Trends in Time to Extubation for Pediatric Postoperative Cardiac Patients and Its Correlation With Changes in Clinical Outcomes: A Virtual PICU Database Study*

Rebecca Epstein, MD[1]
Shelley J. Ohliger, MD[2]
Ira M. Cheifetz, MD, FCCM[3]
Sindhoosha Malay, MPH, PharmD[4]
Steven L. Shein, MD, FCCM[3]

OBJECTIVES: Mechanical ventilation is often used in children after cardiac surgery but can impair hemodynamics and cause lung injury. Early extubation may improve ICU length of stay and survival. We aimed to describe trends in early extubation rates and evaluate if centers that more commonly practice early extubation have better severity-adjusted outcomes.

DESIGN: Retrospective analysis was performed of admissions in the Virtual Pediatric Systems (VPS, LLC) database from 2009 to 2018. Early extubation was defined as patients extubated in the operating room or within 6 hours of PICU admission.

SETTING: PICUs participating in the VPS database.

PATIENTS: Children in the VPS database who underwent cardiac surgery.

INTERVENTIONS: None.

MEASUREMENT AND MAIN RESULTS: Among 69,739 subjects, 20% were neonates, 47% underwent early extubation, 5.3% failed extubation, and 2.5% died. Overall, early extubation rates did not change over the study period. Centers were placed in one of four groups based on their early extubation rate in lower complexity surgeries. Centers that most commonly used early extubation had more ICU-free time among all patients in univariable analysis (lowest early extubation group, 23.8 d [interquartile range, 18.2–25.9 d]; highest early extubation group, 24.7 d [20.0–26.2 d]; $p < 0.001$). After adjusting for center volume, sex, age, surgical complexity, and preoperative ICU admission, increasing center-level early extubation rates were not associated with more ICU-free days. Higher center-level early extubation rate was not associated with mortality in univariable or multivariable analysis but was associated with decreased extubation failure rate (lowest early extubation group, 6.4%; highest early extubation group, 3.6%; $p < 0.001$).

CONCLUSIONS: In this large, multicenter database study, early extubation rates in postoperative cardiac patients did not significantly change between 2009 and 2018. Centers that performed early extubation more frequently did not have shorter ICU stays or difference in mortality rates but did have lower reintubation rates.

KEY WORDS: early extubation; ICU length of stay; mortality; pediatric cardiac surgery

Children recovering from cardiac surgery in a PICU often receive invasive mechanical ventilation for multiple indications, including maintaining adequate oxygenation and ventilation, reducing left ventricular afterload, and decreasing metabolic demands (1, 2). However, mechanical ventilation may be associated with negative sequelae such as decreased systemic venous return, increased exposure to sedative medications (3), ventilator-induced lung injury (4), and nosocomial infection (5, 6). Minimizing exposure

***See also p. 566.**

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to mechanical ventilation after cardiac surgery may be beneficial and has been associated with improved outcomes, including decreased PICU length of stay (7–10), decreased ventilator associated complications (11), and increased overall survival (8, 12). These possible benefits of reducing duration of mechanical ventilation must be weighed against the risks of premature extubation that requires reintubation, which is associated with increased mortality, longer PICU length of stay, and longer hospital length of stay (13, 14).

Favorable clinical outcomes have been associated with early extubation (EE) in postoperative cardiac patients, predominantly in single-center studies (11, 12, 15). Because of the potential benefits of EE, consortiums such as the Pediatric Heart Network Collaborative implemented clinical practice guidelines to promote EE after selected surgeries, which at least temporarily increased EE rates and may have modestly improved ICU length of stay after certain operations (16). Based on the these data and other research showing that EE is often feasible in children undergoing cardiac surgery (10, 17, 18), a recent 2021 consensus statement from the American Association for Thoracic Surgery emphasized that EE is an "integral component" to enhanced postoperative recovery (19). However, it is unknown if there are widespread trends in EE rates over recent years or if centers that more commonly practice EE have better severity-adjusted outcomes, and a recent multicenter study suggested that EE may in fact be associated with longer PICU length of stay (20). We aimed to use the Virtual Pediatrics System (VPS, LLC) "Virtual PICU" database to describe trends in EE rates over time and evaluate if centers' EE rates are associated with improved clinical outcomes in children undergoing cardiac surgery.

MATERIALS AND METHODS

This study was reviewed and approved by the Institutional Review Board of University Hospitals of Cleveland and the review board for the VPS, LLC. STUDY20180059. VPS data were provided by VPS, LLC. No endorsement or editorial restriction of the interpretation of these data or opinions of the authors has been implied or stated. This article has been reviewed by the VPS Research Committee.

Data Source

VPS is the largest collaborative PICU quality improvement database, includes data from over 120 general and cardiac PICUs, and has been used to support previous research in children convalescing from cardiac surgery (21). Trained data coordinators at participating sites prospectively collect mandatory information on subjects including demographics, primary diagnosis, endotracheal intubation, ICU mortality, and ICU length of stay. Each institution can also report other nonmandatory variables, including performance of specific cardiac operative procedures categorized by the Society of Thoracic Surgeons (STS) and the Risk Adjustment for Congenital Heart Surgery (RACHS) score (22, 23).

Subjects

All children in the VPS database less than 18 years old who were admitted between January 2009 and December 2018 were included in the initial dataset if they had an operative cardiac procedure directly prior to or during their ICU admission. Patients were not included in the initial dataset if they had a tracheostomy prior to PICU admission or a diagnosis of heart transplant. Data from centers with fewer than 35 subjects during the study period were excluded, as these low-volume centers had a high prevalence of pericardial drains, persistent ductus arteriosus ligations, and pacemaker procedures, whereas the centers with more cases had more classic congenital heart disease surgeries that are more generalizable to other centers. Additionally, individual subjects were excluded from the final analysis if: 1) they had no documented STS cardiac surgery procedure, 2) their cardiac surgery start time was greater than 24 hours prior to PICU admission as this implied that immediate postoperative care took place in another unit, 3) they had endotracheal intubation procedures that were missing a start and stop time, or 4) they had irrational data (e.g., reported intubation start time after reported intubation end time). Per VPS policy, age at PICU admission was reported as a categorical variable (e.g., <29 d and 29 d to <2 yr).

Study Definitions

For all subjects, we collected demographics; clinical outcomes; RACHS score; and times of endotracheal tube (ETT) insertions, ETT removals, start of cardiac surgery, and ICU discharge (or death). Some procedures are not scored by the RACHS system due to lack of consensus or intentional exclusion (22), and for these procedures, VPS assigns an RACHS score of zero. Subjects missing an RACHS score (11% of subjects) were assigned an RACHS score by an author (R.E.) using the RACHS scoring algorithm (23).

Times of all events in the VPS database are referenced to a "time zero" defined by VPS as the day and time of initial admission to the PICU. Children who presented to the PICU only after undergoing cardiac surgery, therefore, had a reported surgery start time less than zero (e.g., −4 hr) and an exactly known postoperative ICU admission time (i.e., time zero). For children who were admitted to the PICU preoperatively, the cardiac surgery start time was reported (e.g., +3.23 d), but the exact time that the child returned to the PICU postoperatively is not available in the VPS database. For these children, the postoperative ICU admission time was estimated by using the child's cardiac surgery start time and the average surgery duration among all children in the study database with the same RACHS score (see **Supplemental Table 1**, http://links.lww.com/PCC/C27). For example, a child who was admitted to the PICU preoperatively and then underwent an RACHS-3 procedure with a reported start time of 3.23 days would have an estimated postoperative PICU admission time of 3.23 + 0.27 = 3.50 days.

EE was defined as removal of the ETT before or within 6 hours of arriving in the PICU after their surgery (12, 20). Use of an ETT only while in the operating room is not collected in VPS, so all subjects with no intubations reported in the database were considered to have undergone EE by the anesthesia team prior to PICU admission. Among children with an ETT in place at the time of postoperative PICU admission, EE was defined as any reported ETT removal within 6 hours of postoperative admission time. Subjects who did not meet either of these criteria were considered to have a late extubation. Failed extubation was defined as reintubation within 48 hours of ETT removal (24, 25). This includes patients who arrived in the PICU extubated but underwent intubation within the first 48 hours following postoperative PICU admission.

Centers were grouped based on both volume of patients and EE rate. Center volume was assessed by dividing the total number of subjects from that center in the dataset by the number of years that the center contributed data during the study period. Centers were then categorized as small (<150 cases/yr), medium (150–300 cases/yr), or large (>300 cases/yr) volume centers (26). Each center was always considered in the same volume group for all study years, regardless of the number of patients for that particular year.

To categorize centers by EE rate, we measured the EE rate at each center during each individual study year among children undergoing low-moderate complexity surgeries (i.e., RACHS 1–3). For each study year, each center was then categorized as being a very frequent (>62% of low-moderate complexity patients underwent EE), frequent (>48-62%), common (>38-48%), or uncommon (≤38%) EE center, with those cutoffs selected to roughly divide the entire cohort into equal sized quartiles. Each center could be considered in different EE quartiles in different years depending on the actual rate of EE in low-moderate complexity surgeries for that year.

Outcomes and Analyses

Variables were compared between the four groups of centers (very frequent, frequent, common, and uncommon EE) using chi-square for categorical variables and Kruskal-Wallis analysis of variance (ANOVA) for continuous variables (with Dunn test for pairwise comparisons).

The primary outcome was the rate of EE over time. Only centers that submitted data for at least eight of the 10 years were included in this analysis. Logistic regression with center effect was used to evaluate if the rate of EE changed significantly over the study period. This analysis was repeated for subgroups based on center volume (small, medium, and large), RACHS score, and patient age.

The secondary aim of the study was to identify associations between EE and clinical outcomes. The clinical outcomes assessed were mortality and the number of PICU-free days in a 28-day period (with a value of zero for children who died or had PICU length of stay >28 d). First, factors associated with clinical outcomes were identified using standard statistical tests (chi-square to compare rates between groups, Wilcoxon rank-sum or Kruskal-Wallis ANOVA to compare continuous variables between groups, and Spearman correlation to compare two continuous variables [e.g., weight and PICU-free days]). Poisson (PICU-free days) and logistic (mortality) nested regression models were then performed to identify variables independently associated with that outcome.

Sensitivity Analyses

The initial multivariable models, which used RACHS score to quantify patient complexity, were then rerun after replacing RACHS score with the Pediatric Index of Cardiac Surgical Intensive Care Mortality (PICSIM) score, which additionally incorporates severity of illness at PICU admission into the overall mortality risk (27).

Next, to test if our analyses were influenced by estimating the PICU admission time for children who had been admitted to the PICU preoperatively, the univariable analyses were repeated after excluding subjects with an estimated time of postoperative PICU admission and the models recreated as described above.

Statistical analyses were performed using SigmaPlot Version 12.5 (Systat Software, San Jose, CA) and the SAS software Version 9.4 (SAS Institute, Cary, NC). A p value of less than 0.05 was considered significant after using the Bonferroni correction for multiple comparisons. Data are shown as n (%) or median (interquartile range).

RESULTS

Of the 73,096 subjects initially extracted from the VPS database, 69,739 subjects (95.4%) at 79 centers were included for analysis after applying exclusion criteria (**Fig. 1**), including 52,804 who underwent a procedure with an RACHS score of 1–3 and were used to group centers into the four EE groups. The EE rates including all subjects (i.e., RACHS 0–6) were 70.9%, 49.4%, 40.6%, and 28.1% ($p < 0.001$), respectively, for the very frequent, frequent, common, and uncommon EE centers (**Table 1**). Demographics, RACHS scores, and center volume differed between the four EE groups, as did failed extubation rates (very frequent, 3.6%; frequent, 5.3%; common, 6.1%; and uncommon, 6.4%; $p < 0.001$).

As seen in **Figure 2*A***, among all subjects, there was no significant change in EE rates over time for centers (n = 33) with at least 8 years of data (2009, 48%; 2018, 47%). There was also no significant change in EE rates when stratifying subjects by center volume size (**Fig. 2*B***). When subjects were stratified by RACHS score (**Fig. 2*C***) and age (**Fig. 2*D***), RACHS class 3 subjects and children 2–11 years old had statistically significant changes in EE rates over time, though the absolute differences were small.

In univariable analysis, hospitalization in centers that more commonly practice EE was associated with more PICU-free days (**Table 2**). In pairwise comparisons, uncommon EE centers had fewer PICU-free days than each of the other three groups, and very frequent EE centers had more PICU-free days than each of the other three groups. Weight (ρ = 0.5; $p < 0.001$), center case volume, demographics, discharge year, and RACHS score were also associated with PICU-free days and were included in the multivariable logistic regression model. After adjusting for these covariates, hospitalization in a very frequent, frequent, or common EE center was not associated with more PICU-free days compared with hospitalization at an uncommon EE center. As shown in **Table 3**, mortality rates did not differ significantly between the four EE groups in univariable analysis or after adjusting for potential confounders in the multivariable analysis.

When PICSIM was used instead of RACHS in the multivariable models, EE group was again not associated with PICU-free days or mortality (**Supplemental Table 2**, http://links.lww.com/PCC/C28; and **Supplemental Table 3**, http://links.lww.com/PCC/C29). When children with an inexact time of ICU admission were excluded and the models recreated, EE group continued to be associated with PICU-free days in univariable analysis (**Supplemental Table 4**, http://links.lww.com/PCC/C30). In multivariable analysis, common EE centers were associated with more PICU-free days (increase of 2.5% [95% CI, 0.1–4.9%]), but neither frequent nor very frequent centers were associated with PICU-free

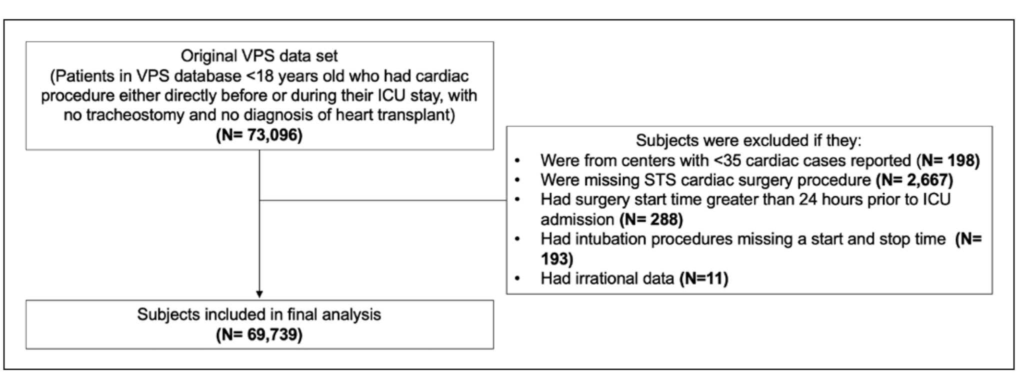

Figure 1. Flowchart showing the number of subjects included in the final analysis after applying inclusion and exclusion criteria. STS = Society of Thoracic Surgeons, VPS = Virtual Pediatric Systems.

TABLE 1.
Patient Characteristics by Early Extubation Category

Variable	All Centers (*n* = 69,739)	Uncommon Early Extubation (*n* = 18,002)	Common Early Extubation (*n* = 17,038)	Frequent Early Extubation (*n* = 17,486)	Very Frequent Early Extubation (*n* = 17,213)	*p*
Gender						
Male	38,594 (55.3)	9,804 (54.5)	9,573 (56.2)	9,576 (55.8)	9,461 (55.0)	0.013
Female	31,137 (44.6)	8,197 (45.6)	7,463 (43.8)	7,726 (44.2)	7,751 (45.0)	
Ambiguous	8 (0.0)	1 (0.0)	2 (0.0)	4 (0.0)	1 (0.0)	
Age						
<29 d	14,009 (20.1)	3,695 (20.5)	3,417 (20.1)	3,521 (20.1)	3,376 (19.6)	< 0.001
29 d to 1 yr	30,093 (43.2)	8,117 (45.1)	7,538 (43.2)	7,454 (42.6)	7,164 (41.6)	
2–5 yr	12,123 (17.4)	2,937 (16.3)	2,913 (17.1)	3,088 (17.7)	3,185 (18.5)	
6–11 yr	6,966 (10.0)	1,717 (9.5)	1,721 (10.1)	1,719 (9.8)	1,809 (10.5)	
12–17 yr	6,548 (9.4)	1,536 (8.5)	1,629 (9.6)	1,704 (9.7)	1,679 (9.8)	
Weight	7.1 (4.1–15.9)	6.9 (4.0–15.0)[b,c,d]	7.0 (4.1–16.0)[a,d]	7.2 (4.2–16.1)[a]	7.5 (4.2–16.6)[a,b]	< 0.001
Risk Adjustment for Congenital Heart Surgery score						
1	8,144 (11.7)	1,863 (10.3)	1,943 (11.4)	2,042 (11.7)	2,296 (13.3)	< 0.001
2	24,748 (35.5)	6,371 (35.4)	6,024 (35.4)	6,269 (35.9)	6,084 (35.4)	
3	19,915 (28.6)	5,296 (29.4)	4,931 (29.0)	4,929 (28.2)	4,759 (27.7)	
4	5,301 (7.6)	1,422 (7.8)	1,364 (8.0)	1,361 (7.8)	1,154 (6.7)	
5 and 6	2,582 (3.7)	660 (3.7)	635 (3.7)	621 (3.6)	666 (3.9)	
0	9,049 (13.0)	2,390 (13.3)	2,141 (12.6)	2,264 (13.0)	2,254 (13.1)	
Pediatric Index of Cardiac Surgical Intensive Care Mortality score	0.006 (0.003–0.02)	0.007 (0.003–0.02)[b,c,d]	0.006 (0.003–0.02)[a,c,d]	0.006 (0.002–0.02)[a,b,d]	0.005 (0.002–0.02)[a,b,c]	< 0.001
Center case volume						
Small	24,415 (35.0)	4,864 (27.0)	6,238 (36.3)	6,329 (36.2)	6,984 (40.6)	< 0.001
Medium	26,802 (38.4)	9,219 (51.2)	7,217 (42.3)	6,005 (34.3)	4,361 (25.3)	
Large	18,522 (26.5)	3,919 (21.8)	3,583 (21.0)	5,152 (29.5)	5,868 (34.1)	
ICU admission >2 d before surgery	8,333 (11.9)	2,129 (11.8)	2,040 (12.0)	2,009 (11.5)	2,155 (12.5)	0.026
Extubated early	32,793 (47.0)	5,051 (28.1)	6,909 (40.6)	8,630 (49.4)	12,203 (70.9)	< 0.001
Failed extubation	3,712 (5.3)	1,144 (6.4)	1,031 (6.1)	926 (5.3)	611 (3.6)	< 0.001
Discharge year						
2009	3,862 (5.5)	1,161 (6.4)	818 (4.7)	661 (3.8)	1,222 (7.1)	< 0.001
2010	5,622 (8.1)	2,729 (15.2)	907 (5.3)	885 (5.1)	1,101 (6.4)	
2011	7,066 (10.1)	2,702 (15.0)	1,120 (6.6)	1,912 (10.9)	1,332 (7.7)	
2012	9,044 (13.0)	2,957 (16.4)	2,177 (12.8)	1,798 (10.3)	2,112 (12.3)	
2013	9,372 (13.4)	1,766 (9.8)	2,814 (16.5)	2,119 (12.1)	2,673 (15.5)	
2014	9,083 (13.0)	1,826 (10.1)	2,749 (16.1)	2,102 (12.0)	2,406 (14.0)	
2015	7,024 (10.1)	1,791 (10.0)	1,309 (7.7)	2,234 (12.8)	1,690 (9.8)	
2016	6,726 (9.6)	1,231 (6.8)	2,283 (13.4)	1,618 (9.3)	1,594 (9.3)	
2017	6,578 (9.4)	1,119 (6.2)	769 (4.5)	3,048 (17.4)	1,642 (9.5)	
2018	5,362 (7.7)	720 (4.0)	2,092 (12.3)	1,109 (6.3)	1,441 (8.4)	

Data are shown as *n* (%) and median (interquartile range). Superscript symbols denote the statistically significant ($p < 0.05$) pairwise comparisons for each category. Early extubation category: [a]uncommon, [b]common, [c]frequent, and [d]very frequent.

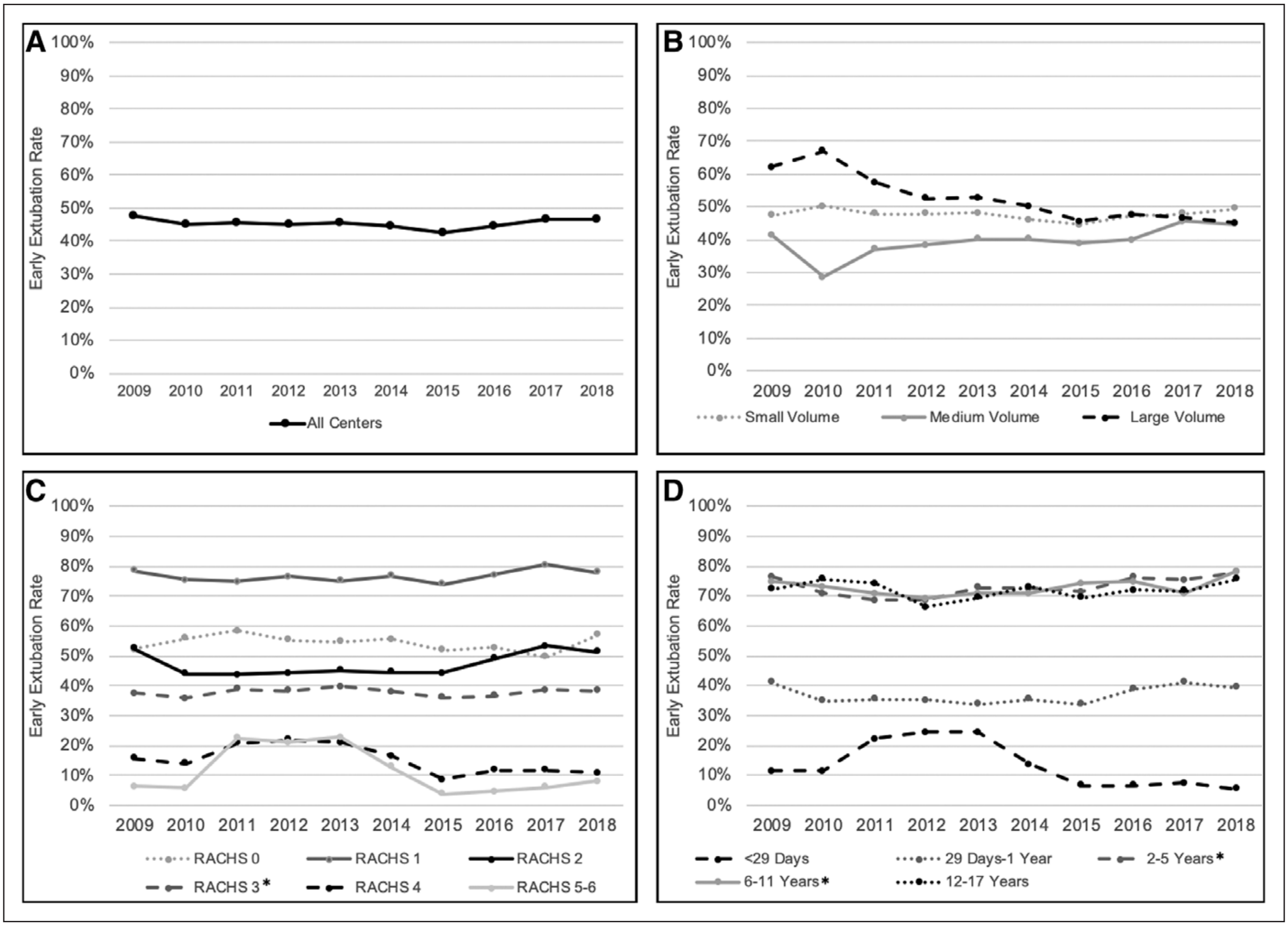

Figure 2. Graphic trends of early extubation rates between 2009 and 2018 for centers with at least 8 yr of data. **A**, Annual early extubation rates for all centers. Early extubation rate data were also stratified by center case volume (**B**), Risk Adjustment for Congenital Heart Surgery (RACHS) score (**C**), and age (**D**). Statistically significant trends over the 10-yr period (with $p < 0.05$) are denoted by an *asterisk* in the legend of each figure.

days. In this subgroup, EE group was again not associated with mortality (**Supplemental Table 5**, http://links.lww.com/PCC/C31).

DISCUSSION

In this large, multicenter database of critically ill children who underwent cardiac surgery between 2009 and 2018, we found that EE rates have not significantly changed over time, including in most subgroups defined by patient age, surgical complexity, or center volume. Centers that more commonly practice EE among their lower complexity patients had no improvement in ICU length of stay or mortality after adjusting for center- and patient-level variables. Extubation failure rates were lowest at the very frequent EE centers. Overall, this does not support that clinical outcomes can be improved by increasing EE at the center level, but further studies are needed to test if EE can be part of a bundle of care that improves outcomes.

We are unaware of other contemporary multicenter assessments that could confirm our finding that EE rates have not increased over the past decade regardless of age, surgical complexity, or center volume, but the consistency of this observation among all subgroups we evaluated supports its validity. This is despite many single-center and multicenter reports showing that EE is feasible in most postoperative cardiac patients, even in younger children with complex cardiac lesions (28–32), and a recent consensus statement from the American Association for Thoracic Surgery stating that EE is an "integral component" to enhance postoperative recovery in children (19).

Although the reasons why EE rates have stagnated are not answerable by our study, it is important to consider what factors could have influenced this trend,

TABLE 2.
Univariable and Multivariable Analyses of Factors Associated With PICU-Free Days

Category	PICU-Free Days (Median [25–75th percentile])	Univariate *p*	Relative Difference in PICU-Free Days in Multivariate Model (% Difference [95% CI])
Early extubation category			
Uncommon	23.8 (18.2–25.9)[+^#]	< 0.001	(Reference)
Common	24.1 (19.0–26.1)[*#]		1.6 (−0.9 to 4.2)
Frequent	24.1 (19.1–26.0)[*#]		1.7 (−1.5 to 5.0)
Very frequent	24.7 (20.0–26.2)[*+^]		3.4 (−1.4 to 8.4)
Center case volume			
Small	23.9 (18.9–25.9)[+^]	< 0.001	(Reference)
Medium	24.1 (19.0–26.1)[*]		3.6 (−1.0 to 8.3)
Large	24.2 (19.6–26.1)[*]		6.6 (1.3–12.2)
Gender			
Male	24.0 (19.0–26.0)	< 0.001	0.5 (−0.1 to 1.0)
Female	24.1 (19.2–26.0)		(Reference)
Age			
< 29 d	16.3 (3.9–21.9)[+^#✧]	< 0.001	−24.8 (−27.6 to −21.9)
29 d to 1 yr	23.9 (19.9–25.9)[*^#✧]		−13.6 (−14.7 to −12.6)
2–5 yr	25.8 (23.9–26.8)[*+#✧]		−2.9 (−3.9 to −1.9)
6–11 yr	25.9 (24.3–26.9)[*+^]		−0.3 (−1.0 to 0.3)
12–17 yr	25.9 (24.1–26.9)[*+^]		(Reference)
Risk Adjustment for Congenital Heart Surgery score			
1	26.0 (24.8–26.9)[+^#✧X]	< 0.001	(Reference)
2	24.9 (21.9–26.1)[*^#✧X]		−1.8 (−2.6 to −1.0)
3	23.0 (17.2–25.8)[*+#✧X]		−12.3 (−13.7 to −10.9)
4	18.4 (9.1–22.9)[*+^✧X]		−19.2 (−21.1 to −17.3)
5 and 6	5.9 (0.0–15.5)[*+^#X]		−50.4 (−55.6 to −44.5)
0	24.7 (19.1–26.3)[*+^#✧]		−10.7 (−11.9 to −9.4)
ICU admission >2 d before surgery			
No	24.9 (21.3–26.1)	< 0.001	(Reference)
Yes	10.7 (0.0–17.2)		−46.9 (−49.8 to −43.7)
Discharge year			
2009	24.1 (20.0–26.0)[$†]	< 0.001	(Reference)
2010	24.2 (20.3–26.1)[#✧X$✓&†]		0.2 (−1.6 to 1.9)
2011	24.1 (19.3–26.0)[$†]		−0.9 (3.0 to 1.3)
2012	24.0 (18.9–26.0)[+]		−1.6 (−4.5 to 1.4)
2013	24.1 (19.1–26.1)[+$†]		−2.2 (−5.1 to 0.9)
2014	24.0 (19.0–26.1)[+$†]		−1.9 (−4.9 to 1.2)
2015	24.0 (18.3–26.0)[*+^✧X]		−2.7 (−6.0 to 0.8)
2016	24.0 (18.9–26.0)[+]		−1.7 (−4.8 to 1.4)
2017	24.0 (19.0–26.0)[+†]		−2.4 (−5.9 to 1.1)
2018	23.9 (18.8–25.9)[*+^✧X&]		−3.8 (−7.1 to −0.3)

The correlation coefficient for weight was 0.5 ($p < 0.001$). Superscript symbols denote the statistically significant ($p < 0.05$) pairwise comparisons for each category. Early extubation category: [*]uncommon, [+]common, [^]frequent, and [#]very frequent. Center case volume: [*]small, [+]medium, and [^]large. Age: [*]< 29 d, [+]29 d to 1 yr, [^]2–5 yr, [#]6–11 yr, and [✧]12–17 yr. Risk Adjustment for Congenital Heart Surgery Score: [*]1, [+]2, [^]3, [#]4, [✧]5–6, and [X]0. Discharge year: [*]2009, [+]2010, [^]2011, [#]2012, [✧]2013, [X]2014, [$]2015, [✓]2016, [&]2017, and [†]2018. The results of the multivariable model show the percentage change in PICU-free days compared with the reference value attributable to that variable. For example, a value of 5 would reflect a 5% increase in the number of PICU-free days from reference.

TABLE 3.
Univariable and Multivariable Analyses of Factors Associated With Mortality

Category	Mortality, *n* (%)	*p*	OR (95% CI)
Early extubation category			
Uncommon	485 (2.7)	0.101	(Reference)
Common	460 (2.7)		1.03 (0.83–1.28)
Frequent	441 (2.5)		1.00 (0.82–1.21)
Very frequent	402 (2.3)		0.93 (0.74–1.16)
Center case volume			
Small	591 (2.4)	< 0.001	(Reference)
Medium	765 (2.9)		1.05 (0.84–1.30)
Large	433 (2.3)		0.78 (0.61–0.98)
Gender			
Male	983 (2.5)	0.848	0.90 (0.81–1.01)
Female	806 (2.6)		(Reference)
Age			
< 29 d	1,014 (7.2)	< 0.001	4.63 (3.35–6.40)
29 d to 1 yr	584 (1.9)		2.41 (1.81–3.21)
2–5 yr	78 (0.6)		0.78 (0.55–1.09)
6–11 yr	42 (0.6)		0.63 (0.46–0.88)
12–17 yr	71 (1.1)		(Reference)
Risk Adjustment for Congenital Heart Surgery score			
1	22 (0.3)	< 0.001	(Reference)
2	233 (0.9)		2.13 (1.33–3.41)
3	531 (2.7)		5.73 (3.60–9.11)
4	288 (5.4)		7.09 (4.49–11.19)
5 and 6	352 (13.6)		14.95 (9.40–23.78)
0	363 (4.0)		11.29 (7.02–18.15)
ICU admission >2 d before surgery			
No	1,128 (1.8)	< 0.001	(Reference)
Yes	661 (7.9)		1.88 (1.62–2.18)
Discharge year			
2009	103 (2.7)	0.483	(Reference)
2010	149 (2.7)		1.00 (0.76–1.32)
2011	179 (2.5)		0.91 (0.67–1.23)
2012	234 (2.6)		0.91 (0.71–1.17)
2013	272 (2.9)		1.06 (0.80–1.40)
2014	221 (2.4)		0.87 (0.64–1.18)
2015	165 (2.3)		0.86 (0.61–1.20)
2016	166 (2.5)		0.88 (0.64–1.19)
2017	176 (2.7)		0.99 (0.73–1.35)
2018	124 (2.3)		0.85 (0.61–1.19)

OR = odds ratio.
Median weight and interquartile range (in kg): 7.3 (4.2–16.1) for living patients, 3.4 (2.8–5.4) for dead patients ($p < 0.001$).

such as the increasing performance of more complex surgeries not adequately captured in the RACHS scoring system or the difficulty of sustaining EE practice algorithms as recently demonstrated by Gaies et al (33). Another important reason why EE rates may not have increased over recent years is the lack of data proving that it improves outcomes. We found that hospitalization in centers where EE is frequently practiced is not associated with shorter ICU stays or lower mortality rates. Although prior retrospective single-center and small multicenter studies have reported that EE is associated with decreased ICU length of stay (7–9, 11, 34-36), our findings are consistent with a recent, large registry study from Rooney et al (20) reporting that hospitalization in a frequent EE center was not associated with decreased hospital length of stay and, in fact, was associated with a higher postoperative ICU length of stay. Although it is possible that randomized trials of EE could show different results, the lack of association with improved outcomes in now two large registry studies does not support increasing EE as a reliable means to improve outcomes at the center level.

Our study found that centers that more frequently practice EE have lower failed extubation rates, consistent with prior studies (20). The reason for this finding is unclear, as one could hypothesize that more aggressive EE at the center level would in fact be associated with greater rates of reintubation. One possibility is that children in more frequent EE centers are simply better candidates for spontaneous breathing, possibly related to more stable post-bypass hemodynamics or better control of postoperative bleeding, when compared with other centers. Thus, centers may practice frequent EE not only due to institutional philosophy but because they are managing subjects who are better candidates for EE, which in itself may translate into lower reintubation rates.

Strengths of our study include its large sample size, inclusion of subjects from many centers over multiple years, and its focus on center-level outcomes. There are several limitations to our study, which are mostly related to its observational nature and database-driven analyses. First, there are likely factors that differed between centers for which we were unable to adjust. Although known potential confounders such as center volume, patient illness severity, and age were included in our multivariable analyses, there may be practice differences at a center level—such as center-specific EE algorithms, participation in the Pediatric Heart Network Collaborative Learning Study, increased use of noninvasive ventilation and high-flow nasal cannula, or presence of intermediate care “step-down units”—that could have affected EE rates and patient outcomes. Large, prospective trials are needed to control for these unmeasured variables. Second, large databases such as VPS have an inherent risk of inaccurate data entry, such as the 0.02% of subjects we excluded due to irrational data. However, the VPS database minimizes these errors with strict quality control measures (37), and our large sample size with almost 70,000 subjects can help offset any inaccuracies. Third, the STS case index that was used to identify cardiac surgeries in the database is not a mandatory reporting field in VPS, so our data were limited to centers who reported this information. Fourth, these analyses only included subjects through 2018, though any trends we would have seen in 2020 or 2021 could be heavily influenced by the COVID pandemic. Fifth, for children who were admitted to the ICU preoperatively, the surgical end time was estimated by using the average surgery durations among all children in the database with the same RACHS score. Importantly, although this may have led to some improper characterization of which patients were extubated early, our study findings were reproducible when using only data from children with known surgical end times. Finally, we reported outcomes of patients of all levels of surgical complexity, but only low-moderate complexity cases were used to determine each center’s extubation category. Higher complexity surgeries less commonly allow for EE, and their performance rates varied between centers, so excluding them from the categorization scheme was needed to not bias higher complexity centers toward a lower extubation category. Including the complex patients in our results may have decreased the discrimination of our extubation categories, but it is likely that centers that extubate their low-moderate complex patients early have a similar approach to the more complex patients.

CONCLUSIONS

Using a large, multicenter, quality-controlled database, we found that EE rates in postoperative cardiac patients did not significantly change between 2009 and 2018. Centers that performed EE were not associated with differences in PICU-free days or mortality rates but did have lower reintubation rates. These data do not support that EE is a reliable way to improve center-level outcomes, but future studies that address our methodological limitations via randomization or that evaluate EE as part of quality improvement bundle could find more supportive evidence.

1 Division of Pediatric Cardiology, Columbia University Irving Medical Center, New York Presbyterian Hospital, New York, NY.

2 Division of Pediatric Cardiac Anesthesiology, Rainbow Babies and Children's Hospital, Case Western Reserve University School of Medicine, Cleveland, OH.

3 Division of Pediatric Critical Care, Rainbow Babies and Children's Hospital, Case Western Reserve University School of Medicine, Cleveland, OH.

4 Department of Pediatrics, Rainbow Babies and Children's Hospital, University Hospitals, Cleveland, OH.

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For information regarding this article, E-mail: ree9025@nyp.org

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