The American Association for Thoracic Surgery Congenital Cardiac Surgery Working Group 2021 consensus document on a comprehensive perioperative approach to enhanced recovery after pediatric cardiac surgery

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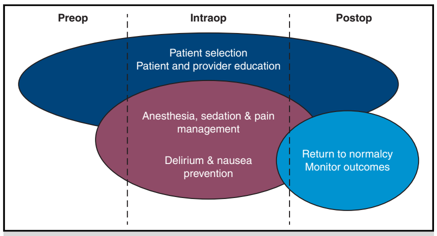

Overview of primary elements in ERPs for pediatric cardiac surgery.

CENTRAL MESSAGE

Consensus multimodality recommendations that account for lesion- and patient-specific variables are presented to facilitate enhanced recovery after pediatric cardiac surgery.

PERSPECTIVE

Enhanced recovery programs (ERPs) are commonly used in adult perioperative cardiac care. Despite early evidence of improved outcomes in the pediatric population, limited data and implementation barriers have impeded expansion of ERPs in the pediatric setting. In these consensus guidelines the application and benefits of ERPs in pediatric patients undergoing cardiac surgery are summarized.

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1. INTRODUCTION

1.1. Preamble

Our mission was to develop an evidence-based American Association for Thoracic Surgery (AATS) consensus document focused on a comprehensive perioperative approach to facilitate enhanced recovery in children after pediatric cardiac surgery. There were no preexisting guidelines for this population and subject matter. This document includes defining and outlining strategies aimed at early extubation (EE), and multimodal management of pain and delirium to minimize opioid use and allow for accelerated postoperative return to normal activity (Figure 1). The writing committee includes 7 congenital cardiac surgeons, 1 cardiologist, 1 anesthesiologist, 1 pediatric cardiac intensivist, and 1 methodologist.

1.2. Selection of Writing Group Members

The Working Group strives to avoid bias by selecting experts from a broad array of backgrounds. Writing committee members represent different geographic regions, sexes, ethnicities, races, intellectual perspectives, and scope of clinical practice.

1.3. Methodology

The AATS Working Group used recommendations of the Institute of Medicine 2011 clinical practice guidelines.[1,2]

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Abbreviations and Acronyms

AATS	= American Association for Thoracic Surgery
COR	= class of recommendation
COX	= cyclooxygenase
CPB	= cardiopulmonary bypass
Dex	= dexmedetomidine
DHCA	= deep hypothermic circulatory arrest
EE	= early extubation
ERP	= enhanced recovery program
ICU	= intensive care unit
LOE	= level of evidence
LOS	= length of stay
OR	= operating room
PHN	= Pediatric Heart Network

As such, an extensive literature review was undertaken focused on randomized controlled trials when available, but included nonrandomized comparative and descriptive studies, cohort studies, case series, systematic reviews, and expert opinion. Key word searches included, but were not limited to, congenital cardiac surgery, early/on-table/immediate extubation, fast-track and enhanced recovery after surgery. Evidence tables were created to summarize relevant publications used by the writing committee to formulate recommendations. All key references are cited. A modified Delphi method was used to achieve a minimum of 75% consensus among experts on all recommendations and determine the strength of the recommendation and the quality of supporting evidence.

1.4. Guideline-Directed Management and Therapy

The term, "guideline-directed management and therapy" includes clinical evaluation, diagnostic testing, and pharmacological treatments. The recommendations include drugs, devices, and treatments approved for clinical use in the United States. Of note, there are also several recommendations that incorporate use of medications and therapies routinely and safely administered in the pediatric population despite no unique or specific guidelines pertaining to use in children. However, because of the routine use and frequent acceptance of these therapies, they are appropriately discussed herein.

1.5. Class of Recommendation and Level of Evidence

The class of recommendation (COR) indicates the strength of the recommendation, on the basis of the certainty of benefit in proportion to risk. The level of evidence (LOE) rates the quality of scientific evidence that supports the intervention on the basis of the type, quantity, and consistency of data from clinical trials and other sources (Figure 2).[3,4]

1.6. Background: Enhanced Recovery Programs

Enhanced recovery programs (ERPs) to facilitate return to normal function after surgery have gained popularity with proven effectiveness in multiple populations, including after pediatric and adult cardiac surgery. These programs are intentionally designed as comprehensive and multidisciplinary approaches that include optimization of fluid balance and nutrition, use of multimodal pain management with a focus on reduction of opioid administration and accelerated return to function (Figure 3). There is increasing evidence that use of either a comprehensive ERP, or components thereof when appropriate, can result in reduced length of stay (LOS), improved recovery, optimal patient experience, and cost effectiveness.[5-7] We herein examine the existing data supporting the use of ERPs in children undergoing congenital heart surgery and provide evidence-based expert guidelines for appropriate and universal application.

2. VALUE PROPOSITION

2.1. Recommendation 1

Approaches to facilitate enhanced recovery after pediatric cardiac surgery are feasible in select patient populations (Table 1; COR = 1; LOE = B-R).[5,6,8-20]

The multidisciplinary engagement necessary to implement and, more importantly, maintain ERP after pediatric cardiac surgery is significant. As such, identifying key strategies that increase the likelihood of success are essential. First and foremost, it is critical to determine the most appropriate patient population and to understand the strengths and weaknesses of each individual program that might affect the likelihood of success. Improvements in clinical outcomes, quality of care, and cost savings with various ERPs have been well established across a broad spectrum of adult[10] and pediatric[9,18] surgical procedures. ERPs have been successfully implemented in the adult cardiac surgery population, in part, facilitated by the greater homogeneity in lesions and procedures. These programs have been shown to reduce LOS as well as postoperative complications.[11-13,16]

Translation of ERPs to the pediatric cardiac surgery population poses many challenges because of the heterogeneity in procedures and broad age spectrum. Various individual components in the perioperative process, including EE, chest tube removal protocols, and minimal opioid initiatives for pediatric cardiac surgery, have been focused end points in efforts to improve efficiency and patient outcomes. The Pediatric Heart Network (PHN) Collaborative Learning Study on EE in patients with tetralogy of Fallot and coarctation achieved shorter times to extubation across multiple sites for select lesions.[29] However, centers had a high

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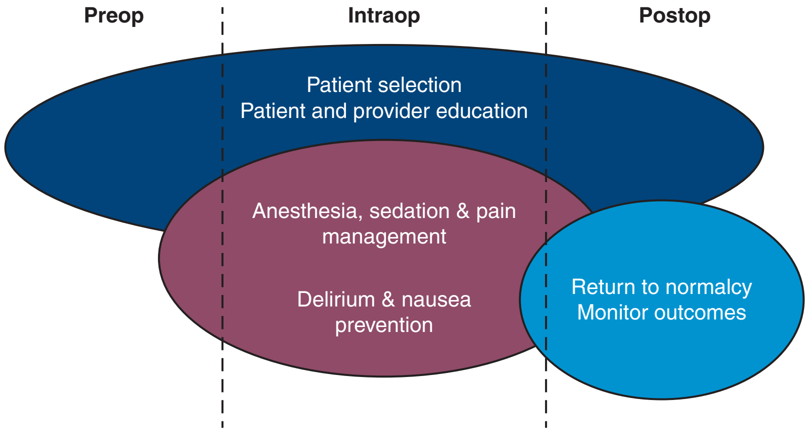

FIGURE 1. Overview of primary elements in enhanced recovery programs (ERPs) for pediatric cardiac surgery. *Preop*, Preoperative; *Intraop*, intraoperative; *Postop*, postoperative.

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degree of variability in success and sustainability, which highlighted the effect of institutional resources and multidisciplinary teamwork necessary for the implementation of such a program.[8,13,14,18]

2.2. Recommendation 2

Protocol-based application of enhanced recovery strategies after pediatric cardiac surgery reduces postoperative LOS in select patient populations (Table 1; COR = 1; LOE = A).[11,14-16,21-25]

The goal of an ERP is to accelerate recovery, reduce LOS and adverse outcomes, and improve patient safety and family satisfaction after congenital heart surgery. Multicomponent fast-track protocols have been successfully applied in select groups of uncomplicated and otherwise healthy pediatric cardiac surgery patients without increase in complications.[14,15,19] These studies highlight that, with appropriate patient selection, ERPs can be successfully implemented safely and with improved outcomes. Safety and LOS benefits of EE after cardiac surgery in children have also been reported by 2 randomized clinical trials.[25,30] Further, a multicenter study reported higher intensive care unit (ICU) mortality and longer ICU LOS among patients who arrived to the ICU intubated after cardiac surgery, compared with patients who were extubated in the operating room (OR).[31] Reduction in hospital LOS is a simple to capture metric that is highly valued by payors, hospitals, and programs. The incremental cost of each additional day of hospitalization and exposure to hospital-related adverse events is a focus of payors as a critical opportunity for cost reduction. For institutions and individual programs, reduction in LOS equates to improved "through put" to allow for increased patient volume. It is therefore not surprising that a primary outcome of interest that is easily measured and highly valued is reduction in postoperative LOS for the overall hospitalization and the ICU phase.

There might be variables that impair transfer from the ICU or discharge from the hospital that are not patient-related; hence readiness for transfer or discharge can be a more specific metric, albeit somewhat more challenging to track. Reduction in ICU and hospital LOS along with time to readiness for transfer or discharge has been repeatedly shown in the adult and pediatric cardiac service lines using focused efforts including minimal opioid strategies,[22] EE,[23] fast-track anesthesia,[25] and a multicomponent ERP.[11,15,16,21,24] A prospective analysis of a fast-track program implemented at Great Ormond Street Hospital that evaluated factors affecting fitness for transfer from the ICU on day of surgery noted that time of surgical procedure (case order), specifically afternoon/second cases were less likely to be "fit" for transfer on day of surgery.[14] The logical conclusion is to appropriately schedule patients who are most appropriate for fast-tracking as the first case of the day to optimize the likelihood of success. This reasoning can be expanded to consider various systems issues that might affect the successful fast-tracking of individual cases such as staffing, time of day, or day of week to optimize timely discharge.

2.3. Recommendation 3

Implementation of protocol-based enhanced recovery strategies reduces costs in pediatric cardiac surgery (Table 1; COR = 1; LOE = B-R).[15,16,21,23,24,26]

Implementation of ERPs can be labor- and resource-intensive for pediatric cardiac programs. Educational time and materials are necessary for staff and families. Commitment to ongoing monitoring of program compliance and outcomes, although imperative, is associated with increased effort and institutional resources. With this perceived, and often considerable, financial and personnel commitment, demonstration of fiscal viability is important. There are no studies to date that have quantified the implementation

CLASS (STRENGTH) OF RECOMMENDATION	
CLASS I (STRONG)	**Benefit >>> Risk**
Suggested phrases for writing recommendations: ■ Is recommended ■ Is indicated/useful/effective/beneficial ■ Should be performed/administered/other ■ Comparative-Effectiveness Phrases†: ○ Treatment/strategy A is recommended/indicated in preference to treatment B ○ Treatment A should be chosen over treatment B	
CLASS IIa (MODERATE)	**Benefit >> Risk**
Suggested phrases for writing recommendations: ■ Is reasonable ■ Can be useful/effective/beneficial ■ Comparative-Effectiveness Phrases†: ○ Treatment/strategy A is probably recommended/indicated in preference to treatment B ○ It is reasonable to choose treatment A over treatment B	
CLASS IIb (WEAK)	**Benefit ≥ Risk**
Suggested phrases for writing recommendations: ■ May/might be reasonable ■ May/might be considered ■ Usefulness/effectiveness is unknown/unclear/uncertain or not well established	
CLASS III: No Benefit (MODERATE) *(Generally, LOE A or B use only)*	**Benefit = Risk**
Suggested phrases for writing recommendations: ■ Is not recommended ■ Is not indicated/useful/effective/beneficial ■ Should not be performed/administered/other	
CLASS III: Harm (STRONG)	**Risk > Benefit**
Suggested phrases for writing recommendations: ■ Potentially harmful ■ Causes harm ■ Associated with excess morbidity/mortality ■ Should not be performed/administered/other	

LEVEL (QUALITY) OF EVIDENCE‡	
LEVEL A	
■ High-quality evidence‡ from more than 1 RCT ■ Meta-analyses of high-quality RCTs ■ One or more RCTs corroborated by high-quality registry studies	
LEVEL B-R	**(Randomized)**
■ Moderate-quality evidence‡ from 1 or more RCTs ■ Meta-analyses of moderate-quality RCTs	
LEVEL B-NR	**(Nonrandomized)**
■ Moderate-quality evidence‡ from 1 or more well-designed, well-executed nonrandomized studies, observational studies, or registry studies ■ Meta-analyses of such studies	
LEVEL C-LD	**(Limited Data)**
■ Randomized or nonrandomized observational or registry studies with limitations of design or execution ■ Meta-analyses of such studies ■ Physiological or mechanistic studies in human subjects	
LEVEL C-EO	**(Expert Opinion)**
Consensus of expert opinion based on clinical experience	

COR and LOE are determined independently (any COR may be paired with any LOE).

A recommendation with LOE C does not imply that the recommendation is weak. Many important clinical questions addressed in guidelines do not lend themselves to clinical trials. Although RCTs are unavailable, there may be a very clear clinical consensus that a particular test or therapy is useful or effective.

* The outcome or result of the intervention should be specified (an improved clinical outcome or increased diagnostic accuracy or incremental prognostic information).

† For comparative-effectiveness recommendations (COR I and IIa; LOE A and B only), studies that support the use of comparator verbs should involve direct comparisons of the treatments or strategies being evaluated.

‡ The method of assessing quality is evolving, including the application of standardized, widely used, and preferably validated evidence grading tools; and for systematic reviews, the incorporation of an Evidence Review Committee.

COR indicates Class of Recommendation; EO, expert opinion; LD, limited data; LOE, Level of Evidence; NR, nonrandomized; R, randomized; and RCT, randomized controlled trial.

FIGURE 2. Recommendation classification system developed by the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines.[3] *LOE*, Level of evidence; *RCT*, randomized controlled trial; *R*, randomized; *NR*, nonrandomized; *LD*, limited data; *EO*, expert opinion; *COR*, class of recommendation.

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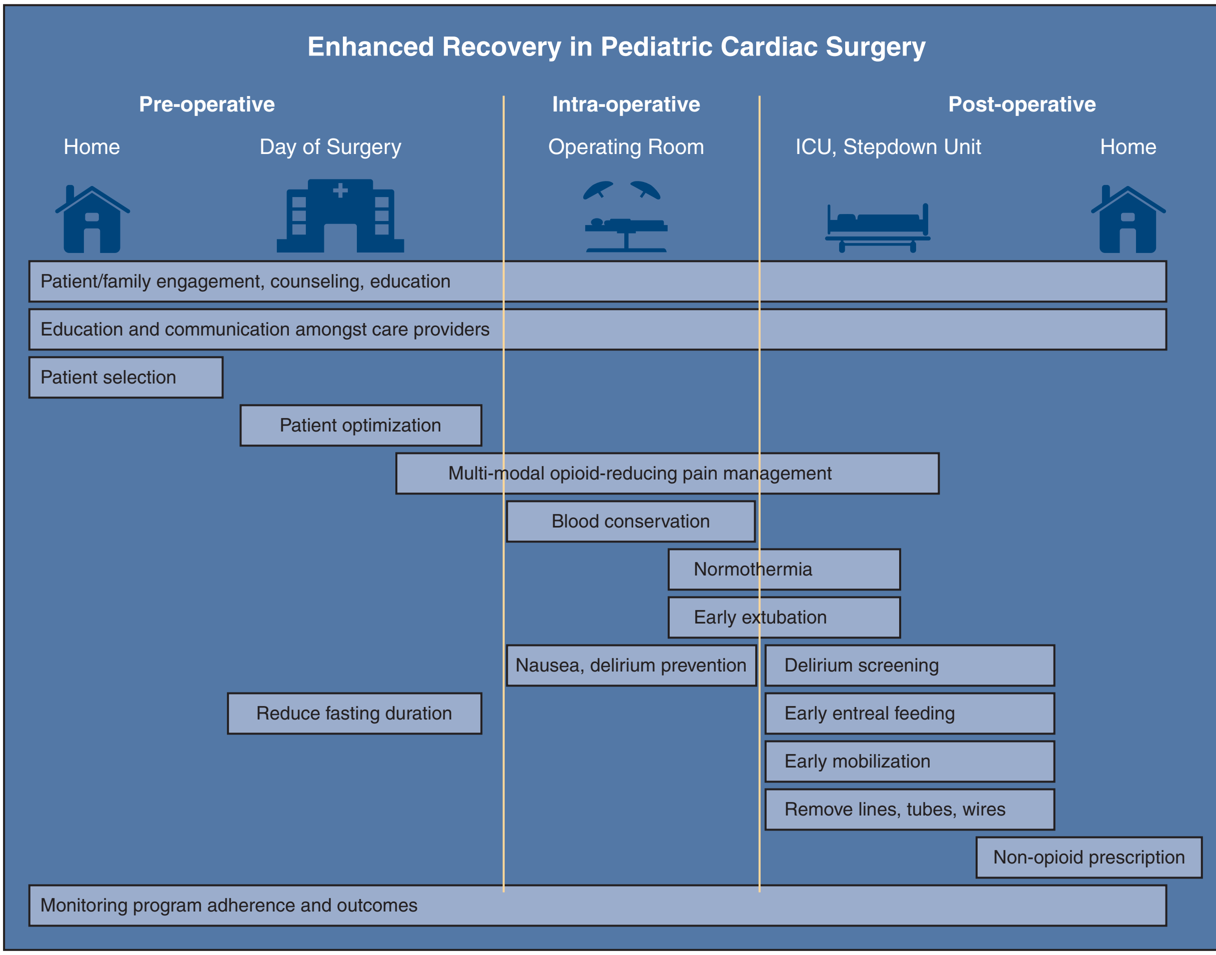

FIGURE 3. Components of enhanced recovery programs (ERPs) for pediatric cardiac surgery across the perioperative period. *ICU*, Intensive care unit.

costs of ERPs. This makes assessment of institutional costs challenging.

Data on cost reductions for payors, however, are easier to capture. Across a variety of surgical specialties, short-term cost effectiveness of ERPs has been demonstrated, although data on out-of-hospital and long-term cost reduction remains limited.[24] Enhanced recovery strategies limited to EE efforts have failed to show reduced costs across a spectrum of low-complexity procedures.[23] The PHN Collaborative Learning Study, however, was able to show lesion-specific cost reduction for patients who underwent tetralogy of Fallot repair, whereas coarctation repairs were cost-neutral.[26] Multi-component ERPs appear to be more successful in cost reduction for adult[16] and pediatric cardiac care.[21] A comparative analysis involving national benchmarking on the basis of the Pediatric Health Information System database, showed that a single institution was able to significantly reduce hospital costs for repair of atrial and ventricular septal defects during a time frame when national costs actually rose.[15]

2.4. Recommendation 4

Protocol-based application of enhanced recovery strategies after pediatric cardiac surgery does not increase morbidity and mortality (Table 1; COR = 1; LOE = A).[5,11,13,15,22,25,27]

Much of the concern regarding implementation of ERPs is the possible unintended consequence of increasing risk of morbidity or mortality because of faster progression through the perioperative process. Multiple studies across age groups and surgical specialties have shown the degree of safety necessary to garner support and ongoing engagement. Implementation of fast-track and ERPs in adult cardiac surgery has shown that not only are risks of morbidity and mortality not increased, but further that low cardiac output syndrome, mortality,[11] and a composite of postoperative complications are reduced.[13] Various programs focused on specific components of the perioperative recovery phase after pediatric cardiac surgery have also shown safety. A low complication rate (3%) was observed after a minimal opioid protocol in pediatric cardiac

TABLE 1. Value proposition

	COR	LOE
1. Approaches to facilitate enhanced recovery after pediatric cardiac surgery are feasible in select patient populations.[5,6,8-20]	I	B-R
2. Protocol-based application of enhanced recovery strategies after pediatric cardiac surgery reduces postoperative length of stay in select patient populations.[11,14-16,21-25]	I	A
3. Implementation of protocol-based enhanced recovery strategies reduces costs in pediatric cardiac surgery.[15,16,21,23,24,26]	I	B-R
4. Protocol-based application of enhanced recovery strategies after pediatric cardiac surgery does not increase morbidity and mortality.[5,11,13,15,22,25,27]	I	A
5. Enhanced recovery strategies might improve patient and family experience.[20,23,28]	I	C-LD

COR, Class of recommendation; *LOE*, level of evidence.

surgery.[22] A prospective randomized trial evaluated the effect of fast-tracking low birth weight pediatric patients requiring cardiac surgery.[25] Agitation scores were lower in the fast-track group at time of extubation (ie, in the OR) in the absence of airway-associated events or other serious complications. In a similar high-risk group, neonates intubated before surgery were also reported to have fewer adverse respiratory events when extubated earlier.[27] In an evaluation of multicomponent ERPs after pediatric cardiac surgery, a retrospective analysis using national comparative data from the Pediatric Health Information System revealed no increase in hospital mortality or readmission rates[15] whereas a prospective single-center trial showed no significant change in complications, readmissions, or reinterventions.[5] With thoughtful protocol development and appropriate patient selection, ERPs can be used safely with many studies revealing an actual reduction in morbidity risk.

2.5. Recommendation 5

Enhanced recovery strategies might improve patient and family experience (Table 1; COR = 1; LOE = C-LD).[20,23,28]

Essential to the implementation of any protocol to improve patient outcomes in the perioperative phase is ensuring that the satisfaction of patients, families, and staff are maintained and hopefully improved. Time spent with families in the preoperative phase of care to set appropriate expectations in terms of pain control and pace of care can tremendously increase parental engagement in their child's care, which in turn might translate into improved satisfaction.[32] An ERP used in noncardiac pediatric surgery, which incorporated education to engage patients and families to be more invested in their care resulted in improved satisfaction in the processes of care.[28] A prospective nonrandomized study of a Knowledge-to-Action Framework for an ERP involving adult cardiac surgery showed an improved patient satisfaction score on a voluntary survey instrument from 86.3% pre-ERP versus 91.8% post-ERP.[20] Similar improvements in satisfaction were noted across multiple domains (patient focus, culture, and engagement) from <76% to >83% positive responses using a work culture survey administered to the cardiothoracic ICU nursing staff.[20] Appropriate anticipatory goal-setting with patients and families might enhance engagement and investment in the faster pace of early removal of noxious stimuli (endotracheal tubes, chest tubes, invasive monitoring lines) along with early mobilization to facilitate return to normal activities, which will ultimately foster an improved experience and satisfaction.

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TABLE 2. Programmatic approach

A. Systems of care	COR	LOE
1. Comprehensive enhanced recovery programs in pediatric cardiac surgery that incorporate preoperative, intraoperative, and postoperative elements of care can be effective to improve outcomes.[8,14,16,20,25,29,33,34]	IIa	B-R
2. Multidisciplinary stakeholder involvement is recommended to enact programmatic change in perioperative pediatric cardiovascular care.[8,14,20,29,33,34]	I	B-NR
B. Setting expectations		
1. Structured education and regular review of quality metrics with care providers is recommended to increase compliance with enhanced recovery program components and improves provider satisfaction.[14,32,35]	I	C-LD
2. Patient and family engagement can be useful to reduce anxiety, promote active participation, and improve satisfaction with care.[14,32,35]	IIa	C-LD

COR, Class of recommendation; *LOE*, level of evidence.

3. PROGRAMMATIC APPROACH

3.1. Systems of Care

3.1.1. Recommendation 1. Comprehensive ERPs in pediatric cardiac surgery that incorporate preoperative, intraoperative, and postoperative elements of care can be effective to improve outcomes (Table 2; COR = 2a; LOE = B-R).[8,14,16,20,25,29,33,34]

ERPs after surgery are comprised of a comprehensive set of evidence-based interventions or steps, and span the perioperative period that targets reduction of surgical stress and catabolic states. Over the past 20 years, adult ERPs have consistently shown reduced complication rates and improved surgical outcomes, as well as shorter hospitalization and improved resource utilization.[6,13,16,20,36] Although rigorous studies in pediatric ERPs are fewer in numbers, available studies have revealed a reduction in duration of mechanical ventilation and ICU LOS with low complication rates in pediatric cardiac care.[5] Additional focused ERPs involving multicomponent approaches centered around anesthesia, multimodal pain strategies, and EE have also shown a reduction in ICU and hospital LOS, and low complication rates.[14,25] Interestingly, fewer components of care were reported in pediatric ERPs compared with adult ERPs. This observation does not suggest fewer elements are required in pediatric care, but might simply reflect differences in the stage of implementation and research of ERPs in pediatric and adult populations.

3.1.2. Recommendation 2. Multidisciplinary stakeholder involvement is recommended to enact and sustain programmatic change in perioperative pediatric cardiovascular care (Table 2; COR = 1; LOE = B-NR).[8,14,20,29,33,34]

At the core of enacting and sustaining comprehensive perioperative approaches is a primary team of providers from different specialties. The role of local "champions" is important to the success of the program, during implementation and to sustain quality improvement. This is one of the critical principles of ERPs in the perioperative period[6,37] and this multidisciplinary participation has been well described as an important component of early ERP experience in both adult[20] and congenital cardiac surgery.[5,14]

Compelling evidence of sustaining programmatic change in pediatric cardiac surgery comes from the PHN follow-up study.[8,29,33] In this study, one center was able to sustain a practice change with a multicomponent perioperative care program, and one of the key differences at this center was the formalized quality improvement process, which included multidisciplinary team members and regular review of outcomes. Team members might include, but are not limited to, anesthesiologists, surgeons, intensivists, cardiologists, nurses from the ICU and step-down units, respiratory, physical and speech therapists, and nutritionists, as well as parents.

3.2. Setting Expectations

3.2.1. Recommendation 1. Structured education and regular review of quality metrics with care providers is recommended to increase compliance with ERP components and improve provider satisfaction (Table 2; COR = 1; LOE = C-LD).[14,32,35]

Quality improvement approaches including provider education and regular review of program outcomes are essential to the success of ERPs.[8,33] Barriers to successful implementation frequently include resistance to change, lack of time, and poor communication, collaboration, and coordination among providers and teams.[6,20] Hence, provider education and feedback are critical. Efforts to widely disseminate ERP protocols and clearly identify patients being managed using these protocols are also of importance. Williams and colleagues[20] reported that successful implementation of an ERP over a year resulted in demonstrable improvements in workplace culture as well as patient focus and engagement.

3.2.2. Recommendation 2. Patient and family engagement can be useful to reduce anxiety, promote active participation, and improve satisfaction with care (Table 2; COR = 2a; LOE = C-LD).[14,32,35]

Educating pediatric patients and/or their families is a valuable component of patient care. According to Kain and colleagues, health care providers spend little time (medians of 2.8-4.8 minutes depending on the type of providers) in preoperative holding areas interacting with children or their families on the day of surgery.[38] This limited interaction might not possibly provide the time, education, and support necessary in complex pediatric cardiac surgery. Tools such as an interactive booklet, video, and simulation of the perioperative environment can reduce emotional distress, anxiety, and maladapted behavioral responses after pediatric surgery.[39] In examining comprehensive perioperative strategies for pediatric noncardiac surgery, Kehlet and Wilmore[39] suggested that a family's understanding of a patient's perioperative pathophysiology and future care plan improves satisfaction and accelerates postoperative rehabilitation. Specific investigation of parental perceptions of the "fast-track" process conducted at Great Ormond Street Hospital[4,32] revealed that parents' expectations of time required for steps such as extubation, mobilization, and LOS (ICU and total hospital stay) were longer than expected. As opposed to being well received, the possibility exists that when children progress rapidly, parents might not believe their child is ready for discharge. Thus, communication and interaction of the family with health care providers is critical, significantly affecting their overall experience and satisfaction. Perioperative teaching is also imperative in fast-track programs to align expectations. Heiss and Raval[28] describe that counseling for enhanced recovery after pediatric surgery extends beyond traditional provider-parent interaction and that there must be a clear explanation of the program with daily goals provided regarding nutrition, mobilization, pain management, and criteria for discharge.[28] The objective is to empower the family to become active stakeholders in the process. This, in turn, improves satisfaction.

4. PATIENT SELECTION

Most patients have a relatively uncomplicated and predictable course after congenital heart surgery. This largely underpins the rationale for the ERP. There are patient- and procedure-specific factors that can help identify those at risk for a complicated postoperative course. When such postoperative complications occur, it is critically important to assess them and to determine if alterations in the ERP need to be considered. It is essential to recognize that ERPs were never designed to override the primary principles in postoperative care, which include early recognition and management of complications with attention to patient safety. When the clinical course is different from, or more complicated than anticipated, it might still be feasible and desirable to implement select aspects of an ERP, as appropriate in the individual case. In the following sections, we highlight some of the common clinical issues that arise in the postoperative period and examine how these might affect the ERP.

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TABLE 3. Inclusion criteria and special considerations

	COR	LOE
1. Modifications to enhanced recovery programs are recommended after pediatric cardiac surgery in patients with independent/mitigating risk factors.[14,19,36,40-59]	I	B-R
2. Enhanced recovery protocols may be applied across all levels of procedural complexity.[19,23,31,41,47,51,60-65]	IIB	B-NR
3. Enhanced recovery strategies may be used in select urgent or emergent cases.	IIB	C-EO
4. Patients with a delayed sternal closure may be considered for an enhanced recovery program when chest closure is achieved.[66]	IIB	C-LD
5. Modifications to an enhanced recovery program after pediatric cardiac surgery are recommended to accommodate systems issues including available staffing, time of day at conclusion of procedure, or availability of clinical expertise.[29,34]	I	B-NR

COR, Class of recommendation; *LOE*, level of evidence.

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4.1. Recommendation 1

Modifications to ERPs are recommended after pediatric cardiac surgery in patients with independent/mitigating risk factors (Table 3; COR = 1; LOE = B-R).[14,19,36,40-59]

4.1.1. Pulmonary hypertension. It is well recognized that postoperative pulmonary hypertension may be managed with heavy sedation and analgesia, paralysis, and mechanical ventilatory settings that allow alkalization through hyperventilation.[67] These interventions contrast with some of the principles of enhanced recovery. Hence, it is important for the clinician to stratify postoperative pulmonary hypertension and identify which patient will benefit from components of an ERP. For instance, patients with severe pulmonary hypertension with systolic pulmonary artery pressure >50% of systolic arterial blood pressure (>75% for neonates) might require the aforementioned aggressive management strategies that preclude implementation of ERP steps.[68] However, in mild or moderate pulmonary hypertension there might be benefits to pursuing an ERP that includes EE, because an endotracheal tube can be noxious to the patient and might induce agitation and irritation, thereby worsening pulmonary hypertension. Another specific group of patients that might have an element of pulmonary hypertension is the subset of patients who undergo cavopulmonary surgeries such as the bidirectional Glenn or Fontan procedures. Numerous studies have shown the benefit of spontaneous ventilation in patients with this physiology.[69] It is also important to recognize that the administration of an inhaled pulmonary vasodilator such as nitric oxide does not by itself mandate invasive mechanical ventilation and might be effectively delivered using noninvasive methods.

4.1.2. Systemic hypertension. Systemic hypertension might occur after congenital heart surgery. There are many reasons for the development of systemic hypertension including acute alterations in physiology, as is the case with repair of coarctation of the aorta. Systemic hypertension might also be exacerbated by pain or discomfort. For that reason, some clinicians have adopted a strategy of aggressive sedation in the setting of systemic hypertension. There might also be hesitation to pursue extubation because of concerns of systemic hypertension. However, there is reason to believe that ERPs might be particularly helpful to children who are at risk of developing systemic hypertension after surgery. Removal of the endotracheal tube can eliminate a noxious stimulus that exacerbates hypertension. In addition, an enhanced recovery model might allow for family members or caregivers to provide comfort and alleviate anxiety that can contribute to hypertension. The collaborative learning project performed by the PHN showed that an EE strategy can safely be performed after coarctation repair and that this strategy ultimately results in less need for opioids and a shorter time to enteral feeds.[29] In this multicenter study, repair of coarctation of the aorta was 1 of the 2 index operations pursued in part because of the putative benefits of EE on hemodynamics, and concerns regarding hypertension. Of note, there were no adverse events attributable to hypertension in patients who underwent EE and prevalence of significant hypertension remained stable after implementation of the EE clinical practices.

4.1.3. Hemodynamic compromise. After pediatric heart surgery, patients might manifest hemodynamic compromise for a multitude of reasons. For example, residual lesions might persist after surgical repair. In one series, up to 29% of patients with complex congenital heart surgery had a residual lesion,[70] some of which can significantly impair organ perfusion. Accordingly, the clinical team needs to carefully assess the severity of residual lesions and determine if the ERP needs to be modified to ensure patient safety. It should be recognized that the effects of many of these lesions might be well tolerated in the immediate postoperative period. Severe valve regurgitation might also give some clinicians pause in pursuing an ERP. However, spontaneous ventilation might be advantageous for residual lesions such as pulmonary insufficiency or tricuspid valve insufficiency. The benefit of spontaneous ventilation for certain residual lesions was shown nicely in a study of cerebral and somatic oxygen saturations after repair of tetralogy of Fallot.[71]

Bleeding is another complication that can contribute to hemodynamic instability after surgery. According to a large single-center series, patients who had bleeding in excess of 4 mL/kg/h in the early postoperative period had worse clinical outcomes.[72] The mechanism, source, and severity of bleeding can vary and might represent an isolated bleeding source versus a generalized coagulopathy. In general, clinicians should consider modifying the ERP when bleeding is significant and prompt resolution is unlikely.

Dysrhythmias, in particular junctional ectopic tachycardia, are also commonly noted in the postoperative period. Postoperative arrhythmias can have significant variability in the degree to which they affect hemodynamics. Although the occurrence of junctional ectopic tachycardia might not affect time to extubation, it can have a significant effect on ICU LOS.[73] As such, ERPs might need to be modified in the setting of postoperative arrhythmias until hemodynamics have normalized. The administration of antiarrhythmic medications alone does not necessitate abandoning the ERP.

4.2. Recommendation 2

Enhanced recovery protocols may be applied across all levels of procedural complexity (Table 3; COR = 2b; LOE = B-NR).[19,23,31,41,47,51,60-65]

There is increasing evidence that patients with high procedural complexity will similarly benefit from EE and other enhanced recovery protocol components as patients who undergo simpler procedures. Contrary to traditional perioperative management and the notion that a lower complexity level is associated with EE, every surgical patient should be considered a candidate for EE and enhanced recovery protocols. Neither age, technical difficulty, use of deep hypothermic circulatory arrest (DHCA), nor long cardiopulmonary bypass (CBP) times constitute an absolute contraindication in the absence of residual lesions.[19] Varghese and colleagues describe immediate and EE in a variety of complex neonatal procedures including hypoplastic aortic arch augmentation, truncus arteriosus repair, repair of total anomalous pulmonary veins, and stage I Norwood.[57,74,75] Several additional case reports[76,77] detail intraoperative extubation after the Norwood procedure and emphasize achieving and confirming physiologic suitability thorough anesthetic planning, optimal hematocrit, meticulous hemostasis, ultrafiltration, and good surgical result assessed using transesophageal echocardiogram.

4.3. Recommendation 3

Enhanced recovery strategies may be used in select urgent or emergency cases (Table 3; COR = 2b; COR = C-EO).

Just as procedural complexity in isolation should not dictate use of enhanced recovery protocols, neither should urgency. Particularly in congenital heart disease, patients are subject to many physiologic perturbations that readily resolve with surgical intervention. When stabilization is achieved, many of these patients become candidates for accelerated recovery. Specific examples include hypoxemia resolved by insertion of a modified Blalock-Taussig shunt, cardiac trauma, or obstructed pulmonary veins.

4.4. Recommendation 4

Patients with delayed sternal closure may be considered for an ERP when chest closure is achieved (Table 3; COR = 2b; LOE = C-LD).[66]

Delayed sternal closure implies that patients are likely to have a more prolonged postoperative course and not benefit from enhanced recovery strategies. Delayed sternal closure is used variably among institutions.[78] For some institutions, delayed sternal closure is routinely performed for specific complex operations such as the Norwood procedure. In other cases, delayed sternal closure is used because of

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concerns for fragile hemodynamics aggravated by sternal approximation or mechanical issues such as conduit compression related to chest closure. No matter what the rationale for delayed sternal closure, postoperative management would traditionally mandate relatively intense analgesia, sedation, and possible paralysis in the early postoperative period. Accordingly, it might be challenging to institute many components of an ERP when the sternum has not been closed.[79] However, when sternal closure is achieved, the ability to pursue an ERP should be reevaluated. Meticulous attention to the enhanced recovery model might be particularly important in this population because extended sedation and immobility might have a profound and lasting effect.

4.5. Recommendation 5

Modifications to ERPs after pediatric cardiac surgery are recommended to accommodate systems issues including available staffing, time of day at conclusion of procedure, or availability of clinical expertise (Table 3; COR = 1; LOE = B-NR).[29,34]

As has been previously outlined, effective ERPs require multidisciplinary commitment and an institutional desire to embrace the principles of enhanced recovery. This requires commitment of adequate resources and staff. However, the clinical demands of a pediatric congenital heart program are variable and potentially unpredictable. There might be occasions in which a high level of acuity of the patients or unanticipated staffing issues might preclude the safe application of some components of the ERP. Previous publications have demonstrated that in toto, ERPs have the potential to reduce resource use and streamline care.[26] However, there are components of the ERP that might require additional resources across the various hospital care units. This is particularly true in the immediate postoperative period in the ICU. Analysis of the PHN Collaborative Learning Project suggested that there was an increased need for a resource nurse in centers that adopted an EE paradigm in the first 6 hours after returning from the OR.[51] Fortunately, among systems that have wholly embraced the enhanced recovery paradigm, issues related to patient acuity or staffing would not routinely affect the program's ability to provide a comprehensive ERP to most patients.[47]

5. PERIOPERATIVE STRATEGIES

The immediate perioperative period includes critical elements that need to be considered in the implementation of an ERP (see Table 4). The following sections address some of these areas sequentially.

5.1. Pain and Sedation Management

5.1.1. Delirium.

5.1.1.1. Recommendation 1. Analgesia and sedative medications that lead to emergence while minimizing delirium and hemodynamic stress are recommended to enhance

TABLE 4. Immediate perioperative variables and considerations in the implementation of ERP[5,57,80]

Component	Considerations
Quality of repair	• No significant residual lesions • Hemodynamic stability
Blood product resuscitation	• Meticulous hemostasis • Goal target hematocrit for patient • Use of modified ultrafiltration
Multimodal pain management	• Neuraxial anesthesia (eg, caudal) • Local anesthetic to incision
Prevention of delirium	• Dex administered intraoperatively
Prevention of nausea	• Intraoperative administration of antinausea medications
Temperature control	• Temperature >36.5°C at separation from CPB • Maintenance of core temperature with ambient means after CPB
Respiratory status	• Spontaneous ventilation and ability to maintain airway • Absence of delirium • Adequate oxygenation and ventilation evidenced by end-tidal monitoring and arterial blood gas

ERP, Enhanced recovery programs; *Dex*, dexmedetomidine; *CPB*, cardiopulmonary bypass.

recovery after pediatric cardiac surgery (Table 5; COR = 1; LOE = B-R).[81,82]

Maintaining hemodynamic stability after pediatric cardiac surgery is critically important and requires an orchestrated transition process from anesthesia to the critical care team. Postoperative physiology is affected by changes in preload, afterload, and systolic and diastolic function, and by systemic inflammation from CPB. Emergence from anesthesia and EE without agitation and with adequate pain control is essential to optimize oxygen delivery and minimize risks of cardiac events and postoperative bleeding.

5.1.1.1.1. Dexmedetomidine. Dexmedetomidine (Dex) is effective in reducing emergence delirium in children after cardiac surgery.[100] In a randomized study,[82] intraoperative Dex bolus and intraoperative infusion decreased the incidence of emergence delirium. Infusion of Dex was associated with a reduction of fluctuations in the level of

TABLE 5. Pain and sedation management

i. Delirium	COR	LOE
1. Analgesia and sedative medications that lead to emergence while minimizing delirium and hemodynamic stress are recommended to enhance recovery after pediatric cardiac surgery.[81,82]	I	B-R
2. Use of an age-appropriate delirium screening tool is useful in the intensive care unit after pediatric cardiac surgery.[83,84]	IIa	B-NR
ii. Pain		
1. Patient and family education regarding opioid-sparing strategies can be useful to set expectations related to pain management in the perioperative period.[38,85]	IIa	C-LD
2. Administration of nonopioid analgesics can be effective opioid-sparing regimens after pediatric cardiac surgery.[5,22,60,86-90]	IIa	B-NR
3. Peripheral regional anesthesia can be implemented as an effective perioperative opioid-sparing modality in pediatric cardiac surgery.[5,22,60,86-90]	IIa	B-R
4. Neuraxial anesthesia may be used as an effective perioperative opioid-sparing modality in pediatric cardiac surgery.[91-98]	IIb	B-R
5. It is reasonable to discharge pediatric patients taking non-opioid analgesics after cardiac surgery when adequate pain control is achieved in hospital with that regimen.[5,22,99]	IIa	B-NR

COR, Class of recommendation; *LOE*, level of evidence.

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melatonin and in markers of stress response after surgery. Patients who received Dex required less opioids and had similar pain scores. A meta-analysis[101] that included randomized and observational studies showed that Dex reduced mechanical ventilation times, analgesia requirements, postoperative agitation and delirium, and patients had attenuated stress response. A second meta-analysis of randomized studies focused on postoperative outcomes showed that Dex was associated with shorter ventilator times, reduced ICU and hospital LOS, and lower incidence rates of postoperative junctional atrial tachycardia.[102]

5.1.1.2. Recommendation 2. Use of an age-appropriate delirium screening tool is recommended in the ICU after pediatric cardiac surgery (Table 5; COR = 2a; LOE = B-NR).[83,84]

Emerging data have led to the recognition that, similar to adults, delirium is a frequent occurrence in critically ill children, particularly after cardiac surgery.[83,103] Delirium is reported in 17% of children in the ICU,[103] and the incidence might be underestimated. In children who underwent cardiac surgery, delirium was present in 57% to 59%[83,103] and was associated with more complex surgeries (The Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery [STAT] category higher than 3) and longer CPB times. Younger age, benzodiazepines, and longer ventilator times are independently associated with delirium. In addition, patients who experienced delirium had prolonged ICU LOS[83,103] and delirium is a strong predictor of mortality in critically ill patients.[103]

The symptoms of delirium can be similar to pain, withdrawal, or agitation, thus a validated and reliable assessment tool, taking into account children's developmental milestones, is essential. The following assessment instruments are validated in the pediatric population:

1. The pediatric Confusion Assessment Method[104] for the ICU, recommended in children 5 years of age or older.
2. The Cornell Assessment Pediatric Delirium[105] for children 0-18 years.
3. The Sophia Observation Withdrawal Symptoms-Pediatric Delirium Scale.[106]
4. The Pediatric Anesthesia Emergence Delirium,[107] best indicated for immediate postoperative use.

Because of the fluctuating nature of delirium, it is important to perform the assessments every 8 to 12 hours, or a minimum of once per shift in the ICU.[103,105] Frequent screening facilitates early identification of children most at risk for delirium-related morbidity and mortality and allows for targeted intervention.

5.1.2. Pain

5.1.2.1. Recommendation 1. Patient and family education regarding opioid-sparing strategies can be useful to set expectations related to pain management in the perioperative period (Table 5; COR = 2a; LOE = C-LD).[38,85]

Literature on pediatric postoperative pain highlights the role and positive effect of parental involvement and family-centered care. This is of particular relevance in the current era when there is growing consensus for management of postoperative pain with opioid-sparing strategies.[99] Numerous studies showed high parental stress in the perioperative period.[108] Harvey and Kovalesky[85] elegantly showed that most parents expect to have their child in a heavily sedated state after the surgery, free of pain. The authors concluded that preoperative preparation relative to expectations for recovery and pain management was needed in pediatric cardiac surgery. Chng and colleagues[109] reported that parents' knowledge and positive attitude correlated with parental satisfaction and better pain management strategies.

5.1.2.2. Recommendation 2. Administration of nonopioid analgesics can be effective opioid-sparing regimens after pediatric cardiac surgery (Table 5; COR = 2a; LOE = B-NR).[5,22,60,86-90]

Optimal pain management aims to reduce perioperative surgical stress associated with surgery, while minimizing side effects and complications of the medication. With this purpose, multimodal pain regimens are effective adjuncts to opioids after surgery. The most frequently used medications involved in such regimens include intravenous acetaminophen and ketorolac.[5,22]

5.1.2.2.1. Intravenous acetaminophen. Acetaminophen inhibits the peroxidase activity of cyclooxygenase (COX)-1 and COX-2 and produces analgesic and antipyretic effects. Its use in cardiac surgery is relatively safe because it has no effect on renal function and platelets, however, it can affect liver function, though not at standard doses.[90] A single-center placebo-controlled randomized trial showed reduced pain scores after pediatric cardiac surgery with administration of intravenous acetaminophen, however, the opioid-sparing effect was not statistically significant.[110] A randomized controlled trial in neonates and infants who underwent major noncardiac surgery showed the opioid-sparing effect of intermittent intravenous acetaminophen at 48 hours.[111] A multicenter randomized trial is under way to evaluate postoperative pain control and opioid-sparing effect of intravenous acetaminophen after cardiac surgery in infants and children younger than 36 months of age.[112]

5.1.2.3. Intravenous ketorolac. Ketorolac is a nonsteroidal anti-inflammatory drug that inhibits the COX enzyme isoforms and prostaglandin synthesis. Other reported analgesic mechanisms involve local nitric oxide synthesis. Although various clinical trials of ketorolac show benefit in reducing pain and opioids in children who undergo various (noncardiac) surgical procedures, a Cochrane review of postoperative pain management in children with ketorolac showed that the quality of evidence for its use in treating postoperative pain was very low. However, there was evidence that intra- and postoperative administration of ketorolac might be opioid-sparing.[87,113] To date, there is no randomized trial published in pediatric cardiac surgery in this regard. Regarding its safety profile, ketorolac is associated with acute kidney injury and increased bleeding. When routinely administered for 48 hours after surgery in infants younger than 6 months, ketorolac caused a significant increase in creatinine from baseline, however, the values remained within normal limits and the significance of this finding is unclear.[114] Ketorolac was associated with acute kidney injury in infants with preexisting renal dysfunction, concomitant use of aspirin, or single-ventricle palliation,[115] and should be used with caution in these settings. A randomized trial did not show increased risk of bleeding after pediatric cardiac surgery.[116] In a recent study on the use of ketorolac as part of an opioid-sparing regimen after cardiac surgery, the authors reported low incidence of postoperative acute kidney injury, and bleeding.[22]

Recent publications on programmatic perioperative approaches using opioid-sparing multimodal regimens in pediatric cardiac surgery showed excellent pain control postoperatively with a combination of intravenous acetaminophen and ketorolac.[5,110] In addition, opioid-free postoperative pain management after pediatric cardiac surgery has been described using a combination of regional anesthesia and multimodal nonopioid pain medications.[91]

5.1.2.4. Recommendation 3. Peripheral regional anesthesia can be implemented as an effective perioperative opioid-sparing modality in pediatric cardiac surgery (Table 5; COR = 2a; LOE = B-R).[5,22,60,86-90] Multiple ultrasound-guided superficial regional anesthetic techniques have emerged in the recent years and have demonstrated opioid-sparing effects.[92,117-120] These might be effective in select patients.

5.1.2.4.1. Bilateral erector spinae blocks. Randomized and matched case studies of pediatric patients undergoing cardiac surgery who received bilateral erector spinae blocks have shown opioid-sparing effects intra- and postoperatively. The technique was performed postoperatively as a single injection or with the use of continuous infusions via catheters. Lower pain scores,[92,118] and reduction of postoperative nausea and vomiting[118] as well as reduction of LOS[92] have been reported. Some blocks were performed in the context of established ERPs with an opioid-sparing multimodal pain regimen.[92]

5.1.2.4.2. Bilateral transverse thoracic muscle plane block. Bilateral transverse thoracic muscle plane blocks performed with[119] or without rector sheath block[120] are opioid-sparing and have shown effects in reducing postoperative pain and mechanical ventilation time after pediatric cardiac surgery. Because lidocaine-containing cardioplegia is frequently used in congenital heart surgery, intra- and postoperative lidocaine concentrations were measured in patients receiving regional anesthesia for cardiac surgery.[93] There was no significant difference in serum concentration between patients who underwent surgery with and without CPB, and no clinical signs of local anesthetic toxicity postoperatively from the regional blocks. Although early results from these superficial regional approaches show opioid-sparing effects, larger well designed studies are needed to better evaluate the effectiveness, and safety of these regional techniques, and their effects on enhancing recovery.[92,94]

5.1.2.5. Recommendation 4. Neuraxial anesthesia may be used as an effective perioperative opioid-sparing modality in pediatric cardiac surgery (Table 5; COR = 2b; LOE = B-R).[91-98]

Neuraxial approaches in congenital cardiac surgery have traditionally included caudal and thoracic epidurals, and spinals. A systematic review of 14 trials including 605 patients showed improvement of postoperative pain with regional anesthesia in pediatric cardiac surgery.[96] A large retrospective study of 220 patients who underwent cardiac surgery with neuraxial anesthesia[121] showed a low incidence of complications, including epidural hematoma. Its use enabled EE and was associated with low pain scores. A double-blind randomized trial in single-ventricle patients showed that a caudal using local anesthetic combined with morphine delayed the need for intravenous morphine in Fontan (stage 3) patients.[97] When used as part of a multimodal regimen, these techniques have been opioid-sparing.[22] Neuraxial anesthesia, despite its demonstrated effects in reducing postoperative pain, carries a risk, albeit low, for epidural hematoma in the setting of obligatory anticoagulation for CPB.

5.1.2.6. Recommendation 5. It is reasonable to discharge pediatric patients after cardiac surgery who are receiving nonopioid analgesics when adequate pain control is achieved in hospital with that regimen (Table 5; COR = 2a; LOE = B-NR).[5,22,99]

Limited data exist regarding opioid prescriptions on discharge after pediatric cardiac surgery. A recent publication that reviewed the results with a minimal opioid postoperative protocol and early discharge reported 4% of patients received opioids at discharge, and only 1 patient (1%) was readmitted for intractable pain.[22] As part of an ERP after cardiac surgery,[5] patients younger than 18 years are not discharged while receiving opioid medications and are optimized on a multimodal pain regimen before discharge. The experience of analgesia with a comprehensive fast-track program in the United Kingdom did not report discharge medications.[122] Recent guidelines for opioid prescribing in children after surgery recommended that, upon ordering discharge analgesics, nonopioid options be the first line of treatment.[99]

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5.2. Intraoperative Anesthetic Management

5.2.1. Recommendation 1. Immediate or EE (<6 hours from completion of cardiac surgery) is recommended as an integral component of an ERP in selected patients (Table 6; COR = 1; LOE = A).[29,47,48,51,123,124]

EE is an integral component of ERPs. EE reduces airway complications related to an indwelling endotracheal tube and reduces the need for ICU sedation and analgesia. It enables use of nonpharmacologic comfort measures including swaddling, parental holding, and resumption of enteral feeds. Shorter durations of mechanical ventilation have been shown to reduce ICU LOS and might decrease costs associated with postoperative care.[5,57]

Multiple studies have shown that immediate extubation (in the OR after cardiac surgery) and EE (<6 hours after completion of the procedure) are feasible without an increase in morbidity and mortality in selected pediatric patients after cardiac surgery.[5,55,59,62,74,124] The rate of reintubation after EE in these select populations has been shown to be the same or less than the rate with longer durations of tracheal intubation. Authors of multi-institutional and single-center studies have generally reported that younger and smaller patients with more preoperative risk factors, patients with higher severity of illness scores, and patients who undergo high-complexity operations were more likely to need a longer duration of mechanical ventilation (Table 7).[14,31]

5.2.2. Recommendation 2. Application of protocol-based multimodal anesthesia with limited intraoperative use of respiratory depressants is recommended to enable early, sustained extubation after pediatric cardiac surgery (Table 6; COR = 1; LOE = B-R).[29,123,125]

Accomplishing early, sustained extubation is predicated with an integrated multimodal anesthetic and postoperative analgesia/sedation plan, which limits the use of drugs that cause respiratory depression. The intraoperative anesthetic plan needs to achieve anesthetic goals while ensuring a smooth transition to the ICU and satisfactory perioperative pain control. Although a number of drug combinations have been used successfully, the only drug that has been consistently associated with reduced duration of postoperative ventilator support after pediatric cardiac surgery is Dex.[130,131] Dex is a highly selective alpha-2 agonist with hypnotic, analgesic, and anxiolytic properties that have little or no effect on respiration. Dex is one of the few drugs for which pharmacokinetics/dynamics have been established for use in neonates and infants undergoing cardiac surgery.[125,132,133] It has been shown that infants can be successfully extubated and remain with a natural airway while receiving an infusion of Dex.[22,125,134]

5.3. Surgical Considerations

5.3.1. Recommendation 1. Enhanced recovery strategies should be modified in patients with hemodynamically significant residual lesions or compromised physiology to ensure patient safety (Table 8; COE = 2a; LOE = B-R).[14,29,30,44,47,59,135,136]

The cardiac team should also develop general guidelines for when to depart from ERPs to pursue a modified course, and when to abandon ERPs altogether. Stakeholders are surgeons, perfusionists, anesthesia care providers, and the cardiologist performing intraoperative transesophageal echocardiography. Further, OR nurses and/or advanced practice providers play an important role in communicating with the family during the surgery and might help set and manage family expectations. In case of a change from the ERP, the ICU team and respiratory therapist should be apprised of the situation to prepare a ventilator and inhaled nitric oxide or other necessary support devices.

TABLE 6. Extubation and anesthesia

	COR	LOE
1. Immediate or early extubation (<6 hours from completion of cardiac surgery) is recommended as an integral component of an enhanced recovery program in selected patients.[29,47,48,51,123,124]	I	A
2. Application of protocol-based multimodal anesthesia with limited intraoperative use of respiratory depressants is recommended to enable early, sustained extubation after pediatric cardiac surgery.[29,123,125]	I	B-R

COR, Class of recommendation; *LOE*, level of evidence.

TABLE 7. Risk factors for prolonged invasive mechanical ventilation[31,52,126-129]

Hemodynamic instability
Bleeding
Low cardiac output syndrome
Cardiac dysfunction
Unbalanced circulation
Residual lesions
Severe pulmonary hypertension
Onset of sepsis
Bloodstream infection
Local infectious complications (mediastinitis)
Necrotizing enterocolitis
Arrhythmia
Junctional ectopic tachycardia
Respiratory dysfunction
Respiratory depression secondary to anesthesia
Pleural effusion
Pneumothorax
Pulmonary edema
Mucous plugging
Aspiration
Atelectasis
Intrinsic lung disease
Viral infection
Diaphragm paralysis/phrenic nerve palsy
Tracheomalacia/bronchomalacia
Tracheal stenosis
Weak cough/hypotonia
Central apnea
Genetic/chromosomal disorder
Upper airway obstruction
Excessive secretions
Airway edema
Airway anomalies (eg, complete tracheal rings, tracheal web)
Airway compression by cardiac chambers or blood vessels
Vocal cord paralysis/paresis
Glossoptosis

In general, extubation should be attempted in all ERP candidates who have appropriate gas exchange and respiratory effort at the conclusion of surgery in the absence of major intraoperative complications, hemodynamic instability, or ongoing bleeding. In a randomized trial of extubation in the OR versus elective extubation in the ICU, in-OR extubation was reported to be safe and associated with significantly shorter ICU and postoperative hospital LOS.[30] In that study, the authors excluded neonates and patients receiving ventilatory support before surgery. For patient safety, the authors also included a pathway for "dropout" of subjects whose intraoperative course did not meet specific criteria. Those criteria included: (1) hemodynamic stability (use of no more than 10 μg/kg/min of dopamine and 0.75 μg/kg/min of milrinone with no increase of the dosages during the postbypass period), (2) urinary output of at least 1 mL/kg during the last hour of the operation, (3) lactate levels in arterial blood at the end of the operation of <50 mg/dL (5.6 mmol/L), (4) acceptable oxygenation (oxygen saturation of 75%-80% in cyanotic patients and 94% in noncyanotic patients with inspired oxygen fraction of 0.6) without the use of nitric oxide, (5) primary closure of the chest, and (6) the use of no more than 20 mL/kg of packed red blood cells and 20 mL/kg of platelets during the postbypass period.[30] Criteria for patient "dropout," or changing course to abandon OR extubation or other aspects of larger ERPs, should be customized by each individual congenital heart center. Although neonates are more prone to postanesthesia apnea, have functional organ system immaturity, and often worse nutritional status compared with older children,[137-140] neonates have been included in several ERP studies on EE and "fast-track" protocols in pediatric cardiac surgery, and they may be considered for an ERP.[47,52,58,126,127] Ultimately, the decision regarding implementation of ERP strategies for an individual patient should be made collaboratively, including a discussion between the surgeon, anesthesiologist, and intensive care team.

5.3.2. Recommendation 2. Enhanced recovery strategies may be considered in select patients after procedural hypothermia including DHCA (Table 8; COR = 2a; LOE = B-NR).[19,52,56,58]

Patients undergoing DHCA may also be considered for ERP, although DHCA has been identified in some studies as a risk factor for extubation failure (requiring reintubation within 48 hours).[52,127,128] Also, in a study of 2060 children (neonates and non-neonates) undergoing cardiac surgery, children of all ages exposed to DHCA were significantly less likely to be extubated in the OR.[58] The authors reported that DHCA was not an influencing factor for EE in non-neonates, but fewer older children underwent DHCA, and lower sample size within that group likely obfuscated the authors' ability to see an effect.[58] Similarly, Vricella and colleagues[19] reported that in a population of 201 electively admitted patients, mostly with lesser cardiac defect complexity, DHCA was applied in 58 patients (29%) and deep hypothermia with reduced flow in another 55 (27%). Neither treatment reduced the likelihood of extubation in the OR, which was achieved in 175 (87%) cases. Only DHCA of duration >20 minutes predicted delay of extubation to 4 hours after surgery, by which time 19 of 22 such patients (86%) were extubated.[19]

6. POSTOPERATIVE MANAGEMENT APPROACHES

6.1. Nausea, Feeding, and Bowel Regimen

6.1.1. Recommendation 1. Tailored pharmacologic approaches in the perioperative period can be beneficial to reduce postoperative nausea and vomiting and facilitate early bowel recovery after pediatric cardiac surgery (Table 9; COR = 2A; LOE = B-NR).[5,141,142]

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TABLE 8. Surgical considerations

	COR	LOE
1. Enhanced recovery strategies should be modified in patients with hemodynamically significant residual lesions or compromised physiology to ensure patient safety.[14,29,30,44,47,59,135,136]	IIa	B-R
2. Enhanced recovery strategies might be considered in select patients after procedural hypothermia including deep hypothermic circulatory arrest.[19,52,56,58]	IIb	C-LD

COR, Class of recommendation; *LOE*, level of evidence.

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Nausea and vomiting are known side effects of general anesthesia. These might be more prevalent after pediatric cardiac surgery if the underlying defect increases mesenteric venous pressures, such as after cavopulmonary connection. Postoperative nausea and vomiting can delay institution of enteral nutrition, prolonging the need for intravenous fluid administration, and preclude early mobilization.[5] The use of intravenous dexamethasone started in the OR and continued postoperatively has been shown to be effective in preventing postoperative nausea. Prophylactic ondansetron started intraoperatively and continued postoperatively in a high-risk pediatric population has been shown to prevent postoperative nausea and vomiting.[141,142] Other pharmacologic agents that have also shown benefit include intravenous metoclopramide and scopolamine patch. In a recent study on the introduction of an ERP in congenital cardiac surgery, pharmacologic prophylaxis against postoperative nausea and vomiting was successfully used in nearly two-thirds of the patients.[5] An aggressive pharmacologic regimen can effectively limit postoperative nausea and vomiting, such that most pediatric patients are able to tolerate full enteral feeds within 48 hours after surgery.[148]

6.1.2. Recommendation 2. Protocol-driven, age-appropriate enteral feeding and bowel regimen should be implemented early to improve return of bowel function and accelerate recovery after pediatric cardiac surgery (Table 9; COR = 1; LOE = B-NR).[5,18,142-146]

It is well established that protein-energy malnutrition is associated with worse outcomes in infants and children who undergo repair of congenital heart disease.[143] In addition, patients who receive enteral nutrition have lower rates of infectious complications and shorter hospital LOS.[149] A focused approach aimed at optimizing enteral nutrition can, therefore, potentially improve surgical outcomes. Optimization of perioperative feeding begins with curtailing the duration of preoperative fasting. A high carbohydrate-containing clear oral solution such as apple juice, clear sports drink, or Pedialyte may be offered up to 2 hours before surgery.[5,150] Early resumption of enteral nutritional support in the postoperative period might be especially difficult in children with congenital heart disease because of the need to limit fluid intake and the risk of necrotizing enterocolitis in neonates, particularly with high osmolar enteral feeds. In this regard, focused algorithms aimed at establishing early enteral nutrition can be successfully used in an age-appropriate fashion.[145] In neonates and infants, these algorithms advocate early establishment of enteral feeding. Oral feeding trials are undertaken 1 to 2 times every day and before each enteral tube-feeding. When 50% to 75% of caloric goal is met with oral feeds, enteral tube feeding is terminated to facilitate early transition to exclusive oral feeding. Even in high-risk populations such as neonates with hypoplastic left heart syndrome, a focused feeding algorithm aimed at rapid advancement to complete enteral nutrition is safe and effective.[146] Such an approach reduces median time to achieve recommended daily allowance of calories without an increase in enteral complications, including enterocolitis. In older children, ice chips can be offered immediately after extubation, with most patients stably tolerating oral fluids within 6 hours.[16] Limiting postoperative intravenous fluid use as soon as when 50% of fluid goals are met enterally might also be beneficial.

ERPs have also evaluated standard postoperative bowel regimens, including oral docusate and bisacodyl suppositories, as well as routine use of oral lactulose until bowel movements occur in older children. Such approaches have not shown a significant reduction in time to bowel movement.[13] The use of chewing gum to accelerate postoperative return of bowel function might be considered in older children.[5] Last, reduced use of opioids also contributes to improved postoperative gastrointestinal function.

TABLE 9. Bowel/nutritional postoperative strategies

A. Nausea, feeding and bowel regimen	COR	LOE
1. Tailored pharmacologic approaches in the perioperative period can be beneficial to reduce postoperative nausea and vomiting and facilitate early bowel recovery after pediatric cardiac surgery.[5,141,142]	IIa	B-NR
2. Protocol-driven, age-appropriate enteral feeding and bowel regimen should be implemented early to improve return of bowel function and accelerate recovery after pediatric cardiac surgery.[5,18,142-146]	I	B-NR
B. Early deintensification and mobilization		
1. Protocol-based approaches aimed at early removal of monitoring lines, drainage tubes, and wires might be useful to reduce length of stay after pediatric cardiac surgery.[5,8,14,18,62,142,147]	IIb	B-NR
2. Protocol-based, age-appropriate strategies are recommended for early mobilization after pediatric cardiac surgery to reduce postoperative length of stay.[5,14,16,18,141,142]	I	B-R

COR, Class of recommendation; *LOE*, level of evidence.

6.2. Early Deintensification and Mobilization

6.2.1. Recommendation 3. Protocol-based approaches aimed at early removal of monitoring lines, drainage tubes, and wires might be useful to reduce LOS after pediatric cardiac surgery (Table 9; COR = 2b; LOE = B-NR).[5,8,14,18,62,142,147]

Management of chest tubes and monitoring lines continues to be a critical aspect in postoperative care after pediatric cardiac surgery. Although it has been recognized that chest tubes cause pain, reduce pulmonary function, and limit patient mobilization, there is marked variation between centers in chest tube removal criteria.[8,151] Studies on enhanced recovery approaches after adult cardiac surgery have shown that specific protocols aimed at early removal of nasogastric tubes, central venous catheters, thoracostomy tubes, and epicardial pacing wires can be safely implemented and promote early patient mobilization.[20] Pediatric patients undergoing EE after cardiac surgery also tend to have shorter durations of chest tube use, indicating that institutional process measures play a significant role in the duration of chest tube drainage.[62] A recent study by Bertrandt and colleagues evaluated specific algorithms aimed at an aggressive approach toward removal of chest tubes after pediatric cardiac surgery.[152] Their results showed that in children who underwent a biventricular surgical procedure, a 25% reduction in chest tube duration was achieved with these algorithms. This was associated with a reduction in ICU, as well as postoperative hospital LOS. This translated into a 37% reduction in average cost of hospitalization, without an increase in complications, including need for chest tube reinsertion. In the absence of sanguineous, chylous, or purulent discharge, protocols that recommend chest tube removal in the setting of more generous outputs have been shown to be safe.[5] Even in the context of children undergoing pulmonary resection, aggressive early removal of chest tubes, including avoidance of routine pleural drainage in select patients, is safe and reduces hospital LOS.[147] There appears to be greater willingness among practitioners to embrace the practice of early chest tube removal.[18] Greater experience with the application of such protocols leads to reduction in length of hospital stay in children who undergo uncomplicated cardiac surgery.[14]

6.2.2. Recommendation 4. Protocol-based, age-appropriate strategies are recommended for early mobilization after pediatric cardiac surgery to reduce postoperative LOS (Table 9; COR = 1; LOE = B-R).[5,14,16,18,141,142]

Early mobilization after surgery, including cardiac surgery, has been shown to positively influence the incidence of venous thromboembolism, atelectasis, and return of bowel function.[141] It has also been suggested that early mobilization can help with fluid mobilization after cardiac surgery.[5] Safe mobilization after pediatric cardiac surgery requires age-appropriate strategies. A recent study showed that a structured and stratified early mobilization program can be successfully implemented in an academic pediatric ICU.[153] Such a program increases early mobilization activities, including ambulation, without adverse events. A successful mobilization program requires multidisciplinary involvement and frequently involves specific additional personnel to help with patient safety.[154] Safe mobilization after pediatric cardiac surgery requires specific additional considerations. These include evaluation of sedation state, monitoring for orthostatic hypotension because of the fluid shifts, and the need to care for monitoring lines and drainage tubes.[5] ERPs generally incorporate guidelines favoring early mobilization. In older patients for example, this can include sitting in a chair within 4 hours and walking around the unit within 8 hours after extubation.[5] In general, providers tend to be more inclined to embrace early mobilization programs,[18] however, there might be reluctance from patients and families.[16] A programmatic approach to discussing the benefits of early mobilization in the preoperative period could facilitate overcoming such reluctance. Increased familiarity and continued experience with implementation of early mobilization programs can result in reduced hospital LOS.[14]

7. FUTURE DIRECTIONS

Whereas ERPs have been implemented widely in adult cardiac and thoracic surgery, strategies to facilitate enhanced recovery after pediatric cardiac surgery have been less frequently implemented and studied. Our group has adapted recommendations from the experience in pediatric noncardiac surgery and adult cardiac surgery to best identify components of enhanced recovery and apply those to pediatric cardiac surgery.

Implementation of these recommendations will require careful and strategic multidisciplinary planning to suit individual institutional needs. Individual institutions are markedly different in their approach to postoperative management, particularly with regard to pain management and sedation. Hence, these guidelines do not have specific parameters regarding medication choices and dosing thereof in the absence of validated data. Rather, each program should thoughtfully adapt what is applicable and possible within their standard of practice.

A critical step in implementation of ERPs is the meticulous evaluation and fine-tuning of the program on the basis of outcomes. Quality metrics should be developed to assess favorable and adverse outcomes related to implementation of an ERP. Such an initiative could even be considered for multi-institutional collaborative learning or as part of large database analyses. As such, focused studies are necessary to prospectively evaluate the feasibility, safety, and value of implementing ERPs in pediatric cardiac surgery. In the era of changing insurance reimbursement guidelines, it is as yet unclear if the costs required to implement these ERP translate into an overall economic benefit. Patient and family satisfaction is of paramount importance and will also need to be specifically addressed in future studies.

8. CONCLUSIONS

Our work provides consensus guidelines aimed at facilitating enhanced recovery after pediatric cardiac surgery. Future prospective studies are required to specifically evaluate the various aspects of these guidelines to further refine their feasibility and benefits.

8.1. Conflict of Interest Statement

Dr Fuller is a consultant for WL Gore. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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