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ORIGINAL ARTICLE

The Experience of Early Extubation After Paediatric Congenital Heart Surgery in a Chinese Hospital

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Background Early extubation has become widely adopted in cardiac surgery practices. This study aimed to present experience of early extubation after congenital heart surgery and to explore the factors that affect successful immediate postoperative extubation and early extubation.

Methods A retrospective analysis was performed of all patients who underwent congenital heart surgery with cardiopulmonary bypass (CPB) at Shenzhen Children's Hospital between 01 May 2015 and 30 September 2019. The demographic and cardiac surgery information were derived from the medical records. Multivariable logistic regression models were used to explore the influence factors for successful immediate postoperative extubation and early extubation.

Results This study consisted of 2,060 patients, 65.0% of whom were extubated in the operating room and 16.1% of whom were extubated early (within 6 hours) in the Intensive Care Unit. The overall rates of reintubation and nasal continuous positive airway pressure were 2.0% and 6.4%, respectively. Preoperative weight (OR, 1.24; 95% CI, 1.20–1.29), preoperative pneumonia (OR, 0.60; 95% CI, 0.44–0.80), CPB type (OR, 1.23; 95% CI, 1.06–1.43), CPB time (OR, 0.98; 95% CI, 0.98–0.99), deep hypothermic circulatory arrest (OR, 0.42; 95% CI, 0.25–0.70), and Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery Congenital Heart Surgery (STAT) categories (OR, 0.54; 95% CI, 0.45–0.65) were included in the immediate post-operative extubation model. In addition to the above six variables, ultrafiltration (OR, 0.63; 95% CI, 0.44–0.89) was also included in the early extubation model. Similar results were found in the immediate postoperative extubation model for non-newborns. The influencing factors for early extubation in the non-newborn population included preoperative weight, preoperative pneumonia, ultrafiltration, CPB time, and STAT categories.

Conclusions Early extubation for children with congenital heart surgery was successful in this hospital. Patients with early extubation had a lower reintubation rate and nasal continuous positive airway pressure rate, and a shorter length of stay in the ICU and hospital. Early extubation was influenced by age, weight at surgery, preoperative pneumonia, CPB type, CPB time, deep hypothermic circulatory arrest, ultrafiltration, and STAT categories.

Keywords Paediatric heart surgery • Early extubation • Perioperative management

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Introduction

Early extubation has widely become adopted in adult surgery practices, including liver transplantation [1], endovascular aneurysm repair [2], and vascular and cardiac surgery [3]. Successful very early extubation after paediatric cardiac surgery was reported 20 years ago [4]; however, early extubation of paediatric patients after cardiac surgery is still challenging because of their immature vital organ systems and unpredictable system responses to cardiopulmonary bypass (CPB) [5]. The rationale for an early extubation strategy is based on several goals of postoperative care, including: decreased mechanical ventilation, shorter length of hospital stays, decreased morbidity and mortality, and reduced hospital costs [6,7]. Therefore, several centres have advocated early extubation after many paediatric cardiac operations, and increased attention is being focussed on the safety and efficacy of early extubation [8–10].

Several recent studies on the predictors of successful early extubation following congenital cardiac surgery in paediatric patients have been performed. Some preoperative and intraoperative factors may influence the time of extubation, including: patient age, weight at surgery, preoperative cardiopulmonary status, anaesthetic drug dose, procedure complexity, duration of CPB, and aortic cross-clamp (ACC) time [11,12]. Studies describing early extubation based on procedure complexity are increasing. There are several scoring systems for assessing procedure complexity: the Risk Adjustment for Congenital Heart Surgery (RACHS-1) categories [13], the Aristotle Basic Complexity score [14] and the Society of Thoracic Surgeons (STS)-European Association for Cardio-Thoracic Surgery (EACTS) mortality categories (STAT mortality categories) [15]. Among them, the STAT categories is the most commonly used useful tool for evaluating the differences in outcomes.

The study in Shenzhen Children's Hospital presented experience with early extubation after congenital heart surgery, and explored factors that affect successful immediate postoperative extubation and early extubation after cardiac surgery.

Material and Methods

Patient Population

A database analysis was performed of all patients (<18 years) who underwent congenital heart surgery with CPB at Shenzhen Children's Hospital between 01 May 2015 and 30 September 2019. All patients who underwent congenital cardiac surgical procedures were included in this retrospective analysis, with the exception of children with preoperative mechanical ventilation. Because the data used for this study were collected for administrative purposes, without any identification of individuals, the study was exempt from Institutional Review Board approval and informed consent by the Ethics Committee.

Data Collection

The database contained demographic characteristics, preoperative respiratory status, cardiac surgery information, postoperative records, and echocardiographic information. The cardiac surgery information included the preoperative diagnosis and surgical procedure, which were recorded immediately after the procedure. The intraoperative variables—including CPB and ACC time—were prospectively collected and documented in the CPB record sheet. The postoperative information primarily consisted of the extubation time in the Intensive Care Unit (ICU), blood gas analysis, reintubation, the use of nasal continuous positive airway pressure (NCPAP), and survival status. A nurse extracted the data from the medical records of inpatients in the department.

Endotracheal Extubation

The primary outcome for this analysis was the rate of successful immediate postoperative extubation (IE) and early extubation (EE). Successful IE was defined as immediate extubation inside the operating room (normally waiting time approximately 15 minutes before extubating and transferring the patient to the ICU) after surgery and successful EE as extubation within 6 hours after admission to the ICU. Delayed extubation (DE) was defined as extubation >6 hours after admission to the ICU. Furthermore, a comparison of clinical outcomes was performed regarding reintubation (defined as reintubation in the ICU of the cardiac department, before discharge from the hospital or a transfer to another department), use of NCPAP after surgery, and postoperative length of stay in the ICU and hospital after surgery. When removing the endotracheal tube, nasal cannulae ventilation with oxygen flow of 1–3 L/minute was given.

The criteria for removing the endotracheal tube in ICU are as follows:

- Patient awakening without stimulation
- Spontaneous respiratory rate >24/minute and stable spontaneous respiratory effort
- Positive end-expiratory pressure (PEEP) ≤5 cmH_2O
- FiO_2 ≤0.4 and SaO_2 >90%
- Oxygenation Index (OI, PaO_2/FiO_2) >200
- $PaCO_2$ ≤50 mmHg, and pH ≥7.25
- Stable haemodynamic status
- Good cough reflex and swallowing function.

Factors

Preoperative variables included sex, age, weight, and preoperative pneumonia. Preoperative pneumonia was diagnosed by the clinician based on the results from the preoperative computerised tomography (CT) examination and was recorded in the medical records. Intraoperative variables included the type of CPB, CPB time, ACC time, deep hypothermic circulatory arrest (DHCA), ultrafiltration, bloodless priming during CPB, and operation time. These data were obtained directly from the medical records. The type of CPB was classified to conventional CPB, miniaturised CPB, and CPB with retrograde autologous priming. Procedure complexity was classified using STAT mortality categories. Procedures were sorted by increasing mortality risk and grouped into five categories that were chosen to be optimal with respect to minimising within-category variation and to maximising the between-category variation of mortality risk. Patients undergoing index operations in STAT categories 1, 2, 3, 4, and 5 had aggregate discharge mortalities of 0.8%, 2.6%, 5.0%, 9.9%, and 23.1%, respectively [15]; thus, categories 3, 4 and 5 were combined because of the high mortality risk.

Perioperative Anaesthesia Management

The plan was to extubate every patient as soon as possible after surgery. The anaesthetic induction and maintenance doses are shown as follows:

For children ≤3 months:

- Induction: midazolam 0.15 mg/kg, fentanyl 5 ug/kg and rocuronium 0.6 mg/kg.
- Maintenance: remifentanil 0.2 ug/kg/minute, rocuronium 5 ug/kg/minute and sevoflurane 1–1.2 minimum alveolar concentration (MAC).

For children >3 months:

- Dexmedetomidine: 0.5 ug/kg was given approximately 15 minutes after entering the operating room.
- Induction: propofol 2.5 mg/kg, midazolam 0.15 mg/kg, sufentanil 1 ug/kg, and rocuronium 0.6 mg/kg.
- Maintenance: remifentanil 0.25 ug/kg/minute, rocuronium 5 ug/kg/minute, sevoflurane 1–1.2 MAC, and dexmedetomidine 0.5 ug/kg/hour.
- After sternal closure, remifentanil and rocuronium were discontinued.
- Sufentanil (1.2 ug/kg/day) and tropisetron (0.2 mg/kg/day) were administered once the intravenous analgesic pump was established.
- Sevoflurane was discontinued before skin closure and dexmedetomidine was continued until the child was transferred to the ICU.

Statistical Analysis

Descriptive statistics were calculated including the mean ±standard deviation (SD) or median and interquartile range (IQR) for continuous variables, and n (%) for categorical variables. Group differences for all categorical data were compared using χ^2 test or Fisher's exact test, and all continuous data were compared using one-way ANOVA or Kruskal-Wallis rank test.

A stepwise approach was used when conducting the multivariable logistic regression models. In order to avoid collinearity, the correlation coefficient (r) between the variables were calculated, and one of the two variables with a coefficient >0.75 was removed. As the r between age and preoperative weight was 0.933 and the r between CPB time and ACC time was 0.854, it was decided to remove age and ACC time, according to clinical judgment. Finally, the models included sex, preoperative weight, preoperative pneumonia, CPB type, CPB time, DHCA, ultrafiltration, bloodless priming during CPB, operation time, and STAT categories.

Adjusted odds ratios with 95% confidence intervals were estimated for the final models of immediate postoperative extubation and early extubation. A cut-off p-value <0.05 was considered statistically significant, and all p-values were two-tailed. All data were analysed using Stata software version 12.1 (StataCorp LP, College Station, TX, USA).

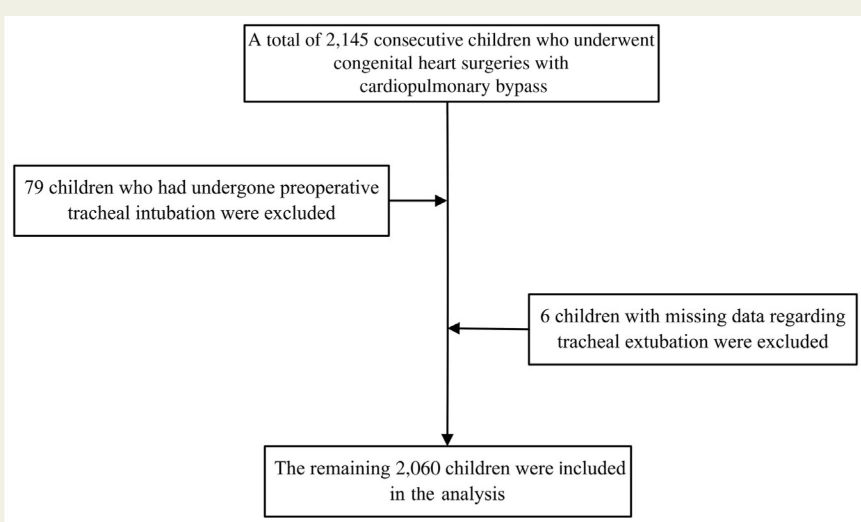

Figure 1 Flow chart of patient selection.

Table 1 Demographic and clinical characteristics of the patients.[a]

Characteristics	Total sample (n=2,060)	Immediate postoperative extubation (n=1,339)	Early extubation (n=331)	Delayed extubation (n=390)	P-value
Sex (male)	1,091 (53.0)	697 (52.1)	187 (56.5)	207 (53.1)	0.349
Age (mo)	8.2 (3.6–24.0)	12.7 (5.9–36.8)	4.7 (2.7–9.7)	3.0 (0.7–6.6)	<0.001
Newborns	143 (6.9)	20 (1.5)	11 (3.3)	112 (28.7)	<0.001
Preoperative weight (kg)	7.2 (5.1–11.0)	8.6 (6.4–13.0)	5.8 (4.6–7.4)	4.6 (3.4–6.3)	<0.001
Preoperative pneumonia	294 (14.3)	136 (10.2)	67 (20.2)	91 (23.3)	<0.001
STAT categories					
Category 1	1,471 (71.4)	1,102 (82.3)	225 (68.0)	144 (36.9)	<0.001
Category 2	342 (16.6)	193 (14.4)	63 (19.0)	86 (22.1)	
Category ≥3	247 (12.0)	44 (3.3)	43 (13.0)	160 (41.0)	
CPB time (min)	75.0±35.6	65.6±24.3	77.6±33.6	105.0±49.9	<0.001
ACC time (min)	38.9±22.0	34.0±16.9	41.1±20.1	53.9±30.3	<0.001
Operation time (min)	151.2±82.2	139.3±57.8	148.0±46.5	194.5±141.6	<0.001

Abbreviations: CPB, cardiopulmonary bypass; ACC, aortic cross-clamp; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery.
[a]Data are presented as n (%) for categorical variables and mean±SD or median (IQR) for continuous variables.

Results

Demographics

A total of 2,060 children were included in the analysis. Figure 1 presents the flow chart of patient selection. The descriptive statistics and analysis are shown in Table 1: 1,339 (65.0%) patients were extubated in the operating room (IE), 331 (16.1%) patients were extubated within 6 hours after surgery (EE), and 390 (18.9%) patients were extubated after 6 hours (DE). The median (IQR) age was 8.2 (3.6–24.0), 12.7 (5.9–36.8), 4.7 (2.7–9.7), and 3.0 (0.7–6.6) months, and the median (IQR) preoperative weight was 7.2 (5.1–11.0), 8.6 (6.4–13.0), 5.8 (4.6–7.4), and 4.6 (3.4–6.3) kg for total patients and the IE group, EE group and DE group, respectively. The differences in extubation time with respect to patient age, newborn, preoperative weight, preoperative pneumonia, CPB time, ACC time, and operation time ($p<0.001$) were statistically significant. No differences were noted between extubation time and sex ($p=0.349$).

Outcomes

Table 2 shows the outcomes of the patients in different groups. The overall reintubation rate was 2.0% (41 of 2,060). Seven (7) (0.5%) patients who were extubated in the operating room required reintubation. Of the children extubated within 6 hours, five (1.5%) required reintubation and 29 (7.4%) who were extubated after 6 hours (DE) required reintubation. Postoperative extubation (IE) and EE were associated with lower rates of reintubation than DE (0.5% and 1.5% vs 7.4%, $p<0.001$). The overall rate of NCPAP after extubation was 6.4% (131 of 2,060). IE and EE were associated with lower NCPAP rates compared with DE (0.7% and 3.3% vs 28.5%, $p<0.001$). The following patients required NCPAP: 111 of the 390 (28.5%) DE patients, nine of the 1,339 (0.7%) IE patients, and 11 of the 331 (3.3%) EE patients. The median (IQR) length of stay in the ICU and hospital was 1.9 (0.9–2.8) days and 6 (5–9) days, respectively. IE and EE were associated with shorter length of stay in the ICU (median, 1.5 and 1.9 vs 3.8 days; $p<0.001$) and hospital (median, 6 and 7 vs 10 days; $p<0.001$) compared with DE.

Table 2 Outcomes of the patients in different groups.

Outcomes	Total sample (n=2,060)	Immediate postoperative extubation (n=1,339)	Early extubation (n=331)	Delayed extubation (n=390)	P-value
Reintubation	41 (2.0)	7 (0.5)	5 (1.5)	29 (7.4)	<0.001
NCPAP after surgery	131 (6.4)	9 (0.7)	11 (3.3)	111 (28.5)	<0.001
ICU stays (d)	1.9 (0.9–2.8)	1.5 (0.9–2.6)	1.9 (1.1–2.8)	3.8 (2.8–5.6)	<0.001
Hospital stays after surgery (d)	6 (5–9)	6 (5–7)	7 (6–10)	10 (7–13)	<0.001

Abbreviations: NCPAP, nasal continuous positive airway pressure; ICU, intensive care unit.

Table 3 Multivariable regression model for immediate postoperative extubation.

Factors	OR (95% CI)	P-value
Preoperative weight	1.24 (1.20–1.29)	<0.001
Preoperative pneumonia	0.60 (0.44–0.80)	0.001
CPB type	1.23 (1.06–1.43)	0.006
CPB time	0.98 (0.98–0.99)	<0.001
DHCA	0.42 (0.25–0.70)	0.001
STAT categories	0.54 (0.45–0.65)	<0.001

Abbreviations: OR, odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery.

Table 5 Multivariable regression model for immediate postoperative extubation in non-newborns.

Factors	OR (95% CI)	P-value
Preoperative weight	1.23 (1.18–1.27)	<0.001
Preoperative pneumonia	0.55 (0.41–0.75)	<0.001
CPB type	1.22 (1.04–1.42)	0.012
CPB time	0.98 (0.97–0.98)	<0.001
DHCA	0.37 (0.19–0.71)	0.003
STAT categories	0.53 (0.44–0.65)	<0.001

Abbreviations: OR, odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery.

Multivariable Analysis

Tables 3 and 4 show the last multivariable logistic regression models for IE and EE after stepwise, respectively. Preoperative weight (OR, 1.24; 95% CI, 1.20–1.29), preoperative pneumonia (OR, 0.60; 95% CI, 0.44–0.80), CPB type (OR, 1.23; 95% CI, 1.06–1.43), CPB time (OR, 0.98; 95% CI, 0.98–0.99), DHCA (OR, 0.42; 95% CI, 0.25–0.70), and STAT categories (OR, 0.54; 95% CI, 0.45–0.65) were included in the IE model. However, in addition to the above six variables, ultrafiltration (OR, 0.63; 95% CI, 0.44–0.89) was also included in the EE model.

It is easy to use mechanical ventilation after surgery for newborns because of neonatal airway insufficiency. Thus, newborns were excluded and a subgroup analysis was performed on the non-newborn population. The last multivariable logistic regression models for IE and EE of the non-newborn population are shown in Tables 5 and 6. Interestingly, the influencing factors for IE in the non-newborn population were the same as for the total population. However, the influencing factors for EE in the non-newborn population only included preoperative weight (OR, 1.23; 95% CI, 1.17–1.30), preoperative pneumonia (OR, 0.55; 95% CI, 0.38–0.79), ultrafiltration (OR, 0.43; 95% CI, 0.31–0.58), CPB time (OR, 0.97; 95% CI, 0.97–0.98), and STAT categories (OR, 0.47; 95% CI, 0.38–0.58).

Table 4 Multivariable regression model for early extubation.

Factors	OR (95% CI)	P-value
Preoperative weight	1.29 (1.22–1.36)	<0.001
Preoperative pneumonia	0.69 (0.49–0.97)	0.033
CPB type	1.29 (1.01–1.66)	0.044
CPB time	0.98 (0.98–0.99)	<0.001
Ultrafiltration	0.63 (0.44–0.89)	0.010
DHCA	0.62 (0.39–0.98)	0.005
STAT categories	0.50 (0.41–0.61)	<0.001

Abbreviations: OR, odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery.

Discussion

Although extubation in the operating room after congenital heart surgery is becoming common practice, these results present successful experience with early extubation. They also confirm that early extubation was influenced by age, preoperative weight, preoperative pneumonia, CPB type, CPB time, DHCA, ultrafiltration, and STAT categories. Moreover, through subgroup analysis, it was found that the factors affecting early extubation in a non-newborn population were somewhat different from the total population.

As previous studies have reported, patient age, weight at surgery, preoperative cardiopulmonary status, anaesthetic drug dose, procedure complexity, duration of CPB, ACC time, procedure complexity, and other factors can be independent predictors of early extubation [11,16–18]. Abuchaim et al. performed a retrospective data analysis and indirectly supported the association between the CPB time and EE [19].

Table 6 Multivariable regression model for early extubation in non-newborns.

Factors	OR (95% CI)	P-value
Preoperative weight	1.23 (1.17–1.30)	<0.001
Preoperative pneumonia	0.55 (0.38–0.79)	0.001
Ultrafiltration	0.43 (0.31–0.58)	<0.001
CPB time	0.97 (0.97–0.98)	<0.001
STAT categories	0.47 (0.38–0.58)	<0.001

Abbreviations: OR, odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery.

They considered that if the CPB time was short or absent, more children could be extubated early after cardiac surgery. The current analysis considered some intraoperative factors that others did not consider such as ultrafiltration, the type of CPB, and bloodless priming. However, the type of CPB actually refers to the CPB strategies: miniaturised CPB and CPB with retrograde autologous priming tend to be associated with early extubation. Moreover, children with ultrafiltration tend to have delayed extubation or extubation failure.

In terms of STAT categories, Miller et al. [20] conducted a retrospective analysis of procedural characteristics for successful extubation in the operating room immediately following infant heart surgery, and they confirmed that higher STAT-category patients had a higher risk of failure of extubation in the operating room. Extubation in the ICU and a reasonable period of postoperative mechanical ventilation in cardiac surgical patients has previously been the routine, with the purpose of reducing myocardial demand. However, with the improvement of surgical techniques and CPB technology, cardiac function can be maintained well after surgery; thus, it is important to try to extubate as soon as possible to reduce ventilator-associated complications. Patients with complex congenital heart disease have a slower recovery of postoperative cardiac function, and they require mechanical ventilation to reduce myocardial demand. Therefore, patients with higher complexity category tend to have delayed extubation or extubation failure.

Newborns, as a special population, often have high rates of preoperative mechanical ventilation and preoperative pneumonia; thus, extubation after surgery is often delayed [18,21]. Of the 143 newborns who were analysed in the current study, 112 (78%) had delayed extubation. Therefore, a subgroup analysis was conducted for non-newborns. It was found that the types of CPB and DHCA were not the influencing factors for early extubation in non-newborns. This may be related to the unbalanced distribution of these two factors in newborns and non-newborns. Older children tend to have CPB with retrograde autologous priming, and fewer older children have DHCA.

One of the strengths of this paper is worth considering. Many papers discussing early extubation in the past have cited excessive intraoperative narcotic use as a predictor of failed immediate or early extubation [22,23]. However, this association did not play a large part in failed extubation in the current patients because of standardised perioperative dosing of narcotics.

There were some limitations that should be considered. First, the study was limited to a single-centre database, and the retrospective analysis had the inherent limitations of its design. Second, many clinical outcomes after surgery were not addressed in the analysis, including detailed complications and mortality. Although short-term outcomes were considered when presenting early extubation, the distribution between EE and long-term clinical outcomes could not be shown. Third, the influencing factors included in the multivariable models were few, especially lack of pregnancy factors and genetic factors.

Conclusions

Implementing an early extubation strategy for children with congenital heart surgery was successful in this hospital. Patients with early extubation had a lower reintubation rate and NCPAP rate, and a shorter length of stay in the ICU and hospital. Early extubation was influenced by age, weight at surgery, preoperative pneumonia, CPB type, CPB time, DHCA, ultrafiltration, and STAT categories. It is hoped that these findings can be further confirmed by conducting future multi-centre research studies.

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Competing Interest Statement

None.

Conflicts of Interest

There are no conflicts of interest to disclose.

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