Review Article

Fast-tracking in pediatric cardiac surgery – The current standing

Alexander JC Mittnacht, Ingrid Hollinger
Department of Anesthesiology, The Mount Sinai Medical Center, New York, NY

ABSTRACT

Fast-tracking in cardiac surgery refers to the concept of early extubation, mobilization and hospital discharge in an effort to reduce costs and perioperative morbidity. With careful patient selection, fast-tracking can be performed in many patients undergoing surgery for congenital heart disease (CHD). In order to accomplish this safely, a multidisciplinary coordinated approach is necessary. This manuscript reviews currently used anesthetic techniques, patient selection, and available information about the safety and patient outcome associated with this approach.

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INTRODUCTION

Fast-tracking in cardiac surgery refers to the concept of early extubation, mobilization and hospital discharge in an effort to reduce costs and perioperative morbidity.[1,2] Fast-tracking is not restricted to anesthetic management and is only made possible by using effective multidisciplinary patient management strategies. Economic concerns such as significant increases in overall medical expenses, decreased reimbursement, a highly competitive market, and the accumulating data that patient's care is not jeopardized but rather perioperative morbidity may actually be reduced by early hospital discharge, have made the concept of fast-tracking attractive for practitioners involved in the care of children with congenital heart disease (CHD) as well. This manuscript reviews the current data on fast-tracking for surgery for CHD, currently used anesthetic techniques, patient selection, and available information about the safety and patient outcome associated with this approach.

BACKGROUND

In the early days of surgery for CHD, the anesthetic technique predominantly involved the use of potent inhalational anesthetics that allowed early extubation within a few hours after surgery. Early extubation was almost a necessity as only unreliable ventilators not suitable for prolonged mechanical ventilation in small children, and sedative drugs with unknown effects in this patient population were available. Costs played a significant role even in the late 70s and early 80s. Introduced in 1980, and implemented nationally in 1983, Diagnosis Related Groups (DRG) have been used in the US to determine how much a hospital gets reimbursed by Medicare for particular cases. Less resource use and shorter ICU/hospital stay translated into more money for the hospitals already struggling with exponentially rising expenses. In 1980, Barash and colleagues published their experience with early extubation in 197 patients less than three years of age including neonates; 61% were successfully extubated in the operating room (OR).[3] The authors mention that "in this era of cost containment, any technique that allows maximal use of resources without jeopardizing patient safety is welcome". This statement seems even more appropriate at present, with cost issues being even more concerning today as compared to 30 years ago.

In 1984, Schuller and colleagues reported on 209 consecutive children undergoing complex

Address for correspondence: Alexander JC Mittnacht, The Mount Sinai Medical Center, One Gustave L. Levy Place, Box 1010, New York, NY USA 10029.
E-mail: alexander.mittnacht@msnyuhealth.org

open-heart surgery with 88% of those older than 12 months extubated in the OR.[4] The authors concluded that early extubation after open-heart surgery for CHD has minimal risk in carefully selected patients. In the same year, Heard *et al.* published their experience on early extubation following surgery for CHD in 220 patients, of which 147 (67%) were extubated in the OR, or within six hours in the ICU.[5] None of the patients required reintubation. Early extubation was associated with lower costs due to earlier ICU/hospital discharge and less use of resources. Following this initial experience with early extubation in surgery for CHD, the next two decades saw a rapid development of new surgical techniques that allowed the palliation and repair of more complex congenital heart defects in even younger children. At the same time, an opioid-based anesthetic had become the standard of care in adult as well as pediatric cardiac surgical patients. A high-dose opioid anesthetic technique had proved to provide hemodynamic stability in these high-risk patients many of them with marginal cardiac reserve. However, a high-opioid technique required prolonged mechanical ventilation following surgery. In the early 90s, reports about early extubation and rapid hospital discharge in patients undergoing adult coronary artery bypass grafting surgery appeared.[6] The feasibility and safety of such a 'fast-tracking' approach was later shown in large case series in patients undergoing adult cardiac surgery. It became apparent that fast-tracking in cardiac surgery is safe, reduces costs, leads to improved patient/parent satisfaction, and may actually benefit the patient.[7] This was made possible, in large part, by the introduction of improved and new anesthetic agents such as modern inhalational anesthetics, short-acting opioids, hypnotics and sedatives with favorable pharmaco-dynamics and kinetic profiles. Consequently, a high-dose opioid anesthetic technique is rarely used in today's adult cardiac surgical practice. However, a high-dose opioid anesthetic technique is still a common practice in many centers specializing in surgery for CHD. There are large institutional differences with respect to pediatric cardiac patient management. While certain centers adopted a fast-tracking concept and attempted extubation in the OR or within a few hours following surgery, others still routinely continue mechanical ventilation and deep sedation postoperatively for a day or two in the intensive care unit (ICU).

CURRENT DATA ON FEASIBILITY OF FAST-TRACKING IN SURGERY FOR CHD

A summary of the current literature on the feasibility of fast-tracking in surgery for CHD is presented in Table 1. It immediately becomes apparent that fast-tracking in surgery for CHD is feasible in simple as well as complex surgical cases for all age groups. It should also be noted, that the definition of 'early extubation,' which is a fundamental part of a fast-track approach to cardiac surgery is not consistent and poorly defined. Generally, the term 'early extubation' is used when the endotracheal tube is removed within six to eight hours after the surgery. However, early extubation has been associated with extubation in the OR and as late as 24 hours following surgery. Additionally, when reviewing the current literature and the reported success rate of early extubation following surgery for CHD, inclusion/exclusion criteria such as patient age and case complexity have to be considered.

ANESTHESIA TECHNIQUES

As mentioned above, fast-tracking pediatric cardiac cases requires an anesthetic technique that allows safe early extubation either at the end of the procedure in the OR, or within a few hours in the ICU. Therefore, a high-dose opioid technique is typically not used for this approach. One could argue that any patient could be awakened at the end of the surgery; however, the concern is the safety of such an approach. It is now well documented that with proper patient selection, and the use of modern anesthetic agents, various anesthetic techniques can be used to accomplish this goal. Table 2 summarizes anesthetic techniques reported in the methods section of more recent studies on fast-tracking in surgery for CHD, the anesthetic agents of choice, and the rate of early extubation.

The use of a neuraxial technique can be beneficial in an attempt to minimize the use of intravenous opioid administration in a fast-track protocol. The use of single shot intrathecal, or caudal morphine with or without local anesthetic has been reported, as well as the insertion of thoracic epidural catheters in children.[8] While there is no doubt that a neuraxial technique provides long lasting analgesia with significant opioid sparing effect, there still remains a controversy as to the safety, and benefits (outcome measures) of such an approach.[9,10] Compared to an indwelling epidural catheter, the risk of an epidural hematoma associated with a single shot technique should be even lower. Particularly in small children, a single shot caudal or spinal technique with a small-bore needle provides adequate pain control for several

Table 1: Results from current literature on the feasibility of fast-tracking in surgery for CHD

Author, Year published	Type of study	Patients enrolled	Findings
Neirotti *et al.*, 2002[43]	Retrospective	901 (s, c)	- 73% extubated in OR - Younger age, lower weight were factors for prolonged MV
Vricella *et al.*, 2000[46]	Retrospective	201 (s, c)	- 87% extubated in OR - Fast-tracking in surgery for CHD is feasible and safe
Davis *et al.*, 2004[78]	Retrospective Multivariate analysis	219 (≤36 mos) (s, c)	- 47% extubated within 24hrs
Heinle *et al.*, 1997[44]	Retrospective	56 (< 90days)	- 50% of neonates and young infants extubated in OR or within 3 hrs on ICU - 3 patients required reintubation - Patients extubated early had shorter ICU/hospital stay
Kloth *et al.*, 2002[62]	Retrospective	102 (> 2 mos) (s, c)	- 41% extubated in OR - Mild respiratory acidosis immediately following early extubation well tolerated - No patient reintubated
Mittnacht *et al.*, 2008[42]	Retrospective	224(> 1 month <18 years), (s, c)	- 79% in OR - No patient reintubated

mos = month of age, hrs = hours, wks = weeks, PHT = pulmonary hypertension, S = simple cases (e.g ASD, VSD), C = complex cases (e.g. TOF, AV canal, Fontan), MV : Mechanical ventilation.

Table 2: Anesthetic techniques reported in more recent studies on fast-tracking in surgery for CHD, the Anesthetic agents of choice, and rate of early extubation

Author, Year published	Patients enrolled	Early extubation protocol	Anesthetic agents	Neuraxial	Ultrafiltration	Extubation
Marianeschi *et al.*, 2000[64]	88, infants to adults	Yes	I: Sevoflurane, sufentanil M: Sufentanil, sevoflurane, midazolam	No	Not specified	80% within 2 hrs
Mittnacht *et al.*, 2008[42]	224, > 1 month <18 years	Yes	I: Sevoflurane, fentanyl, ketamine M: Isoflurane, fentanyl	Yes	Yes (conventional and MUF)	79% in OR
Cray *et al.*, 2001[79]	103, > 6 month < 18 years	Yes	I: Halothane, ketamine, thiopental, fentanyl M: Isoflurane, propofol, fentanyl	No	Not specified	54% within 6 hrs
Vricella *et al.*, 2000[46]	201, infants to 18 years	Yes	I: Halothane, Ketamine, Thiopental M: Isoflurane, fentanyl,	No	Yes (conventional)	87% in OR
Heinle *et al.*, 1997[44]	56, < 90 days	Not specified	I: Halothane, midazolam M: Isoflurane, fentanyl	Yes	Yes (conventional)	50% within 3hrs
Neirotti RA *et al.*, 2002[43]	901	Not specified	I: Halothane, sevoflurane, propofol, ketamine, pentothal M: Inhalational, fentanyl	No	Yes (conventional)	73% in OR
Peterson *et al.*, 2000[8]	220	No	Not specified	Yes	Not specified	89% in OR

MUF = modified ultrafiltration, I: Induction M: Maintenance

hours following surgery. Apart from providing superior analgesia, epidural or intrathecal opioids have been shown to blunt the stress response to surgery and CPB,[17-19] improved analgesia,[20-21] shorter time to extubation,[22,23] improved pulmonary function,[24] reduced time with mechanical ventilatory support and consequently reduced costs.[25]

With the help of modern short acting opioids, however, fast-tracking of pediatric cardiac patients can be achieved safely with or without neuraxial anesthesia. The short acting opioid remifentanil (not available in all countries) allows for a 'high-dose opioid' technique without the need for prolonged mechanical ventilation. Many fast-track anesthesia protocols include remifentanil to blunt stress response and to insure adequate analgesia. The use of non-opioids in the postoperative period has been advocated. The use of acetaminophen and ketorolac for supplementary postoperative pain control has been reported.[26,27] In 1999, the FDA approved the short acting alpha-2 agonist dexmedetomidine for use in adult patients, with additional changes in 2008 extending its use for sedation to 24 hours. There is currently no FDA approval for the use of dexmedetomidine in children.

However, since its introduction to the US market, it has been increasingly used in children of all age groups including the postoperative care of children following surgery for CHD.[28-31] Aside from its sedative properties, dexemedetomidine provides effective pain relief with an opioid sparing effect. This proves to be particularly helpful in spontaneously breathing patients in the ICU as part of an anesthetic regimen suited for early extubation.[32] Although hypotension and bradycardia have been reported as side effects,[33] in the author's experience, this is not of clinical significance in children following surgery for CHD.

Aside from the anesthetic management, the surgical technique, CBP management, and the postoperative ICU care are important factors for safe fast-tracking, especially with more complex surgery. Efforts should be made to reduce the inflammatory response typically seen with long CPB times and circulatory arrest. Various ultrafiltration techniques are already being used frequently,[34-36] and newer developments such as low priming volume CPB circuits for infants and small children,[37,38] and the use of hypertonic solutions,[39,40] are promising strategies to decrease blood transfusion requirements, extravascular lung water, and positive fluid balance, all of which can influence the fast-tracking. A detailed discussion about the pros and cons of these techniques is beyond the scope of this review.

FACTORS ASSOCIATED WITH PROLONGED MECHANICAL VENTILATION FOLLOWING SURGERY FOR CHD

Several studies report on factors that prevented early extubation in children following surgery for CHD [Table 3]. Typically it is the younger child undergoing complex surgery requiring a long CPB/aortic cross clamp time, with significant hemodynamic support that requires prolonged mechanical ventilation.[41,42] However, most currently available data are based upon retrospective analyses, and even fewer studies were analyzed with statistical methods that allowed for determining independent predictors of early extubation or failure to extubate. Often, it cannot be assessed retrospectively what the true intention to extubate was in the reported patient population, and what factors actually prevented extubation in a particular patient.

Despite these considerations, there are certain factors that are consistently associated with failure of early extubation and fast-tracking. Younger age is frequently found to be associated with prolonged mechanical ventilation following CHD surgery.[43,44] Often it is the preference of the anesthesiologist, surgeon, intensivists, or institutional policy not to extubate children below a certain age after CHD surgery. This is despite numerous publications of successful early extubation strategies in all age groups, including neonates.[44] Longer CPB time is also repeatedly reported to be associated with prolonged mechanical ventilation following CHD surgery.[4,5,8,46,47] This is not surprising , since longer CPB time is required for more complex cases or if unexpected difficulties occur. Furthermore, longer CPB time is associated with an increased risk of inflammatory response syndrome with generalized edema, decreased respiratory compliance, acute lung injury, and coagulopathy, all of which affect the ability to extubate a patient soon after surgery. Inotropic support after CPB is typically required in patients with compromised ventricular function. Low levels (e.g. Dopamine <5 μg/kg/min, Milrinone <0.5 μg/kg/min) of inotropic and vasoactive drugs typically do not prevent extubation in the OR, however, patients who require high-dose inotropic support are usually too hemodynamically unstable to allow for safe early extubation. While preoperative pulmonary hypertension has not been consistently cited as a risk factors for prolonged mechanical ventilation in children undergoing surgery for CHD,[42,48,49,51] significant pulomonary hypertension (PHT) following CPB (e.g. greater than two third systemic right sided pressures) would probably be considered by most practitioners as a contraindication for an early extubation strategy. Down's syndrome has also been documented to be a predisposing risk factor for failure to extubate early.[50,51] Since airway obstruction is more likely in Down's patients, it seems reasonable to carefully consider a fast-tracking technique in this patient population, particularly in younger patients and after long CPB times.

POTENTIAL BENEFITS OF FAST-TRACKING IN SURGERY FOR CHD

What are the potential benefits of fast-tracking in surgery for CHD and who is actually benefiting from it? Is patient outcome improved? Is parent satisfaction higher? And, if there are cost-savings associated with fast-tracking, who is the beneficiary? Potential advantages of fast-tracking children following surgery for CHD are:

1. Fewer ventilator associated complications such as:
   - Accidental extubation
   - Laryngotracheal trauma
   - Mucous plugging of endotracheal tube
   - Pulmonary hypertensive crisis from endotracheal suctioning

- Barotrauma from positive pressure ventilation
- Ventilator associated pulmonary infections and atelectasis

2. Reduced requirements of sedatives (and associated hemodynamic compromise)
3. More rapid patient mobilization
4. Earlier ICU discharge
5. Decreased length of hospital stay
6. Reduced costs (ventilator associated, as well as length of ICU/hospital stay)
7. Reduced parental stress

Published studies reporting on patient outcome with early extubation and/or fast-tracking in surgery for CHD are summarized in Table 4.

As mentioned earlier, extubating patients soon after surgery is often considered an important component of a fast-track approach to cardiac surgery. But is there evidence that early extubation is associated with improved outcome? For certain lesions and stages of repair for CHD there is evidence that it does. For example, in children following the Fontan completion of a single ventricle palliation, central venous pressure becomes the driving force of pulmonary blood flow against the pulmonary vascular resistance and thus, for maintaining left ventricular preload and cardiac output. It has long been suggested that lower intrathoracic pressure associated with spontaneous ventilation benefits these patients.[52,53]

A study of 50 patients undergoing either bi-directional Glenn or Fontan operation, who were extubated either in the OR or within one hour postoperatively, showed improved hemodynamics (decreased pulmonary artery pressure and increased cardiac index) compared to values before extubation.[49] More recently, Morales *et al.*,[54] published their results of a retrospective analysis comparing two groups (extubation in OR versus non early extubation group) in patients undergoing the Fontan procedure. They found that in the early extubation group, mean pulmonary artery and atrial pressure were lower and mean arterial pressure was higher compared to the non early extubation group. Additionally, the patients who were extubated in the OR required less inotropic support, time to chest tube removal was shorter, and ICU/hospital stay and costs were reduced. In patients following a bidirectional Glenn surgery, perfusion of the lung depends on the amount of venous blood draining into the superior vena cava (SVC). Cerebral vasodilation secondary to hypercapnia and a mild respiratory acidosis frequently seen in patients who are extubated early should increase blood flow to the SVC and lungs.[55-58] Hoskote *et al.* investigated the systemic and pulmonary hemodynamic effects of different CO_2 tensions in patients following bi-directional Glenn anastomosis in a prospective trial.[59] Mild hypercarbia ($PaCO_2$ up to 55 mmHg) resulted in improved systemic oxygenation, increased systemic (Qp) and pulmonary (Qp) blood flow (Qp/Qs unchanged), increased cerebral blood flow, and decreased systemic vascular resistance. Pulmonary vascular resistance remained unchanged in this study. Based upon these findings and additional studies on the effect of mild hypercapnia in patients following bi-directional Glenn surgery,[60] the authors concluded that permissive hypercapnia might improve outcome in this patient population.

In another retrospective study in children following right hearty bypass surgery, early extubation and spontaneous ventilation resulted in decreased pulmonary vascular resistance, lower mean pulmonary artery pressure, and fewer pulmonary complications such as pneumonia and atelectasis.[53] Despite the above mentioned findings, there are widespread concerns about the safety of fast tracking and early extubation in this patient population.

Patient and parent satisfaction is increased in children who are extubated in the OR, or soon after ICU arrival. Early extubation allows earlier mobilization and verbal communication between the child, parents and hospital staff involved. Prolonged mechanical ventilation in children can be one of the most distressing experiences for the patient and parents.[55]

There is good evidence that early extubation and fast-tracking in surgery for CHD results in shorter ICU and hospital stay [Table 4]. Aside from cost savings that will be discussed below, prolonged hospital stay can increase the risk for hospital-acquired complications such as infections.

PATIENT SELECTION

Appropriate patient selection is important in successfully fast-tracking patients presenting for surgery for CHD. Pre- and intra-operative factors have to be considered in the decision-making process. Several studies have shown that young children and even neonates can be successfully extubated early. However, with an increase in the rate of reintubation in the very young (reintubation in 11% of neonates in one study (Heinle)) the question remains what age should be recommended

Table 3: Factors associated with prolonged Mechanical ventilation following surgery for CHD

Author, Year published	Patients enrolled	Type of study	Primary outcome measure	Factors associated with prolonged mechanical ventilation (failed early extubation)
Mittnacht *et al*., 2008[42]	224, >1 month < 18 years	- Retrospective - Multivariate analysis	OR extubation	Independent factors associated with early extubation: younger age, longer CPB time, higher inotrope use
Szekely *et al*., 2006[78]	411	- Prospective - Multivariate analysis	MV > 61 hrs post surgery	-Longer CPB time, intraoperative transfusion, post-CPB arterial oxygen tension, fluid intake on postoperative day 1
Davis *et al*., 2004[76]	219 (< 36 mos)	- Retrospective - Multivariate analysis	Extubation within 24hrs	-Younger age, PHT, CHF, prematurity, aortic cross clamp time (>45min)
Neirotti *et al*., 2002[43]	901	- Retrospective	Extubation within 6 hrs	-Younger age, lower weight
Harrison *et al*., 2002[50]	219	- Retrospective - Multivariate analysis	Reintubation within 24hrs	-Preoperative PHT, Down syndrome, DHCA
Kanter *et al*., 1986[41]	140	- Retrospective	Prolonged mechanical ventilation (>postoperative day 1)	-Younger age, longer CPB time, longer aortic cross clamp time, preoperative mechanical ventilation

MV = mechanical ventilation, PHT = pulmonary hypertension, CHF = congestive heart failure, DHCA = deep hypothermic circulatory arrest, OR: Operating room, CPB: Cardiopulmonary bypass

Table 4: Benefits in patient outcome reported with early extubation and/or fast-tracking in surgery for CHD

Author, Year published	Patients enrolled	Reported benefits of early extubation/fast-tracking
Preisman *et al*., 2009[71]	100, > 1 month	Shorter ICU and hospital stay in early extubation group
Heinle *et al*., 1997[44]	56, < 90 days	Shorter ICU and hospital stay, reduced costs.
Kurihara *et al*., 2009[53]	71, 6 month –10 years, RHB only	Fewer postoperative respiratory complications, shorter ICU stay.
Laussen *et al*.,1996[63]	102, ASD only	Reduced costs
Morales *et al*., 2008[54]	112, Fontan only	Improved postoperative hemodynamics, decreased hospital resource use, shorter hospital stay, reduced costs
Vida *et al*., 2006[51]	100, VSD with PHT only	Decreased ICU and hospital stay, reduced costs.
Neirotti *et al*., 2002[43]	901	Simplified postoperative care and increased patient and family satisfaction.

RHB = Right Heart Bypass (Fontan, bi-directional Glenn), ICU: Intensive care unit, ASD: Atrial septal defect, VSD: Ventricular septal defect, PHT: Pulmonary hypertension

for safe fast-tracking in surgery for CHD. In the author's experience children older than three to six months can almost always be considered for early extubation. It is the infants (less than one month of age) who will typically not all fulfill adequate extubation criteria at the end of the procedure. Age as a criteria for fast-tracking in surgery for CHD may be viewed differently from institution to institution and also depends on the surgeon's or intensivist's preference. There are several studies showing that early extubation following complex surgery for CHD is possible.[42,51] However, most practitioners would probably opt not to attempt early extubation in complex neonatal surgery. When the Risk Adjustment for Congenital Heart Surgery (RACHS) score,[61] is applied to assess surgical risk, multiple studies have shown that patients listed in risk category 1-3 are frequently eligible for fast-tracking. In children classified as RACHS 4 and 5, the practitioner can opt to choose a fast-tracking anesthetic technique and reevaluate the patient for early extubation at the end of the procedure. RACHS six patients (stage 1 repair of hypoplastic left heart syndrome) are typically not considered eligible for fast-tracking.

In summary, with a less conservative approach, the anesthetic technique chosen should allow the anesthesiologist to not only base his/her decision about fast-tracking in a particular patient on preoperative factors, but rather keep this option open until the end of the procedure. Should intraroperative factors such as long CPB time with significant inflammatory response, severe PHT following discontinuation of CPB, hemodynamic instability requiring high inotropic support, uncontrolled hemorrhage, or other factors precluding fast-tracking and early extubation be present at the end of the procedure, the anesthetic technique can then easily be converted to allow transfer of a the patient to the ICU under deep general anesthesia. This approach will allow many more patients to be eligible for early extubation compared to a rigid protocol based upon preoperative factors only.

CONCERNS AND SAFETY OF FAST-TRACKING

Despite increasing evidence that fast-tracking in surgery for CHD can be achieved safely,[42,44,46,62-64] there still remains significant individual as well as institutional concerns about the safety of such an approach. Large series in adult cardiac surgery have shown that fast-tracking can be accomplished safely and may actually benefit the patient.[65-67] After early extubation in children undergoing surgery for CHD had been introduced as a viable option in the late 70's and early 80's, a high-dose opioid technique was considered to be beneficial in improving outcome in the more complex surgery for CHD in the years that followed.[68] It was shown that a high opioid technique can blunt the stress response to surgery and CPB,[69] and was thought to provide superior hemodynamic stability. However, with the development of short acting anesthetics, opioids, and inhalational anesthetics with less cardiac depressive effects than halothane, these goals can be achieved safely even without prolonged mechanical ventilation and ICU stay.[54] Additionally, early extubation can clearly benefit some patients (see above), and it was demonstrated that early extubation (within six hours) in children undergoing surgery for CHD has no negative affect on cardiac function.[70] The rate of reintubation following early extubation with modern anesthetics is low and mostly unrelated to fast-tracking. Preisman and colleagues recently published the results of a prospective randomized pilot study comparing a high opioid 'conventional' group to patients with an anesthetic management targeted to early extubation.[71] The authors found no difference in perioperative mortality, need for re-exploration for bleeding, reintubation, incidence of abnormal chest radiographic studies, cardiac and septic complications between the two groups. The early extubation group had a significant shorter ICU and hospital stay. Based upon these available data, it can be concluded that fast-tracking can be achieved safely even in small children undergoing complex surgery for CHD. Settings in surgery for CHD where fast-tracking cannot be considered safe include all patients who are hemodynamically unstable, coagulopathic patients, or patients that do not meet generally accepted extubation criteria.

POSTOPERATIVE CONSIDERATIONS

Rapid discontinuation of mechanical ventilation that sometimes can be accomplished in the OR at the end of the procedure or soon after ICU arrival is part of a fast-tracking protocol. Regardless of how soon the patient is extubated, pain management and sedation without respiratory depression become important considerations for all practitioners involved. As mentioned above, a neuraxial anesthetic technique can be helpful in this respect. The introduction of dexmedetomidine in the clinical practice and its off-label use for sedation in children on the ICU has also certainly helped to accomplish this goal.[72,73] A mild respiratory acidosis is frequently encountered in children that were extubated early, however, this is typically well tolerated and has not led to any reported complications.[8,54,62,63] In the author's experience, with proper patient selection and ICU management, it is mostly for reasons other than respiratory depression that a child requires reintubation. The surgical technique and complications such as postoperative hemorrhage, residual lesions, and rhythm problems that lead to hemodynamic instability are, however, more important. The reported rate of reintubation following early extubation in patients undergoing surgery for CHD is typically very low, and rates less than 2-3% are usually reported.[42,46] A higher incidence of reintubation as reported by Heinle *et al.* following early extubation is usually related to patient selection criteria such as very young age.[44] The application of nasal continuous positive airway pressure (CPAP) in patients presenting with signs of mild respiratory depression following early extubation helps prevent reintubation and preserves the advantages of spontaneous ventilation.

ECONOMIC IMPLICATIONS

The strongest predictors of costs for patients undergoing cardiac surgery are intensive care and hospital LOS, OR time, and postoperative complications. Any technique resulting in earlier patient discharge without compromising patient's safety should therefore result in cost savings. Significantly more data including prospective randomized studies have been published about the economic implications of fast-tracking in adult cardiac surgery. Most of those studies conclude that fast-tracking results in shorter ICU and hospital LOS, and decreases in resource use, all of which leads to decreased costs.[66,67,74,75] However, it is difficult to compare one clinical setting to another, and results from adult cardiac surgery may not be easily transferred to surgery for CHD. Nevertheless, results from studies in children undergoing surgery for CHD show similar findings. Heinle *et al.*[44] documented a significant cost reduction ($21,108 ± $14,941 versus $31,608 ± $9,861) in patients extubated early due to shorter ICU/hospital stay. Vida and colleagues showed that patients

with preoperative PHT that were extubated early had significantly shorter ICU and hospital stay, and every additional day spent on the ICU increased overall costs of the procedure by 10%.[51] In 112 patients undergoing a Fontan operation, Morales *et al*. demonstrated that those extubated early had significantly reduced ICU and hospital stay.[54] Costs in the early extubation group were significantly lower compared to those patients not extubated in the OR, or within 30 minutes of ICU arrival (35% reduced ICU costs, 31% for hospital stay). Following simple atrial septal defect repair, Laussen *et al*. reported similar ICU charges regardless of time of extubation.[63] This can mostly be attributed to the fact that patients after simple procedures are typically discharged from the ICU on the first postoperative day regardless of extubation in the OR, or within a few hours of ICU arrival. However, combined ICU and OR charges were reduced mainly because of avoidance of postoperative mechanical ventilation.

It should be noted, however, that most of these reports on cost savings in surgery for CHD with a fast-track regimen are based upon retrospective analyses, and not from randomized, contemporary matched patient population. When comparing costs using a historic control group, additional factors such as experience of the surgeon, inflation, increased costs due to new technologies, etc. have to be considered and are almost impossible to accurately account for. Another valid concern regarding cost savings and fast-track anesthesia is that a potential increase of postoperative complications associated with this approach and in particular with early extubation would outweigh the potential cost-saving benefits. Avoiding postoperative complications such as bleeding, arrhythmias, cardiogenic shock, renal failure is essential.

CONCLUSION

With careful patient selection, fast-tracking can be performed in many patients undergoing surgery for CHD. In order to accomplish this safely, a multidisciplinary, coordinated approach is necessary. There is some evidence, mostly from retrospective analyses, that fast-tracking can be beneficial; however, prospective randomized studies are required to determine if fast-tracking improves outcome in children undergoing surgery for CHD.

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