Original Article

One-Year Experience after Adoption of an On-Table Extubation Protocol Following Pediatric Cardiac Surgery

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ABSTRACT

Objective: To report our initial experience with on-table extubation following cardiac surgery for congenital heart disease, assessing its efficacy and safety, and the potential for fast-tracking these patients through the intensive care unit (ICU).

Methods: We decided to implement a multidisciplinary protocol aiming toward on-table extubation following congenital cardiac surgery at our hospital. Between December 2018 and January 2020, 376 patients underwent congenital cardiac surgery. The management strategy involved choosing the patients preoperatively, a specific anesthetic technique, application of a standard extubation protocol, multidisciplinary team approach, and perioperative echocardiogram for assessment of surgical repair. Relevant data were collected and analyzed.

Results: Out of the 376 patients who underwent congenital cardiac surgery during the study period, 44 patients were extubated on-table. Although a majority of these patients belonged to Risk Adjustment for Congenital Heart Surgery-1 score (RACHS-1) 1 and 2 categories, 18% of the patients who were extubated on-table were of RACHS-3 category. This included a wide spectrum of anatomical substrates such as endocardial cushion defects, pulmonary venous anomalies, single ventricle physiology, valvular defects, and others such as cor triatriatum and sinus of Valsalva aneurysm. There was no in-hospital mortality related to on-table extubation. Only one patient was reintubated following on-table extubation resulting in a reintubation rate of 2.27% among those patients extubated on-table. The patients extubated on-table had a shorter ICU stay (25.89 ± 7.20 h) compared with those patients who underwent delayed extubation (59.30 ± 6.80 h). The duration of the hospital stay was also significantly reduced in these patients (91.09 ± 20.40 h) leading to an earlier discharge compared with those patients who underwent delayed extubation (134.40 ± 16.20 h).

Conclusion: On-table extubation is an attractive alternative in limited-resource environments to enhance recovery in patients following congenital cardiac malformations. Owing to the lack of significant comorbidities such as Chronic Obstructive Pulmonary Disease (COPD) in this patient population, corrective surgery for cardiac malformation usually optimizes the cardiorespiratory status. This results in more chances of successful extubation immediately following surgery. However, this requires proper perioperative planning, a careful discussion about the choice of patients, adoption of an extubation protocol, and most importantly, a multidisciplinary team approach. It is associated with low morbidity and mortality, with reduced length of stay in the ICU and hospital. This preliminary study demonstrated that on-table extubation is feasible following congenital cardiac surgery at our center and greatly reduces the intensive care requirements. This article focuses mainly on the decision-making process which determines the ideal candidates for on-table extubation and the anesthetic protocol implemented in a low-resource environment to enable the same.

Keywords: On-table extubation, Fast-tracking, pediatric cardiac surgery

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INTRODUCTION

Congenital heart disease accounts for a large number of patients undergoing surgical intervention in the pediatric age group. This requires a complicated interaction among multiple healthcare departments, including cardiology, surgery, anesthesia, critical care, nursing, respiratory therapy, and nutrition.

With healthcare reforms, there is a continued focus to improve patient outcomes while reducing costs.[1] Cardiac surgery is the only type of elective surgery where immediate extubation is not considered a routine procedure. This is due to the higher dose of opioid agents used to suppress the stress response associated with surgery, risk of postoperative bleeding, and reduced tolerance of perioperative hemodynamic perturbations.

Early extubation was a common practice following cardiac surgery in the 1960s. This was more due to a lack of the availability of ventilators and adequate knowledge of respiratory mechanics. However, this practice lost favor in the latter half of the twentieth century due to increasing focus on the suppression of the inflammatory response with high-dose opioid analgesia.

The practice of early extubation received a renewed interest in the 1980s. In 1984, Schuller *et al.* reported that early extubation after pediatric cardiac surgery has minimal risk in carefully selected patients.[2]

However, it is yet to become a common practice following pediatric cardiac surgery due to the number of challenges imposed by the immature organ systems seen in this age group and their unpredictable response to cardiopulmonary bypass. This problem is compounded by the presence of pulmonary hypertension, the complex nature of surgeries performed, and limited respiratory reserve in these patients.[3]

In developing countries, on-table extubation offers an attractive option owing to the economic issues and resource constraints. Even though the financial benefits may be limited in an already cash-strapped pediatric cardiac surgery environment, the strategy assumes special significance in the presence of bed shortages in a vastly populated country like India. Our hospital has a two-bedded pediatric cardiac surgical intensive care unit (ICU) (where 376 patients recovered after congenital heart surgery last year), which, therefore, necessitates a patient-care strategy with rapid turnover.

On-table extubation offers a multitude of benefits such as the reduced need for sedation, early initiation of feeding, early parental interaction, and reduced incidence of ventilator-associated pneumonia. This expedites the recovery process with minimal iatrogenic physiological alterations. Such a drastic change in practice, however, requires a significant alteration in the mindset of the entire surgical team, including the physicians and nursing staff. Here, we present our initial experience with the development of an immediate extubation protocol, our challenges faced, and early outcomes after the adoption of such a protocol.

MATERIALS AND METHODS

Patient selection

Patients undergoing congenital heart surgery between December 2018 and January 2020 were included in this study. Overall, 376 patients were evaluated for on-table extubation in this observational study. All patients aged more than 1 year with Risk Adjustment for Congenital Heart Surgery (RACHS) 1, 2, and 3 statuses were considered potential candidates for on-table extubation. The anesthetic technique was modified accordingly in these patients (ethical approval 14 July 2018). The pre-requisites for considering on-table extubation in these patients were the following:

1. Stable hemodynamics with:
    a. Absence of hemodynamically unstable arrhythmias
    b. Pacing independent
    c. Vasoactive inotropic score <10.
2. Echocardiographic parameters:
    a. Absence of residual shunts
    b. Absence of Left ventricular (LV) dysfunction.
3. Coagulation parameters:
    a. ACT <140 s
    b. Absence of active surgical bleeding during sternal wiring.
4. Other parameters:
    a. Rectal temperature >35.5°C
    b. Rectal-nasal temperature difference <2°C
    c. Cardiopulmonary bypass time (CPB) time <120 min.
5. Respiratory dynamics:
    a. Absence of difficult intubation
    b. Physiologically appropriate SpO_2 and E_TCO_2
    c. Presence of ET tube leak.

Patients who were excluded were:

1. Syndromic patients
2. Those who were ventilated preoperatively
3. Complex surgical repairs
4. Residual defects on Trans-esophageal echocardiography (TEE)
5. Postoperative arrhythmias
6. Poor lung compliance <0.5 mL/kg/cm H_2O
7. Poor ventricular function.

Anesthetic technique

Patients who were considered as candidates for on-table extubation received a tailored anesthetic technique. These cases were done by one of two pediatric cardiac anesthetists and a single pediatric cardiac surgeon.

All patients were induced intravenously with propofol or ketamine as determined by their physiology. Neuromuscular paralysis was achieved and maintained with vecuronium. Intraoperative analgesia was maintained with titrated fentanyl boluses. Tranexamic acid 100 mg/kg was given at induction and the same dose was repeated on CPB.

A single anesthesia machine (GE Avance CS_2 model, Model number G 1500213, GE Healthcare, Chicago, Illinois) was used for anesthetic management. All patients were ventilated with pressure-controlled ventilation volume-guaranteed (PCV-VG) mode of ventilation with a tidal volume of 8–10 mL/kg and the respiratory rate adjusted to the $PaCO_2$. Balanced anesthesia was maintained with isoflurane for all patients. CPB was initiated with aortic and venous cannulation following heparinization with 300 units/kg unfractionated heparin. Most patients received the last dose of neuromuscular blocking agents on initiation of CPB. The anesthetic plane was maintained on CPB by the administration of fentanyl (2–3 μg/kg) and midazolam (0.05–0.2 mg/kg) into the venous reservoir on initiation of CPB. Sevoflurane was administered continuously by means of a vaporizer inserted into the gas supply line of the CPB circuit. The patients were not paralyzed following the termination of CPB.

On termination of CPB, the patients were assessed for adequacy of surgical repair and ventricular function using transesophageal echocardiography (Philips IE 33 system, Philips Healthcare, Andover, MA). Following the confirmation of optimal echocardiographic parameters, arterial blood gas samples were taken to rule out any metabolic acidosis. Subsequently, the patients were weaned from PCV-VG mode to Synchronized intermittent mandatory ventilation mode SIMV-PCV-VG = Pressure controlled ventilation- volume guaranteed mode and CPAP + PSV mode. Lung compliance was continually monitored during ventilatory weaning to ensure optimal pulmonary function. Recruitment maneuver was performed in all the patients prior to sternal closure with visual confirmation of lung expansion. In all the patients, weaning to Continuous Positive Airway Pressure (CPAP) mode with optimal triggers was accomplished by the time the sternal wires were inserted. Once the patients were weaned to the CPAP mode, additional analgesia was provided in the form of paracetamol (infused over 20 min) and clonidine boluses (up to 2 μg/kg) to maintain immediate postoperative analgesia.

By the time of skin closure, all the patients were weaned to spontaneous ventilation with isoflurane administration to maintain the depth of anesthesia. A local anesthetic (0.25% bupivacaine 1 mL/kg) was infiltrated subcutaneously at the incision and intercostal drain insertion sites prior to skin closure. During this time, neuromuscular blockade was reversed with neostigmine and glycopyrrolate infused over 10 min. Arterial blood gas samples were taken to determine the adequacy of respiratory efforts. The patients were then extubated following confirmation of respiratory effort (tidal volume >5 mL/kg) and pattern in deep planes. Deep plane was preferred to prevent movement and dislodgement of drains and catheters in all the patients. The airway was assessed for obstruction before leaving the operation theater. In the presence of airway obstruction, airway positioning or nasal airway was inserted.

Following extubation, the patients were shifted into the postoperative ICU where they were taken care of by an independent pediatric cardiac intensivist. On arrival in the ICU, the patients were assessed for respiratory effort and pattern. An arterial blood gas analysis was performed to confirm the adequacy of ventilation following extubation. Early use of non-invasive ventilation was initiated in those patients with borderline ventilatory mechanics as evidenced by a $PaCO_2$ >55 mmHg and pH <7.30. Failure of improvement following initiation of Non-invasive ventilation (NIV) was treated with endotracheal intubation.

Statistical methods

Data entries were made in the Microsoft Excel software in codes and analysis was done with the SPSS-20 computer package. Categorical variables are expressed as percentages whereas continuous variables are expressed as mean ± standard deviation. The correlation between the continuous variable is determined by Pearson correlate (*r*) and *P* value <0.05 is considered statistically significant.

RESULTS

Overall, 376 patients underwent corrective surgery for congenital heart disease during this observational study. We were able to successfully extubate 44 patients on-table using the study protocol. Early extubation (within 6 h) was accomplished in 207 patients (55.05%). Among those patients who were fast-tracked, 102 patients (49.27%) were extubated within 2 h of surgery (ultrafast-tracking). The remaining 105 patients (50.72%) were extubated 2–6 h following surgery. Thus, we were able to extubate close to one-third of our patients (27.12%) within 2 h of surgery.

More than half the patients who were extubated on-table were less than 5 years of age (52.3%), with a mean age of 7.86 ± 7.56 years. A detailed break-up of the age-wise distribution of the patients has been provided in Table 1. A majority of these patients belonged to RACHS 1 and 2 categories (81.8%). The aortic cross-clamp time and CPB time for these patients were 40.56 ± 13.16 and 60.41 ± 17.75 min, respectively. The time to shifting the patient from the time of the application of surgical dressing was 18.72 ± 3.68 min. The average duration of surgery and anesthesia was 166.70 ± 48.05 and 224.20 ± 47.51 min, respectively.

Table 1: Demographic data

Table 2: Risk Stratification

Table 3: Disease spectrum

The mean PaO_2 and $PaCO_2$ values in the patients extubated on-table were 128.30 ± 35.445 and 45.80 ± 8.20 mmHg. Almost all patients had mild respiratory acidosis on shifting to the ICU. Thirteen patients required non-invasive ventilatory support to optimize blood gases. In these patients, the mean PaO_2 and $PaCO_2$ values were 110.07 ± 22.76 and 58.92 ± 2.95 mmHg. The average duration of non-invasive ventilation in these patients was 4.95 ± 10.42 h. Eighteen patients (40.90%) required no inotropic or vasodilator support to maintain postoperative hemodynamic stability. Oral feeds were initiated after 8.91 ± 4.345 h and intercostal drains were removed after 21.16 ± 6.871 h.

The lung compliance measurements following termination of CPB were studied in relation to immediate post-extubation $PaCO_2$ and PaO_2 values for any correlation using Pearson's correlation coefficient.

There was a strong negative correlation between post-extubation $PaCO_2$ and post-CPB lung compliance values. Pearson's correlate was found to be ($r = -0.784$) which was statistically significant ($P < 0.001$). This suggested that patients who had lower lung compliance had higher post-extubation $PaCO_2$ values.

Table 1: Demographic data

Variable	Category	Frequency (*n*)	Percentage
Age	<5 years	23	52.3
	5-10 years	8	18.2
	>10 years	13	29.5
Weight	<10 kg	9	20.5
	10-20 kg	20	45.5
	>20 kg	15	34.1
CPB time	≤45 min	10	22.7
	45-90 min	31	70.5
	>90 min	3	6.8
ACC time	< 30 min	14	31.8
	30-60 min	27	61.4
	>60 min	3	6.8
Hospital stay	72-96 h	19	43.2
	96-120 h	23	52.3
	≥ 120 h	2	4.5

Table 2: Risk stratification

RACHS	Frequency	Percent
1	21	47.7
2	15	34.1
3	8	18.2
Total	44	100.0

Table 3: Disease spectrum

Diagnosis	Frequency
Endocardial Cushion Defects	
ASD	12
VSD	5
Partial AV canal defect	4
Tetralogy of fallot	3
Pulmonary venous anomalies	
TAPVC (total anomalous pulmonary venous connection)	2
PAPVC (partial anomalous pulmonary venous connection)	7
Single ventricle physiology	
Modified BT shunt	2
Completion fontan	1
Valvular defects	
Mitral valve repair	1
Mitral valve replacement	
Others	
Sub-aortic membrane excision	1
Ruptured sinus of valsalva aneurysm	1
Coarctation of aorta	2
Cortriatriatum	1
Division of vascular ring	1

Table 4: Correlation between lung compliance and $PaCO_2$

Correlation Between	Pearson Correlate	*P*
$PaCO_2$ (mmHg) Lung compliance (mL/Kg/cmH_2O)	-0.784	<0.001

Figure 1: Correlation between $PaCO_2$ and lung compliance

Table 4: Correlation between $PaCO_2$ and lung compliance

The correlation between post-extubation PaO_2 and lung compliance was also studied similarly. Pearson's correlate was found to be ($r = 0.375$) which indicates that there was a positive moderate correlation between the PaO_2 values

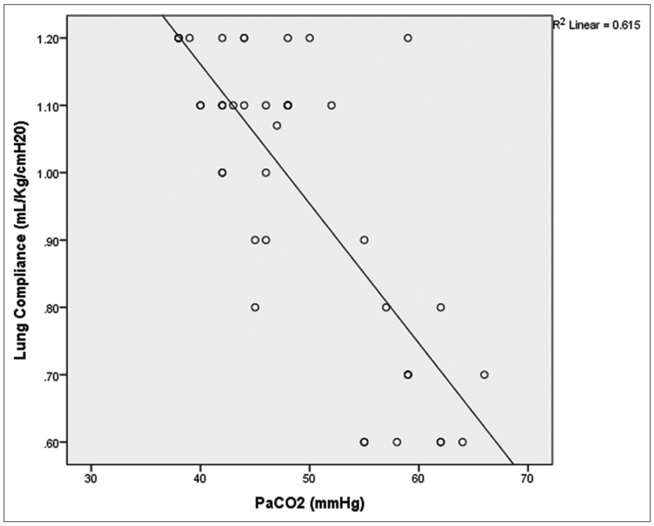

Figure 1: Correlation between lung compliance and $PaCO_2$

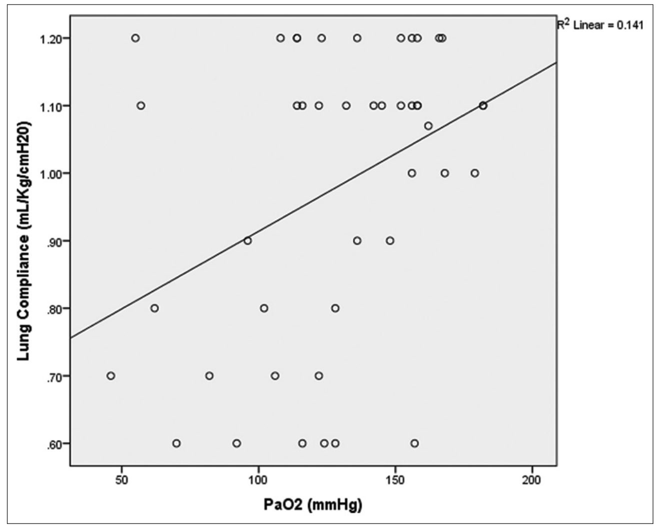

Figure 2: Correlation between PaO_2 and lung compliance

Table 5: Correlation between lung compliance and PaO_2

Correlation Between	Pearson Correlate	*P*
PaO_2 (mmHg) Lung compliance (mL/Kg/cmH_2O)	0.375	0.012

and lung compliance. This was found to be statistically significant (P = 0.012). Thus, patients with lower postoperative lung compliance had poorer post-extubation oxygenation status.

Figure 2: Correlation between PaO_2 and lung compliance

Table 5: Correlation between PaO_2 and lung compliance

There was no in-hospital mortality related to on-table extubation. Only one patient was reintubated following on-table extubation resulting in a reintubation rate of 2.27%. This 12-year-old patient was operated on for sinus venosus Atrial Septal Defect (ASD) closure and partial anomalous pulmonary venous connection (PAPVC) re-routing and developed severe respiratory acidosis refractory to non-invasive ventilatory support following extubation.

The patients extubated on-table had shorter ICU stay (25.89 ± 7.20 h) compared to those patients who underwent delayed extubation beyond 6 h postoperatively (59.30 ± 6.80 h). The duration of hospital stay was also significantly reduced in these patients (91.09 ± 20.40 h) leading to an earlier discharge compared with those patients who underwent delayed extubation (134.40 ± 16.20 h).

DISCUSSION

Multiple clinical studies have shown that most children undergoing congenital heart surgery can be extubated in the operating room.[4] This has been greatly aided by improvement in surgical techniques and better CPB management such as reduced circuit sizes for pediatric patients.[5] However, the anesthetic technique plays a key role in determining successful outcomes after on-table extubation.

Early extubation has been associated with lower morbidity, shorter lengths of ICU and hospital stay.[6] This may be partly related to the mitigation of problems directly associated with endotracheal tubes such as subglottic edema, tracheomalacia, tube obstruction, mucus plugging, kinking, and the risk of accidental extubation.[7] Extubation also avoids the barotrauma which accompanies positive pressure ventilation, along with atelectasis and pulmonary infections.[8] This said, early extubation failure has been shown to cause increased morbidity and prolongs hospital stay, thus doing more harm than benefit.[9]

Thus, patient selection is a key determinant of a successful outcome following immediate extubation as has been elucidated by multiple studies.[10-12] Thus, we decided to only consider patients beyond 1 year of age with lower RACHS score for immediate extubation following surgery. Age was found to be an important predictor of successful extubation in the previous studies as well.[13,14]

Although patient selection may be done preoperatively based on the physiological characteristics of the patients, it is most often a continuous ongoing evaluation during surgery which includes careful evaluation of the complexity of surgery accommodating any change in the surgical plan, residual defects post-surgery, anesthetic requirements, ventilatory requirements, and last but not the least, the ever-present potential for postoperative bleeding. Thus, even though only one out of approximately nine patients were extubated on-table after consideration of all these factors, our reintubation rate was very low at 2.27% (less than 3%). This was the key to ensuring the sustainability of such a protocol in a limited-resource pediatric cardiac unit.

The two main criteria we used intraoperatively for on-table extubation were hemodynamic stability with adequate lung compliance. In the absence of other comorbidities such as smoking and COPD in the pediatric population, optimization of the cardiopulmonary status usually guarantees a successful outcome following extubation. Also, lung compliance and ventricular function are usually well-preserved in this population as a result of which immediate extubation is better tolerated. However, an accurate assessment of the physiological adaptation post-repair has to be made and this was done in our study using transesophageal echocardiography, arterial blood gases, and constant monitoring of pulmonary compliance. This said, many patients have long-standing pulmonary hypertension which may not resolve at the end of the surgery. Ventricular function, too, can worsen in the few hours following surgery. Thus, due vigilance should be exerted in this regard by the intensivist in the early postoperative hours.

The maintenance of the perioperative anesthetic plane and optimal analgesia is the key to ensuring patient compliance following surgery. Thus, maintaining the anesthetic planes during the key instances of surgery such as intubation, surgical incision, sternotomy, and initiation of cardiopulmonary bypass is important. In this regard, the timing of the opioid doses rather than the total opioid dose plays a key role. Low-dose opioid analgesia (<10 μg/kg fentanyl) has been associated with a greater postoperative stress response.[15] However, by supplementing opioids at key intervals during the surgery, the postoperative stress response was blunted as evidenced by the absence of metabolic acidosis in our patients.

Also, analgesia was supplemented with non-opioid analgesics such as paracetamol and single-dose clonidine administered just prior to extubation. Clonidine has been used successfully for postoperative sedation following pediatric cardiac surgery in multiple previous studies.[16,17] Clonidine is a long-acting drug with elimination half-life ranging from 12 to16 h.[18] The administration of clonidine toward the end of surgery enabled a combined multimodal analgesic regimen which extended well into the postoperative period.[19] Clonidine also minimized the hemodynamic perturbations during extubation. This was particularly significant considering the cost constraints of using a dexmedetomidine infusion postoperatively in a low-resource setting. Regional blocks given at the start of surgery can give prolonged analgesia lasting well into the postoperative period. Various neuraxial interventions that have been used in pediatric cardiac anesthesia include thoracic epidural, caudal epidural, and subarachnoid approaches administering single bolus or continuous infusion of local anesthetics, opioids, and alpha-2 agonists.[20] Recently, muscle plane blocks such as the erector spinae block, and a combination of transverse thoracic muscle plane block and rectus sheath block have been added to the cardiac anesthesiologists' armamentarium to provide additional analgesic alternatives following pediatric cardiac surgery.[21,22]

Postoperative bleeding is a clear and ever-present danger following cardiac surgery. The risk is compounded manifold with on-table extubation owing to the absence of airway control in the event of hemodynamic deterioration. Thus, an accurate assessment of surgical bleeding and coagulation status is imperative prior to chest closure. This requires mutual communication and confidence between the surgical and anesthetic teams. In our institute, this was ensured by retaining a constant anesthetic and surgical team for all on-table extubation cases to guarantee an objective assessment of the possibility of excessive postoperative bleeding. Thus, none of the patients who were extubated on-table required re-intervention for excessive postoperative bleeding.

CONCLUSIONS

Immediate on-table extubation is a feasible and cost-effective strategy following congenital heart surgery. However, this involves a paradigm shift in the physicians' thought process and practice from the comfort of delayed extubation in the ICU. Thus, it is challenged by natural physician inertia which can be overcome by adopting an on-table extubation protocol and multi-departmental enthusiasm. This said, accurate assessment of almost every step of the surgical process is required as an error at any stage can adversely impact patient outcomes. Nursing education and an enthusiastic respiratory therapy team also play a key role in ensuring the success of such a program.

The development of a center-specific protocol greatly aids in ensuring the successful implementation of such a program. However, patient selection plays a key role in ascertaining the longevity of such a program as reintubation in the initial stages is bound to raise apprehensions about the protocol. Thus, the success of an on-table extubation program is not difficult to achieve in a limited-resource environment, provided patient selection, execution of the protocol, and clinical judgment are done diligently. Also, retaining a constant perioperative team with mutual trust is quintessential in maintaining personnel comfort during the evolution of such a program.

Limitations

The depth of anesthesia or neuromuscular blockade was not monitored in our study. The impact of on-table extubation on the cost of therapy was not assessed in our study. Further evaluation on the protocol's competence, when extrapolated into the infant population, is required. The use of regional anesthetic techniques may reduce the dependence on opioid analgesia further, which has not been evaluated in this study.

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Conflicts of interest

There are no conflicts of interest.

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