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Early extubation in pediatric heart surgery across a spectrum of case complexity: Impact on hospital length of stay and chest tube days

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Unstructured abstract

Early extubation is increasingly common in congenital heart surgery, but there are limited outcomes data across the spectrum of case complexity. We performed a retrospective review of 201 pediatric operations using cardiopulmonary bypass between 2012 and 2014. Patients extubated in the operating room or immediately on arrival to the ICU were compared to those extubated by traditional protocols. In-hospital mortality, major complications, need for re-intubation, hospital length of stay, and chest-tube days were compared between groups and by Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery Congenital Heart Surgery (STAT) mortality category. Outcome measures of hospital length of stay and chest tube days were analyzed using multivariable regression modeling.

Early extubation subjects were older, weighed more, had shorter bypass and aortic cross-clamp time, more often received caudal anesthesia, and had shorter hospital length of stay and fewer chest tube days. Subjects not extubated early had more chromosomal abnormalities, more preoperative co-morbidities, and had more major complications. In-hospital death, major complications, and re-intubation were rare outcomes for both groups across all STAT categories. Multivariable regression analysis showed that cardiopulmonary bypass time was a significant

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predictor of hospital length of stay and chest tube days. Hospital LOS and chest tube days were significantly lower for the early extubation group in both the unadjusted and adjusted analyses. Early extubation can be performed safely in congenital heart surgery across a spectrum of case complexity. No increased early mortality or re-intubation was observed with early extubation although there were important differences between the groups that merits further study. The potential benefits of early extubation include decreased hospital length of stay and fewer chest tube days, particularly in young children and patients with long bypass times.

Keywords

congenital heart disease; mechanical ventilation; outcomes

Introduction

There is renewed interest in early extubation in modern congenital heart surgery(1–3). Although early postoperative extubation was commonplace in the 1980s, the practice was largely abandoned as advancements in the fields of surgery and anesthesia resulted in a more complex patient population. Also, technological and medical advances in critical care provided better ventilators and facilitated high-level care of intubated patients recovering in the pediatric intensive care unit (PICU). In the current era, attention to healthcare costs and resource allocation has revived the concept of early extubation as an essential component of fast track protocols in congenital heart surgery(4).

The feasibility of early extubation across various age groups has been demonstrated(1, 5–7). In single ventricle patients extubated early after bi-directional Glenn and Fontan operations, a hemodynamic benefit has been described(8). Potential cost-saving benefits include decreased ICU and hospital length of stay (LOS)(1, 2, 4, 9, 10). Other advantages to early extubation include avoiding the negative physiologic effects of positive pressure ventilation, reducing ventilator-associated complications, and reducing patient discomfort and narcotic use. Potential disadvantages include concern for hemodynamic instability, risk of airway compromise and need for reintubation, and possible respiratory acidosis early after cardiopulmonary bypass (CPB).

Recent reports have described extubating early after complex operations, but outcomes data are limited for these patients(2, 11, 12). Studies describing the outcomes of extubation in the immediate postoperative period across the spectrum of case complexity are rare. The Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STS-EACTS) Congenital Heart Surgery (STAT) mortality category aims to predict in-hospital mortality based on case complexity where STAT 1 is the least complex, and STAT 5 is the most complex. To our knowledge, outcomes for early extubated patients based on case complexity using STAT category have not been reported.

The primary aims of this study were to: 1) describe clinically-relevant outcomes of inhospital mortality, major complications, reintubation, chest tube days, and hospital LOS for children in a medium-volume congenital heart center who were extubated immediately after heart surgery and, 2) to compare these outcomes across a spectrum of case complexity.

A secondary objective of this study was to describe outcomes in consecutive congenital heart operations where patients were extubated immediately following surgery, and to compare those outcomes to a contemporaneous group of patients extubated by traditional protocols. Herein, we also report successful use of caudal anesthesia in this patient population and discuss a team-based approach to early extubation.

Methods

Study population

A retrospective cohort study was conducted at the North Carolina Children's Hospital (NCCH) after obtaining institutional review board approval. NCCH is home to a moderate-sized congenital heart program consistently performing between 175–200 cases per year where all anesthesia care is provided by experienced pediatric cardiac anesthesiologists. Consecutive patients >30 days and <19 years old undergoing congenital cardiac surgery with CBP from January 2012 to March 2014 were included. Patients requiring mechanical ventilation preoperatively, an open chest at end of the operation, and/or immediate pre- or post-operative use of extra-corporeal membrane oxygenation (ECMO), were excluded.

All patients > 30 days undergoing operations in STAT categories 1–4 were generally considered candidates for a fast-track protocol that included extubation immediately after surgery. All candidates for early extubation (EE) were preoperatively given a single-shot caudal or spinal anesthesia when anatomically practical. Standard maintenance of anesthesia for EE candidates included volatile agents with limited narcotics. Extubation was attempted in all patients who demonstrated appropriate gas exchange and respiratory effort at the conclusion of the case in the absence of major intraoperative complications or ongoing bleeding. The final decision regarding early extubation was made after a multi-disciplinary team discussion including surgeon, anesthesiologist, and ICU attending. Subjects were categorized as “early extubation” (EE) if they were extubated in the operating room or immediately on arrival to the ICU by the anesthesia team. Subjects were categorized as “not early extubation” (NEE) if they were extubated any other time. The NEE patients were extubated using a traditional PICU model: extubation timing based on the clinical perceptions and judgment of the PICU physicians when the patients have met age-appropriate ventilator-based respiratory parameters. For patients with a tracheostomy, extubation was defined as return to tracheostomy collar or room air without positive pressure support.

Primary outcome measures for this study were: in-hospital mortality, major complications, re-intubation, hospital LOS, and chest tube days. Re-intubation was documented as positive if this event occurred at any point during the post-operative hospitalization. Major complications included mediastinal bleeding requiring reoperation, stroke, cardiac tamponade, bowel perforation, and sepsis. A chest tube day was recorded if a subject had a chest tube for any portion of that day (ie: day of chest tube removal was considered a chest tube day).

Data collection was accomplished by medical record review. Demographic and perioperative variables collected included extubate status, STAT category, age (months), race (white/non-

white+other), gender, weight, chromosomal abnormalities, single ventricle physiology, use of caudal anesthesia, CPB time, cross clamp time, and pre-existing co-morbidities (tracheostomy, gastrostomy tube, or colostomy).

Statistical Analysis

Baseline descriptive statistics were calculated including the mean $\pm$ standard deviation (SD) and minimum/maximum for continuous variables, and as n (%) for categorical variables. Differences between groups were evaluated by the Fisher's exact test, Student t test, and Chi squared test. Significance level was set at 0.05.

Multivariable regression analysis was used to assess the joint effects of demographic and perioperative variables on the outcomes of hospital LOS and chest tube days. Given the study sample size, scientific questions of interests, and preliminary analyses, all variables including interaction terms for extubate status by age and extubate status by CPB were included in an original "full" model and the model was reduced using backward elimination, removing variables with $p > 0.05$ (13). For both hospital LOS and chest tube days, the regression models reduced to a final model that included extubate status, age, CPB, extubate by age, and extubate by CPB. Due to the low frequency of events, reintubations, preoperative co-morbidities, and major complications were not included in the full model.

Results

Study population

A total of 201 consecutive operations in 197 unique patients between January 2012 and Dec 2014 were included. The majority of subjects were extubated early, including those in STAT category 4 (Figure 1). Overall, the median age was 1.9 years (range: 0.1–18.9). Subjects in the EE group were significantly older and weighed more than subjects in the NEE group (Table 1). The EE cohort had shorter average CPB and cross clamp times, fewer associated chromosomal abnormalities and preoperative co-morbid conditions, and more often received caudal anesthesia. The case mix for the EE and NEE groups is shown in Table 2.

When grouped by STAT category, the subjects in STAT categories 2 and 4 were the most homogeneous by age and weight (data not shown). In a bivariate analysis, hospital length of stay was significantly shorter for EE patients in STAT categories 1–3 (Fig 2). Also, subjects extubated early enjoyed significantly fewer chest tube days in STAT categories 1 and 4 (Fig 3).

Primary outcomes

In this study, deaths, major complications, and reintubations were rare events across all STAT categories. However, there were fewer deaths, major complications ($p=0.03$), and reintubations in the EE group (Table 1).

Multivariable regression analysis for hospital length of stay and chest tube days

Using multivariable regression, age (months), CPB time and the interaction terms for extubate by CPB and extubate by age (months) were the only significant predictors of

hospital length of stay and chest tube days. All other variables, including STAT category, were not significant predictors of hospital LOS or chest tube days in reduced models (Table 3).

The significant interaction between age and EE, adjusting for mean CBP, may be interpreted to mean that younger patients had significantly shorter hospital LOS after being extubated early when compared to older patients (Fig 4A). For example, at 60 months (5 years) of age, the predicted difference between EE and NEE, adjusting for mean CBP, was 8.1 ± 1.6 days ($p < 0.0001$). At 1 month of age, the predicted difference between EE and NEE, adjusting for mean CBP, was 11.1 ± 1.9 days ($p < 0.0001$). Thus, in our model, subjects <5 years old who were extubated early had a mean hospital LOS approximately 8 to 11 days shorter than their NEE counterparts. For children ≥ 5 years who were extubated early, the predicted LOS benefit was sustained until about the age of 16 years when the lines crossed (Fig 4A).

Another clinically important interaction was found between EE status and CPB time for the outcome of hospital LOS. Among subjects with long CPB times and adjusting for mean age (months), those who were extubated early enjoyed shorter hospital stays than their NEE counterparts, with differences becoming more pronounced with increasing CPB times (Fig 4B). Differences in hospital LOS became significantly different with CPB times beginning around 100 minutes (mean difference 3.6 ± 1.8 days, $p=0.049$).

When the outcome of chest tube days was considered, similar interactions were found between extubate status and age and extubate status and CPB time (Fig 5A–B). Subjects <5 years old who were extubated early had the greatest benefit: a mean of nearly 2 to 3 (1.9 ± 0.5 to 2.8 ± 0.6) fewer chest tube days was observed for EE subjects compared to their NEE counterparts (Fig 5A). For children ≥ 5 years who were extubated early, the predicted difference in mean number of chest tube days decreased from 1.9 to zero before the relationship reversed at about age 15 years. Similar to hospital LOS, among subjects with long CPB times and adjusting for mean age (months), those who were extubated early had their chest tubes removed earlier than their NEE counterparts, with differences more obvious as CBP time increased (Fig 5B). Differences in chest tube days become significantly different with CBP beginning around 140 minutes (mean difference 1.2 ± 0.6 , $p=0.0400$).

Discussion

In this study of 201 operations using cardiopulmonary bypass, mortality, major complications, and reintubation were rare outcomes across all STAT mortality categories. Here, STAT designation was not a significant predictor of measured outcomes, however sample size limited our ability to perform a stratified analysis. Exploratory multivariable regression analysis showed that age and cardiopulmonary bypass time were significantly related to both hospital length of stay and number of chest tube days. However, early extubation status affected hospital length of stay and chest tube days differently, depending on the age of the subject, and his/her CBP time. Simply put, even though being younger and having a longer bypass time appeared to be associated with longer hospital stay and more chest tube days, early extubation was able to neutralize those effects.

This study aimed to describe clinically-relevant results of an aggressive early extubation practice in a medium-sized congenital heart program where strict criteria for early extubation have not been defined. However, it is important to recognize that outliers at the extremes of age and CBP time have an impact on predictive models for length of stay and chest tube days. This exploratory study used all available data, including extreme values that were valid values for this observed sample. Regardless, early extubation in adults and children has been long associated with decreased length of ICU and hospital stay, as well as decreased cost(7, 14). Chest tubes are painful, and it stands to reason that earlier removal of chest tubes is a desirable outcome(15). Also, shorter hospitalizations are clearly important to patients, caregivers, insurance providers, and the healthcare system overall. In the current study, the finding that early extubation may level the playing field for younger patients and patients undergoing a long bypass run was unexpected but compelling. Given the opportunity to significantly reduce hospital LOS and chest tube days, implementing an aggressive strategy for early extubation in congenital cardiac surgery may substantially increase patient and caregiver satisfaction; congenital heart teams should consider every patient for potential early extubation.

Many authors have described successful algorithms for selecting candidates for early extubation(6, 9, 14, 16, 17). Unfortunately, across published reports, the definition of early extubation has not been consistent. Some authors have defined “early” as extubation in the operating room while others consider early to be up to 24 hours after surgery(5, 6, 18). In addition, the patient populations are often mixed bypass and non-bypass cases(1, 12, 19). In the current study, only non-neonatal bypass cases were included, and early extubation is defined as extubation in the operating room, or immediately on arrival to the ICU, before handoff from the anesthesia provider to the ICU team. This definition was used because it allowed for the most pure categorization of patients into those the team intended to fast-track and those they did not. Timing of extubation in the ICU after anesthesia hand-off is variable and dependent on many factors, including the level of acuity in the unit and competing caregiver priorities that are difficult to measure. In published reports and in the current study, typical cases chosen for “fast track” protocols include ASD closure, VSD closure, single valve replacements, stage II and III palliation for single-ventricle lesions, and conduit replacements, but the variety and complexity of cases followed by early extubation is increasing (Table 2) (1, 4, 17). The results of the current study suggest that early extubation can be widely utilized in modern congenital heart surgery, regardless of STAT classification.

A team-based process is essential to successful implementation of an early extubation protocol. Early extubation and fast-tracking at NCCH is embedded within an integrated clinical pathway using the evidence-based teamwork system TeamSTEPPS®(20). Planning for early extubation begins in a weekly multi-disciplinary heart team conference where upcoming cases are discussed with the patient’s cardiologist, surgeon, PICU team members, and the cardiac anesthesia team. Communication between these disciplines continues on the day of surgery with updates given to the PICU during the operation. Postoperatively, a structured team hand-off is performed at the bedside in the ICU. First, an anesthesia report provides information about IV access, airway, medications, and hemodynamics during the case. Next, a surgical report describes the operation that was done, the intraoperative findings, and postoperative management goals. Questions and discussion from nursing,

PICU team members, and cardiologists follows in order to provide a seamless transition of care. Written clinical pathway worksheets for common case types (ie: ASD, VSD, TOF repair, RV to PA conduit change) are begun at the time of hand-off regardless of extubation status and are updated twice daily on rounds to facilitate standardized and efficient progression of care.

Thoughtful attention to the anesthetic regimen for early extubation candidates is also critical. At NCCH, a mask induction is typical, followed whenever anatomically possible by a single-shot caudal anesthetic for patients <5 years of age. The caudal shot contains 50–100 mcg/kg of preservative-free morphine and 1–2 mcg/kg clonidine. For patients 5–8 years, a spinal anesthetic using morphine 5–10mcg/kg and 1mcg/kg of clonidine is an option. For maintenance of anesthesia, a volatile agent (sevoflurane or isoflurane) is used with limited narcotics (10–15 mcg/kg fentanyl). At the end of the operation, IV acetaminophen (15mg/kg) is given +/- a dexmedetomidine bolus or infusion. Reversal with neostigmine and glycopyrrolate is given just prior to extubation in the operating room or immediately on arrival to the ICU.

At NCCH, extubation in the operating room after congenital heart surgery has been routine since 2010. It is important to note that the current study captures an era after the team moved beyond the initial learning curve. However, the most critical determinant of outcomes related to early extubation in our experience is appropriate case selection. Unfortunately, it is difficult to quantify the specific decision-making used in each case as the ultimate team decision was made in operating room without strict criteria. In general, patients were considered candidates if older than 30 days. A case-by-case, aggressive and collaborative approach to patient selection is endorsed. Future work will include an evaluation of candidates selected for early extubation based on recently-created STAT morbidity categories.

In conclusion, early extubation can be performed safely across the spectrum of case complexity. Extubating early may facilitate fewer chest tube days and shorter hospital length of stay. Close collaboration between the surgery, anesthesia, and intensive care teams is essential to appropriately identify early extubation candidates, and to coordinate care accordingly. Caudal anesthesia should be used liberally to facilitate fast-tracking and early extubation by providing reliable postoperative pain control without respiratory compromise. In this single-center study, sample sizes within STAT category 3 and 4 limit a stratified analysis. Future studies with larger sample sizes may allow for a more detailed analysis stratified by STAT category.

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Highlights

- Early extubation in congenital heart surgery requires a team approach
- Early extubation may be accomplished safely across a spectrum of case complexity
- Hospital length of stay and chest tube days may be reduced by extubating earlier

Figure 1.
Proportion of patients extubated early versus not early by STAT category.

Figure 2.
Mean hospital LOS by STAT category for patients extubated early versus not early. *
 $p < 0.01$.

Figure 3.

Mean number of chest tube days by STAT category for patients extubated early versus not early. * $p < 0.01$.

Figure 4. Plots of predicted hospital LOS by age (A) and by CPB time (B) for patients extubated early versus not early.

Figure 5.
Plots of predicted chest tube days by age (A) and by CPB time (B) for patients extubated early versus not early.

Table 1

Patient characteristics, overall study population (N=201)

Characteristics	Early (n=133)	Not early (n=68)	p value
Male sex	67 (50)	31 (46)	0.55
Age (months)	65 ($\pm$ 65) (3, 228)	40 ($\pm$ 63) (1, 231)	0.01
Weight (Kg)	22 ($\pm$ 21) (3, 107)	14 ($\pm$ 18) (3, 93)	0.01
Race			0.88
Caucasian	78 (59)	39 (57)	
Black	33 (25)	22 (32)	
Hispanic	12 (9)	3 (4)	
Other	10 (8)	4 (6)	
STAT			<0.01
1	57 (43)	17 (25)	
2	46 (35)	19 (28)	
3	19 (14)	22 (32)	
4	11 (8)	10 (15)	
Cardiopulmonary Bypass Time (minutes)	96 ($\pm$ 45) (29, 245)	157 ($\pm$ 75) (38, 446)	<0.0001
Cross clamp time (min)	41 ($\pm$ 36) (0, 168)	86 ($\pm$ 55) (0, 197)	<0.0001
Single ventricle	17 (13)	2 (3)	0.02
Chromosomal abnormalities	12 (9)	24 (35)	<0.001
Preoperative co-morbidities	6 (5)	11 (16)	0.01
Use of caudal anesthesia	79 (59)	18 (26)	<0.0001
Deaths	0 (0)	2 (3)	0.11
Major complications	4 (3)	7 (10)	0.05
Reintubations	4 (3)	4 (6)	0.45
Hospital LOS (days)	6 ($\pm$ 5) (2, 39)	16 ($\pm$ 19) (3, 85)	<0.0001
Chest tube days	3 ($\pm$ 2) (1, 20)	5 ($\pm$ 5) (1, 33)	<0.0001

N represents 201 individual operations on 197 different patients. Data are presented as n (%) for discrete variables and mean $\pm$ SD and (minimum, maximum) for continuous variables. Preoperative co-morbidities included pre-existing tracheostomy, colostomy, or gastrostomy tube.

Table 2

Case mix (N=201)

Case type	Early (n=133)	Not early (n=68)
ALCAPA	1	0
Anomalous origin of coronary artery from the Aorta	1	0
ASD		
Primum	7	1
Secundum	16	1
Sinus venosus	7	0
ASD/VSD	8	6
AV repair	0	2
AV replacement (AVR)		
AVR, isolated	1	2
AVR + Asc. Ao replacement	1	0
AVR + Konno	0	1
AVR + RV to PA conduit	0	1
AVSD	1	10
AVSD, DORV	0	1
Bi-directional Glenn (BDG)		
BDG +/- atrial septectomy	11	2
BDG + Fontan	1	0
BDG + MV repair	0	1
DORV	4	3
Fontan	9	0
HOCM (septal myectomy)	2	0
Intracardiac tumor/mass resection	2	0
LV to PA conduit	1	0
MV repair	2	0
MV replacement	1	3
Pulmonary artery reconstruction	1	0
Pulmonary valvuloplasty	0	1
Ross operation	1	3
RV to PA conduit placement or replacement	16	7

Case type	Early (n=133)	Not early (n=68)
Scimitar repair	1	0
Sub AS resection		
Sub AS	3	1
Sub AS + MV repair	1	0
Sub AS + VSD	6	0
Supravalvar AS repair	3	0
TOF repair	7	13
VSD repair	18	9

N represents 201 individual operations on 197 different patients. Abbreviations: ALCAPA, anomalous origin of the left coronary artery from the pulmonary artery; AS, aortic stenosis; ASD, atrial septal defect; AV, aortic valve; AVSD, atrioventricular septal defect; DORV, double-outlet right ventricle; HOCM, hypertrophic obstructive cardiomyopathy; LV, left ventricle; MV, mitral valve; PA, pulmonary artery; RV, right ventricle; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Multivariable regression results for reduced models for outcomes of hospital LOS and chest tube days

Table 3

Effect	Outcomes					
	Hospital LOS			Chest Tube Days		
	Estimate	SE	p value	Estimate	SE	p value
Intercept	1.97	2.97	0.51	0.37	0.95	0.70
Extubate (yes)	0.97	3.69	0.79	1.20	1.18	0.31
Age (months)	-0.07	0.02	<0.001	-0.01	0.01	0.02
Cardiopulmonary Bypass Time (CBP) (minutes)	0.11	0.02	<0.0001	0.03	0.01	<0.0001
Extubate*CPB	-0.07	0.03	0.01	-0.02	0.01	0.01
Extubate*age	0.06	0.02	0.01	0.02	0.01	0.04