of Units	BiPAP/CPAP, Median (IQR)	HFNO, No. of Units	HFNO, Median (IQR)
2009	76	72	13.6 (9.2–18.2)	61	1.1 (0.6–1.8)	51	7.6 (3.1–11.6)	41	8.4 (3.2–15.6)
2010	91	89	13.8 (9.8–21.4)	74	0.9 (0.4–1.7)	58	7.4 (2.6–11.6)	52	9.1 (3.4–20.5)
2011	92	91	13.5 (9.6–22.4)	82	0.9 (0.5–1.4)	56	6.3 (3.3–9.9)	52	13.8 (6.7–20.5)
2012	101	101	13.2 (8.9–21.5)	87	0.8 (0.4–1.5)	65	6.0 (3.9–9.9)	60	13.4 (6.9–20.7)
2013	108	107	13.4 (8.0–21.3)	83	0.9 (0.5–1.5)	70	7.3 (3.6–11.3)	63	14.7 (9.3–24.2)
2014	113	110	12.4 (8.0–18.9)	84	0.6 (0.4–1.3)	72	7.8 (3.8–12.8)	70	14.2 (8.2–22.5)
2015	115	112	11.4 (7.0–16.1)	86	0.7 (0.4–1.1)	74	8.5 (4.0–13.9)	71	14.5 (8.6–22.2)
2016	113	110	10.0 (6.4–14.4)	84	0.7 (0.3–1.3)	93	8.1 (3.0–12.8)	82	13.6 (8.6–21.6)
2017	106	106	9.5 (6.6–13.4)	84	0.6 (0.3–1.0)	105	8.3 (5.3–14.2)	101	13.3 (9.9–21.6)

BiPAP = bilevel positive airway pressure, CMV = conventional mechanical ventilation, HFNO = high-flow nasal O₂, HFOV = high-frequency oscillatory ventilation. IQR = interquartile range.

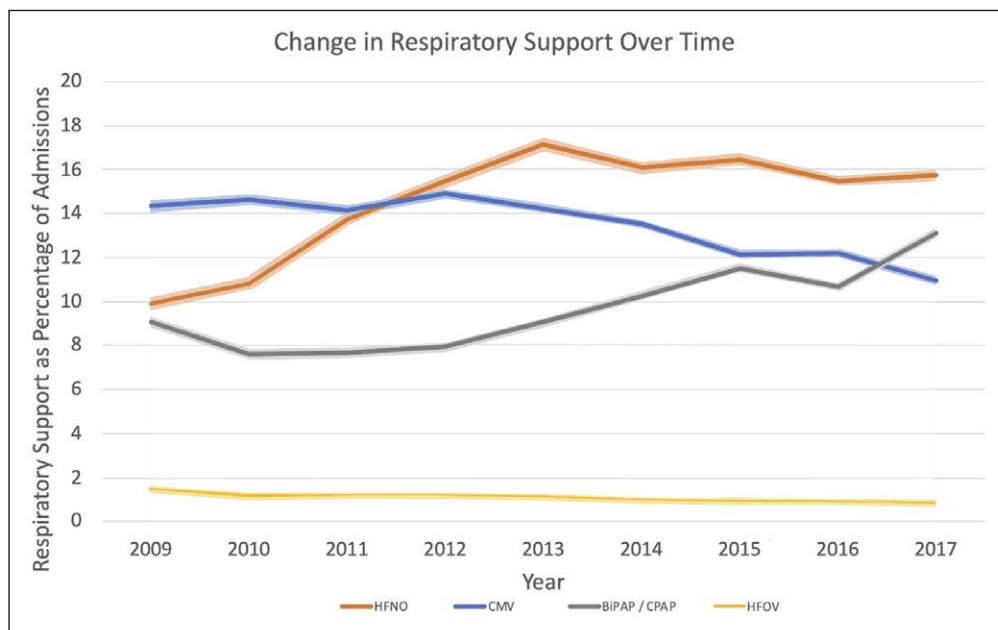


Figure 2. Change in respiratory interventions over the years 2009 to 2017. Data are shown as type of respiratory support used as a percentage (solid line with 95% CI shaded) for all admissions that year. Included are conventional mechanical ventilation (CMV), high-frequency oscillatory ventilation (HFOV), high-flow nasal oxygen (HFNO), and bilevel positive airway pressure (BiPAP)/continuous positive airway pressure (CPAP).

Directors where 62% felt the number of tracheal intubation opportunities were insufficient to maintain competency among their faculty (21). There is no literature indicating whether PICU faculty are performing enough intubations to remain competent. The same arguments as for maintaining competency for tracheal intubation apply to placement of arterial catheter and CVC. In short, we may be doing fewer procedures per admission and must worry about acquiring and maintaining our skills. Simulation may help, but it is imperfect and

needs refinement to reflect real world conditions with anatomy that varies. Simulation also needs outcome measures that reflect the clinical environment. Finally, as to the documentation of the maintenance of our skills, currently, there is no assessment of procedural skills (including mechanical ventilation in diverse clinical situations) required to maintain American Board of Pediatrics Critical Care certification. This is counter to the American Board of Anesthesiologists which requires a simulation course to complete Maintenance of Certification in Anesthesiology. This requirement should be addressed going forward for PCCM.

Our study has several limitations. First, we have only aggregate data for institutions and year. We unfortunately did not have individual patient-level data nor individual procedures for each provider over time. It is possible that an individual patient may have had multiple procedures or admissions. We cannot verify the accuracy of the reporting as it occurs at the level of the contributing PICUs. However, many institutions such as ours will have trained individuals specifically employed to contribute data to this registry. Further, there is no large multiinstitutional existing dataset with this level of detail to our knowledge, and this analysis may represent the most detailed assessment possible

TABLE 4.

Incidence Rate Ratio for Procedures and Respiratory Interventions Over Time for the Entire Virtual Pediatric Systems Population.

Year	Model No. 1		Model No. 2		Model No. 3		Model NO. 4	
	Conventional Mechanic Ventilation		High-Frequency Oscillatory Ventilation		Bilevel Positive Airway Pressure/Continuous Positive Airway Pressure		High-Flow Nasal O ₂	
	IRR	<i>p</i>	IRR	<i>p</i>	IRR	<i>p</i>	IRR	<i>p</i>
2009	Reference		Reference		Reference		Reference	
2010	1.03 (0.94–1.14)	0.503	0.79 (0.66–0.95)	0.10	0.88 (0.70–1.09)	0.241	1.10 (0.85–1.42)	0.492
2011	0.97 (0.88–1.07)	0.514	0.72 (0.61–0.86)	< 0.001	0.85 (0.68–1.06)	0.156	1.37 (1.06–1.78)	0.018
2012	0.96 (0.87–1.06)	0.400	0.66 (0.56–0.79)	< 0.001	0.94 (0.75–1.17)	0.581	1.58 (1.22–2.04)	0.001
2013	0.95 (0.87–1.05)	0.339	0.66 (0.55–0.79)	< 0.001	1.07 (0.86–1.33)	0.546	1.84 (1.42–2.38)	< 0.001
2014	0.89 (0.81–0.98)	0.017	0.57 (0.46–0.65)	< 0.001	1.09 (0.87–1.35)	0.458	1.76 (1.37–2.27)	< 0.001
2015	0.84 (0.76–0.92)	< 0.001	0.55 (0.46–0.65)	< 0.001	1.25 (1.01–1.56)	0.041	1.98 (1.54–2.56)	< 0.001
2016	0.82 (0.75–0.91)	< 0.001	0.56 (0.47–0.67)	< 0.001	1.27 (1.03–1.57)	0.026	1.97 (1.53–2.53)	< 0.001
2017	0.77 (0.70–0.86)	< 0.001	0.53 (0.44–0.64)	< 0.001	1.72 (1.39–2.13)	< 0.001	2.47 (1.91–3.18)	< 0.001

IRR = incidence rate ratio.

Data are analyzed using multilevel mixed effects negative binomial regression model controlling for mean value of Pediatric Risk of Mortality III per unit per year for each individual outcome. Year is treated as a categorical value in the model and the baseline value is 2009. The model controls for unit level effects addressing the issue that observations in the same ICU are correlated because they share common cluster-level random effects.

of procedures over time in pediatric critical care. It is possible that if we had provider level data, our results would be different. Second, for some measures, not all units presented data to VPS for every year, and this could have biased our results. As example, HFNO became a mandatory field only in mid-2017. Fortunately, for intubations, CVC, arterial catheters, and invasive mechanical ventilation, we have very little missing data over the period 2009–2017.

We have demonstrated a decline in the number of procedures performed as well as the use of HFOV and CMV with a rise in noninvasive support. For our trainees, we need to discuss how we can demonstrate that they have achieved proficiency. Do we need to set a minimum number of successful intubations during fellowship? Should we be conferring a certificate of competency for HFOV and CMV at the conclusion of their fellowship? It is also important to note that we did not have data to assess changes in practice on placement of chest tubes. We believe that this is also decreasing and needs to be considered. Consider that although the California Children's Services PICU Standards (1999), the American Academy of Pediatrics Guidelines (2004), and Society of Critical Care Medicine Practice Statement (2019), all stress competence in placing chest tubes and the former require documentation annually, none specify the numbers expected to maintain such competence assuming it was ever attained in training (22–24). Finally, we must as group discuss the means of maintaining and certifying competency in our PCCM faculty.

CONCLUSIONS

Over the 9 years of this study of North American PICUs, there has been a significant decrease in the rate of intubations, CVC insertions, and arterial catheter insertions and an increase in PICC insertions per admission. There has also been a significant decrease in the use of invasive mechanical ventilation which was offset by an increase in noninvasive means of respiratory support. These data have significant implications for the development and maintenance of procedural skills in the field of PCCM.

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (<http://journals.lww.com/ccxjournal>).

Drs. Ross, Engorn, Newth, and Bhalla conceptualized and designed the study. They also participated in the acquisition, analysis, and interpretation of data. They participated in the drafting and revising of the article critically for important intellectual content including final approval of the version to be published. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Ms. Gordon and Dr. Soto-Campos conceptualized and designed the study. They also participated in the acquisition, analysis, and interpretation of data. They participated in the revising of the article critically for important intellectual content including final approval of the version to be published. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

The authors have disclosed that they do not have any potential conflicts of interest.

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