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Influence of early extubation location on outcomes following pediatric cardiac surgery

Sydney R Rooney, MD¹, Christopher M Mastropietro, MD², Brian Benneyworth, MD, MS², Eric M. Graham, MD³, Darren Klugman, MD⁴, John Costello, MD³, Nancy Ghanayem, MD, MS⁵, Wenying Zhang, MS⁶, Mousumi Banerjee, PhD^{6,7}, Michael Gaies, MD MPH MSc⁸

¹Children's Hospital of Pittsburgh, University of Pittsburgh Medical Center, Pittsburgh, PA;

²Division of Critical Care, Department of Pediatrics, Indiana University School of Medicine, Riley Hospital for Children, Indianapolis, IN;

³Department of Pediatrics, Division of Pediatric Cardiology, Medical University of South Carolina, Charleston, SC;

⁴Department of Critical Care Medicine and Cardiology, Children's National Medical Center, Washington, District of Columbia;

⁵Department of Pediatrics, Division of Critical Care, Texas Children's Hospital and Baylor College of Medicine, Houston, TX;

⁶Center for Healthcare Outcomes and Policy, University of Michigan, Ann Arbor, MI;

⁷Department of Biostatistics, School of Public Health, University of Michigan, Ann Arbor, MI;

⁸Department of Pediatrics and Communicable Disease, Division of Cardiology, C.S. Mott Children's Hospital and University of Michigan Medical School, Ann Arbor, MI

Abstract

Objective: Early extubation following pediatric cardiac surgery is common, but debate exists whether location affects outcome, with some centers performing routine early extubations in the operating room (OR) and others in the cardiac intensive care unit. We aimed to define early extubation practice variation across hospitals and assess impact of location on hospital length-of-stay and other outcomes.

Design: Secondary analysis of the Pediatric Cardiac Critical Care Consortium (PC4) registry.

Setting: 28 PC4 hospitals.

Patients: Patients undergoing Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STAT) mortality category 1–3 operations between 8/2014–2/2018.

Interventions: None.

Corresponding Author: Sydney Rooney, MD, Children's Hospital of Pittsburgh, 4401 Penn Ave, Pittsburgh, PA 15224, **Telephone:** 412-864-8371, rooneyrs@upmc.edu. Address for Reprints: Michael Gaies, MD, C.S. Mott Children's Hospital, 1540 E Hospital Drive, Ann Arbor, MI 48109, Reprints will not be ordered.

Measurements and Main Results: We defined early extubation as extubation <6 hours after postoperative admission. Hospitals were categorized based on the proportion of their early extubation patients who underwent an OR extubation. Categories included low- (<50% of early extubation, n=12), medium- (50–90%, n=8), or high- (>90%, n=8) frequency OR early extubation centers. The primary outcome of interest was postoperative hospital length-of-stay. We analyzed 16,594 operations (9,143 early extubation, 55%). Rates of early extubation ranged from 16%–100% across hospitals. OR early extubation rates varied from 16%–99%. Patient characteristics were similar across hospital OR early extubation categories. Early extubation rates paralleled the hospital OR early extubation rates – 77% patients underwent early extubation at high-frequency OR extubation centers compared to 39% at low-frequency OR extubation centers ($p<0.001$). High- and low-frequency OR early extubation hospitals had similar length-of-stay, cardiac arrest rates, and low mortality. However, high-frequency OR early extubation hospitals used more non-invasive ventilation than low-frequency hospitals (15% vs 9%, $p<0.01$), but had fewer extubation failures (3.6% vs 4.5%, $p=0.02$).

Conclusions: Considerable variability exists in early extubation practices after low- and moderate-complexity pediatric cardiac surgery. In this patient population, hospital length-of-stay did not differ significantly between centers with different early extubation strategies based on location or frequency.

Keywords

airway extubation; artificial respiration; quality of healthcare; perioperative care; congenital heart surgery

Introduction

Early extubation after pediatric cardiac surgery has gained momentum in recent years such that it is now a common practice in perioperative care. Theoretical benefits of early extubation include the potential for decreased length of stay (1), decreased patient exposure to narcotics and sedation (2), minimization of ventilator-related complications, and physiologic advantages for certain patient populations such as children recovering from tetralogy of Fallot repair or cavopulmonary anastomosis (3). Multiple studies have demonstrated success of early extubation practice across a variety of patient ages and surgical complexities (4, 5).

While early extubation practice may be increasing, questions remain about its benefits and how best to implement an early extubation strategy. One area of practice variation relates to the preferred location of early extubation: operating room (OR) vs intensive care unit (ICU) (6, 7). Despite evidence of safety, a recent multicenter study of administrative data for over 25,000 pediatric cardiac surgical patients demonstrated that only 25% were extubated in the OR (8). Some clinicians may find OR extubation less desirable because predicting extubation readiness is less precise under these conditions (9), raising concerns about reintubation or need for assisted ventilation after OR extubation (6, 8, 10). Finally, OR extubation may be difficult for some institutions trying to maintain throughput in the OR as this practice could delay room turnover. In contrast, planned early extubation in the ICU after postoperative admission can be delayed for a number of reasons, many of which are not

patient-related, and can result in unnecessary exposure to mechanical ventilation and increased narcotic and sedation administration. There is insufficient literature defining the characteristics and outcomes of patients extubated in the OR versus the ICU, describing variations in practice, or comparing outcomes across hospitals with different early extubation practice patterns. Consequently, best practices surrounding early extubation after pediatric cardiac surgery are unclear.

In this context, we performed an analysis of the Pediatric Cardiac Critical Care Consortium (PC4) clinical registry to describe variation in early extubation practice, focusing on the preferred location of early extubation after low- and medium-complexity congenital heart surgery across hospitals. We also sought to assess the impact of early extubation practices on postoperative length-of-stay and other secondary clinical outcomes. We hypothesized that hospital preference for OR vs. ICU early extubation does not significantly impact postoperative outcomes.

Materials and Methods

Data source

The Pediatric Cardiac Critical Care Consortium (PC4) is a voluntary quality improvement collaborative that collects data on all patients with primary cardiac disease admitted to the cardiac ICU attending service of participating hospitals (11). PC4 maintains a clinical registry that includes data on patient demographics, comorbidities, surgical procedures/interventions, critical care therapies, and complications in order to support research and quality improvement initiatives. At the time of this analysis 28 hospitals were submitting cases to the PC4 registry.

Trained data managers must pass a certification exam prior to collecting and entering data in accordance with the standardized PC4 Data Definitions Manual at each PC4 institution. The PC4 registry shares common terminology and definitions from the International Pediatric and Congenital Cardiac Code (IPCCC) (12), Society of Thoracic Surgeons (STS) Congenital Heart Surgery Database, and American College of Cardiology Improving Pediatric and Adult Congenital Treatment (IMPACT) Registry, as previously described (11). Participating hospitals are audited on a regular schedule and audit results suggest complete, accurate and timely submission of data across hospitals, with the most recent published results demonstrating a major discrepancy rate of 0.6% across 29,476 fields (13).

The University of Michigan Institutional Review Board provides oversight for the PC4 Data Coordinating Center; this study was reviewed and approved with waiver of informed consent.

Inclusion and exclusion criteria

All hospitalizations with an index surgical procedure defined by the STS (14) between August 1st, 2014 and February 1st, 2018 were considered for the analysis. We excluded patients who weighed <2.5kg and were undergoing isolated patent ductus arteriosus closure, had a tracheostomy *in situ* at the time of the index operation, or did not receive immediate postoperative care in the cardiac ICU. Surgical complexity was classified according to the

Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STAT) mortality categories (14). We only included patients in STAT categories 1–3 because most patients in categories 4 or 5 are unlikely to be considered early extubation candidates at most hospitals.

Exposures and Outcomes

We defined early extubation as extubation in the OR or CICU within 6 hours of postoperative admission, consistent with previous literature (15, 16). Patient characteristics analyzed included age, prematurity, gender, weight status at surgery, race, ethnicity, chromosomal/syndromic or genetic anomaly, and airway anomaly. Weight-for-age z-scores were calculated using World Health Organization or Centers for Disease Control standards (17).

The percentage of early extubation out of all qualifying STAT mortality category 1–3 surgeries was calculated at each hospital. We then categorized hospitals based on frequency of OR EE. The cutoff points for OR early extubation frequency categories were determined by graphing the hospitals from lowest to highest OR early extubation frequency and grouping the centers in an effort to clearly define high- and low-frequency groups with demonstrably different practice (See Figure 1). Based on this analysis, hospitals were categorized as low-frequency (<50% of early extubations occurred in the OR), medium-frequency (50–90%), or high-frequency (>90%) OR extubation centers.

The primary outcome used for comparison was postoperative hospital length-of-stay. Additional outcomes included extubation failure rate, cardiac ICU mortality, postoperative cardiac ICU length-of-stay (defined as time to medically ready for discharge or transfer from the cardiac ICU), cardiac arrest, unplanned cardiac ICU readmission within 48 hours, use of non-invasive positive pressure ventilation, and use of high-flow nasal cannula. Extubation failure was defined as reintubation within 48 hours of a planned extubation to align with previous reports (18–21).

Statistical Analysis

Characteristics and perioperative variables were described for OR and cardiac ICU early extubation patients (Supplemental Table 3). We compared differences in patient characteristics and clinical outcomes across high-, medium-, and low-OR early extubation frequency hospitals. We analyzed differences in clinical outcomes across the OR early extubation frequency categories, focusing on comparisons between the high- and low-frequency categories as these hospitals seemed to have clearly different postoperative extubation practices from each other. We also included supplemental material describing differences in patients who underwent early extubation and those who underwent a late extubation (i.e. >6 hours post-operatively) (Supplemental Tables 1 and 2). Chi-square test, Fisher's exact test, or Wilcoxon Rank Sum test were used as appropriate for all univariate comparisons. A p-value < 0.05 was chosen *a priori* to define statistical significance. All analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC) or STATA Version 14 (Stat Corp, College Station, TX).

Results

Patient Characteristics

A total of 16,594 surgical hospitalizations met inclusion criteria. Early extubation occurred in 9,143 (55.1%). Early extubation of neonates was rare (<2%). Patients who underwent early extubation were also less likely to be underweight and have chromosomal, genetic, or syndromic abnormalities. Patients who underwent early extubation also had shorter durations of cardiopulmonary bypass and aortic cross clamp, and were less likely to be on vasoactive infusions or mechanical ventilation at the time of surgery. The frequency of early extubation across complexity categories was 66% in STAT 1, 55% in STAT 2, and 31% in STAT 3.

Patients who underwent OR early extubation are compared to those who underwent CICU early extubation in Supplemental Table 3. While there were several statistically significant differences in baseline and operative characteristics between these two subgroups of patients, the absolute differences were small.

Hospital Variation in Early Extubation Practice

The proportion of patients undergoing early extubation in any location ranged from 16%–100% across hospitals. The proportion of patients extubated in the OR as a percentage of all early extubations for each PC4 hospital are illustrated in Figure 1a. When grouping the hospitals by OR early extubation frequency, there were 12 low-, 8 medium-, and 8 high-frequency OR early extubation hospitals. The variations in the proportion of all patients who underwent early extubation and the proportion of early extubation patients who were extubated in the OR across hospitals were similar (Figure 1b). In other words, overall early extubation rates (OR + CICU early extubations) were significantly greater at high OR early extubation frequency hospitals compared to both medium- and low-frequency hospitals ($p<0.001$).

Table 1 shows the aggregate patient demographic and preoperative characteristics by hospital OR early extubation frequency category. While age, presence of airway anomalies, presence of preoperative risk factors, and STAT mortality category had statistically significant differences among groups, absolute differences across these variables were small.

Postoperative outcomes at high- and low- OR early extubation frequency category hospitals are displayed in Table 2. Median postoperative hospital length-of-stay was not statistically different for patients at high-frequency versus low-frequency OR early extubation hospitals (5 days). Median postoperative CICU length-of-stay, on the other hand, was greater at high-frequency OR early extubation versus low-frequency OR early extubation hospitals. Moreover, high frequency OR early extubation hospitals did have a significantly lower extubation failure rate and a lower rate of unplanned CICU readmission within 48 hours. Non-invasive positive pressure ventilation use was more common at medium- and high-frequency OR early extubation hospitals, but high flow nasal cannula was more common at low-frequency OR early extubation hospitals ($p<0.05$ for both).

Discussion

We examined early extubation practices across PC4 hospitals to determine whether location of early extubation confers any advantage in postoperative outcomes. Our results highlight persistent wide variation in post-operative extubation practices across hospitals, both in terms of where (OR vs. CICU) and how often they perform early extubation for low- and moderate-complexity cardiac surgical patients. Our analysis suggests that higher center OR early extubation frequency does not lead to shorter length-of-stay or better clinical outcomes for patients undergoing these surgical procedures. The frequency of all early extubation (in either the OR or cardiac ICU) also differed between hospital OR frequency groups, and paralleled the rate of OR extubation. Thus, we can also infer that higher frequency of early extubation, regardless of location, does not lead to shorter length-of-stay.

Previous literature on early extubation does not suggest a benefit in terms of reducing length-of-stay (22), but it was unclear prior to our study whether the predominate location of extubation (OR vs. CICU) at a hospital modified the impact of an early extubation program on length-of-stay. There was no difference in length-of-stay among groups of hospitals with clearly different early extubation location preferences. Thus, our findings indicate that neither an aggressive approach to OR early extubation or early extubation in the CICU is sufficient to drive shorter length-of-stay among patients who undergo low- and medium-complexity cardiac surgery. These findings suggest that there are several other aspects of postoperative care both in the CICU and on the acute care ward that are equally important to examine in efforts to decrease length-of-stay after cardiac surgery. For example, removal of chest tubes may be a critical aspect of postoperative care that prolongs hospitalization, and initiatives are underway to target earlier removal (23) and determine the impact on hospital length-of-stay.

While our study does not provide evidence to favor either OR or CICU early extubation as a strategy to reduce length-of-stay, it is possible that hospital costs are impacted by one or the other strategy. There is some evidence that suggests OR extubation strategies can likely reduce costs in adult cardiac surgery (24). McHugh and colleagues recently demonstrated a cost savings in the Pediatric Heart Network Collaborative Learning Study (22) among patients undergoing tetralogy of Fallot repair after institution of the early extubation clinical practice guideline. Notably, the greatest reduction among cost domains included “clinical” costs such as mechanical ventilation and respiratory treatments. Therefore, it is possible to conclude that OR early extubation strategies (relative to CICU) might have a positive impact on hospital costs even without reducing length-of-stay, particularly in certain operation subgroups. However, it is also possible that the increased time the OR required for OR early extubation could lead to an increase in costs, which may or may not be balanced by the other clinical cost reductions. Both clinical and cost outcomes should be considered by hospitals when planning a perioperative approach to mechanical ventilation.

High frequency OR early extubation hospitals did exhibit higher utilization of noninvasive positive pressure ventilation (NIPPV) and longer CICU length-of-stay. Extubation failure rates were lower at the high OR early extubation hospitals, but the absolute difference was small. These findings could suggest a potential mechanism to explain why hospital length-

of-stay is not shorter at hospitals where OR extubation is more common. If OR extubation results in greater use of NIPPV, then length of observation in the ICU or on the acute care floor may offset the benefits of the approach. Previous literature from PC4 demonstrated significant variation in how pediatric CICUs utilize NIPPV after infant surgery (25), and there are little data to guide optimal use to prevent respiratory failure and avoid prolonging critical care. This is an important area for future study and could lead to greater understanding of how to implement a comprehensive plan for perioperative respiratory care that promotes early liberation from mechanical ventilation without lengthening the CICU stay.

Though we saw no difference in length-of-stay and no suggestion of benefit for OR early extubation after low- to moderate-complexity surgery, it is possible that the location of early extubation does matter in certain subgroups within our population (e.g. cavopulmonary anastomoses) or in higher complexity patients. STAT category 4 and 5 operations such as arterial switch with ventricular septal defect closure and Norwood operations, respectively, are associated with much longer median duration of ventilation and CICU and hospital length-of-stay, so there is greater potential for early extubation to impact length-of-stay as compared to the population we studied. As more hospitals apply early extubation strategies to these higher complexity subgroups it will be crucial to study both the benefits and risks to determine whether other hospitals should adopt similar practice, and how best to achieve safe, high-quality care. Further, as hospitals in PC4 accrue larger numbers of patients in specific operative subgroups that are most likely to benefit from early extubation based on physiology and other nuanced aspects of postoperative care, future study can elucidate whether OR vs. CICU early extubation results in any benefit for patients.

It is important to consider our findings given certain limitations of our study. As with any clinical registry study we were limited in our analysis to the variables routinely collected in the database. The registry does include data on hospital-specific ventilation and extubation protocols, nor on specific practices in acute care cardiology wards. These will be crucial to investigate with our colleagues from the Pediatric Acute Care Cardiology Collaborative (PAC3) (23, 26) to ascertain how to unlock potential benefits of an OR or CICU early extubation approach as it pertains to reducing hospital length-of-stay. Common sense would suggest that reducing the duration of one of the main postoperative critical care therapies – mechanical ventilation – should shorten length-of-stay, but the lack of benefit for either OR early extubation or overall early extubation illustrates that we have not yet determined the key factors driving this outcome, and this study provides only limited evidence on this question. There were some statistically significant differences in patient characteristics across hospital OR early extubation categories, but they do not appear clinically meaningful. For example, while the frequency of airway abnormality was statistically different between high- and low-OR early extubation frequency groups, the absolute difference was only ~1%. Finally, our study was conducted during a time when the results of many early extubation studies were entering the literature, so practice may be evolving. This cohort of hospitals represents mostly larger cardiac surgical programs with dedicated CICUs, and may not be representative of findings at hospitals with a different organizational structure or case-mix.

Conclusions

In conclusion, we demonstrated that wide variation in early extubation practices after low- and moderate-complexity pediatric cardiac surgery exists across hospitals and found no significant association between early extubation practice and clinical outcomes. It is important to determine whether our attention should turn to other aspects of the perioperative care process if we hope to get children and families home earlier and safely after surgery. Alternatively, our results could indicate that extubation location is more impactful only in certain more homogenous groups of patients and that future work should be aimed towards delineating which groups would benefit most from safe early extubation practice.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1a.

Percentage of OR extubations out of all early extubations by hospital.

Figure 1b.

Percentage of OR extubations out of all early extubations and percentage of early extubations by hospital.

Table 1:

Patient characteristics across hospital operating room early extubation (OR EE) categories

	High-Frequency OR EE (N=4,358)	Medium-Frequency OR EE (N=6,385)	Low-Frequency OR EE (N=5,871)	p-value
Patient Characteristics				
<u>Age at Operation</u>				<0.0001*
Preterm neonate	59 (1.4%)	92 (1.5%)	53 (0.9%)	
Neonate	331 (7.6%)	413 (6.5%)	378 (6.4%)	
Infant	1581 (36.3%)	2313 (36.3%)	2276 (38.8%)	
Child	2089 (47.9%)	3115 (48.9%)	2866 (48.8%)	
Adult	298 (6.8%)	432 (6.8%)	298 (5.1%)	
Any chromosomal, genetic, or syndromic abnormalities	904 (20.7%)	1419 (22.3%)	1307 (22.3%)	0.1
Any airway abnormalities	196 (4.5%)	328 (5.2%)	201 (3.4%)	<0.0001
Pre-Operative Risk Factors				
Mechanical circulatory support	12 (0.3%)	16 (0.3%)	16 (0.3%)	1.0
Preoperative mechanical ventilation	228 (5.2%)	307 (4.8%)	311 (5.3%)	0.4
Other major preoperative risk factors	53 (1.2%)	111 (1.7%)	96 (1.6%)	0.08
Minor preoperative risk factors	1203 (27.6%)	1981 (31.1%)	1570 (26.7%)	<0.0001
<u>STAT Mortality Category</u>				0.0007*
STAT 1	1600 (36.7%)	2563 (40.3%)	2264 (38.6%)	
STAT 2	1970 (45.2%)	2749 (43.2%)	2520 (42.9%)	
STAT 3	788 (18.1%)	1053 (16.5%)	1087 (18.5%)	

Multi-category group (more than 2 categories) overall significance test results noted with *. Significance test performed on data within the same shaded box.

Table 2:

Clinical outcomes by hospital operating room early extubation (OR EE) frequency category.

	High-Frequency OR EE (N=4,358)	Medium-Frequency OR EE (N=6,385)	Low-Frequency OR EE (N=5,871)	p-value (comparing low- and high- frequency groups)
Early Extubation (n, %)	3335 (76.5%)	3519 (55.3%)	2289 (39.0%)	<0.0001
Primary Outcome				
Postoperative Hospital Length of Stay (days, IQR)	5 (4–9)	6 (4–10)	5 (4–9)	0.5
Secondary Outcomes				
Postoperative CICU Length of Stay (days, IQR)	3 (2–5)	2 (1–4)	2 (1–4)	<0.0001
Extubation Failure (n, %)	155 (3.6%)	262 (4.1%)	262 (4.5%)	0.02
CICU Mortality (n, %)	39 (0.9%)	46 (0.7%)	37 (0.6%)	0.1
Postoperative Cardiac Arrest (n, %)	58 (1.3%)	77 (1.2%)	80 (1.4%)	0.9
CICU Readmission within 48 hours (n, %)	37 (0.9%)	75 (1.2%)	87 (1.5%)	0.004
Use of Non-Invasive Positive Pressure Ventilation (n, %)	656 (15.1%)	684 (10.8%)	514 (8.8%)	<0.0001
Use of High-Flow Nasal Cannula (n, %)	1115 (25.6%)	1841 (28.9%)	1766 (30.1%)	<0.0001