J Anesth (2011) 25:321–329
DOI 10.1007/s00540-011-1130-7

ORIGINAL ARTICLE

Fast-track postoperative care for neonatal cardiac surgery: a single-institute experience

Yuka Yamasaki · Nobuaki Shime · Takako Miyazaki · Masaaki Yamagishi · Satoru Hashimoto · Yoshifumi Tanaka

Received: 5 April 2010 / Accepted: 7 March 2011 / Published online: 13 April 2011

Abstract

Purpose Perioperative fast-track management has gained wide acceptance in the field of neonatal corrective heart surgery. We have examined its impact on morbidity outcomes.

Methods Between 1997 and 2009, 52 consecutive neonates underwent corrective repair of congenital heart defects on cardiopulmonary bypass. Fast-track management was introduced in 2006 with the aim of simplifying care; it includes early postoperative extubation with low-dose fentanyl and an pulse oximeter oxygen saturation (SpO_2) target of $\leq$95%, early removal of indwelling lines, and early introduction of early enteral feeding. This was a retrospective review of the medical records in which perioperative characteristics and outcomes of patients operated on prior to the introduction of fast-track management care (controls, group C) were compared with those operated on following its introduction (fast-track group, group F).

Results Intraoperative fentanyl was administered in significantly lower doses in group F (29.5 ± 11.5 μg/kg) than in group C (65.6 ± 34.0 μg/kg) ($p < 0.001$). The median number of days of postoperative mechanical ventilation and inotrope administration was significantly lower in group F (2 and 4 days, respectively) than in group C (9 and 9 days, respectively) ($p < 0.001$ and $p = 0.003$). More patients ($p < 0.001$) in group F (56.3%) than in group C (0%) was extubated within <24 h. The median number of days to postoperative weight recovery was significantly lower in group F (16 days) than in group C (29 days) ($p = 0.003$). Finally, the median number of days in the Intensive Care Unit was significantly lower ($p = 0.01$) in group F than in group C (16 vs. 26 days, respectively). Mortality in group F was 0% versus 17% in group C ($p = 0.21$).

Conclusions Fast-track management with simple care for neonates undergoing complete biventricular repair of congenital heart defects was associated with better postoperative recovery.

Keywords Neonatal care · Postoperative care · Cardiac surgery · Congenital heart disease · Early extubation

Introduction

Despite the known correlation between very young age or low body weight and poor outcome after congenital heart surgery [1–3], neonatal care is evolving toward the performance of reparative operations at an increasingly younger age, rather than offering palliative procedures while awaiting the patient's growth and development before proceeding with total repair [4]. The advantage of an early repair lies in the prompt correction of congenital cardiac defects and, consequently, of the pathophysiologic consequences of these defects, such as volume and pressure overload, chronic hypoxemia, and abnormal growth and development [5]. Advances in preoperative diagnosis and perioperative

---

The participants in this study were admitted to the pediatric intensive care unit of Kyoto Prefectural University Hospital.

Y. Yamasaki · N. Shime (✉) · S. Hashimoto · Y. Tanaka
Intensive Care Division, Department of Anesthesiology
and Intensive Care, Kyoto Prefectural University of Medicine,
465 Kajiicho, Kamigyo-ku, Kyoto 602-8566, Japan
e-mail: shime@koto.kpu-m.ac.jp

T. Miyazaki · M. Yamagishi
Department of Pediatric Cardiac Surgery,
School of Medical Sciences, Kyoto Prefectural University
of Medicine, Kyoto, Japan

management, including minimally invasive techniques and cardiopulmonary bypass (CPB), have facilitated the performance of early surgical interventions [6, 7].

Fast-track care, which is the simplification of perioperative management and shortening of the time spent in the intensive care unit (ICU) is also an important means of further improving the outcome and lowering the medical costs of pediatric patients undergoing cardiac surgery [8–10]. In a number of studies, such patients were extubated within 24 h after surgery (4–8 h after simple procedures), had a lower rate of pulmonary complications and a shorter stay in ICU and, in particular, gained more favorable psychological effects [11–13]. However, clinical experience with such simple care, fast-track management in neonates remains limited [14, 15].

In this single-center study, we examined whether fast-track care has modified the postoperative outcomes of neonates who underwent corrective repair of congenital biventricular heart defects, excluding isolated patent ductus arteriosus and simple coarctation of aorta. We retrospectively reviewed the medical records and compared the perioperative characteristics and outcomes of patients who were operated before the introduction of fast-track care, as control, with those of patients who were operated on after the introduction of this fast-track strategy.

Patient population and methods

With the approval of our Institutional Review Board, who waived the need for written, informed consent from the parents of the patients, we retrospectively reviewed the hospital records of 51 consecutive neonates (36 males and 15 females) who, between January 1997 and June 2009, underwent corrective surgery for congenital heart disease on CPB at the University Hospital of Kyoto Prefectural School of Medicine and who were admitted to the pediatric ICU (PICU). One patient who died in the operation theater was excluded.

The final diagnosis was made by echocardiography, computed tomography and/or cardiac catheterization. All patients were critically ill and suffered from low-output syndrome, severe cyanosis, and/or congestive heart failure. Inotropes, diuretics, and prostaglandins to preserve the ductal-dependent blood flow, atrial balloon septostomy, and mechanical ventilatory support were used, depending on the cardiac defect and hemodynamic status.

Surgical procedure and techniques

All patients underwent primary repair by a single surgeon, via median sternotomy and under hypothermic CPB. No changes in CPB or intraoperative procedures occurred during the study period. Standard neonatal CPB techniques and instrumentation were used, including non-pulsatile roller pumps (HAS; Senko Medical Instrument, Tokyo, Japan) and a SAFE-MICRO membrane oxygenator (Senko Medical Instrument). The priming solution contained 5 ml/kg of 10% mannitol, 3 ml/kg of 8.5% sodium bicarbonate, acetated Ringer's solution, and packed red cells, as needed. Chlorpromazine 1–3 μg/kg/min and nitroglycerin 1–2 μg/kg/min were also continuously added to the venous reservoir of the CPB priming solution. The aorta was cannulated with a straight Teflon cannnula. Each vena cava was drained with cannulas entering the right atrium. CPB was performed under moderate hemodilution in order to maintain a hematocrit between 35 and 40%, hypothermia between 28 and 36°C, and whole body anticoagulation with 375 U/kg of heparin. The pump was set to maintain a >70% continuously monitored, systemic venous oxygen saturation and a ≥150 ml/kg/min flow to keep the mean arterial pressure between 30 and 50 mmHg. Cardioplegic arrest was induced by cold crystalloids. In patients presenting with transposition of the great arteries, intermittent cold cardioplegia was usually administered anterogradely into the aortic root and retrogradely via the coronary sinus.

No patient underwent deep hypothermic circulatory arrest. Dilutional ultrafiltration began immediately after hemodynamic stabilization and was continued throughout the CPB. The hemodiafiltration circuit consisted of a dialysis membrane of polymethyl methacrylate (HEMOFEEL CH-0.6N; Toray Medical, Tokyo, Japan) and dialysate (Sublood BS; FUSO Chemical, Osaka, Japan) at a flow rate of 2,000–2,500 ml/h. The CPB was discontinued upon completion of the surgical procedure and the return of normal body temperature, hemodynamic stability, and normal sinus rhythm. After discontinuation of the CPB, hemodiafiltration was continued for 10–15 min using the CPB circuit for circulatory access.

Tracheal intubation and anesthetics

The patients were premedicated with transrectal chloral hydrate, oral trichlophos, or oral diazepam, at the discretion of the anesthesiologist, 20–30 min before admission to the operating room. The trachea was intubated through the oral cavity using an age-adjusted cuffed or non-cuffed tube fit to ensure suitable ventilation in a premature neonate or in a full-term neonate. Anesthesia was induced with intravenous midazolam 0.2–0.3 mg/kg, vecuronium 0.1–0.2 mg/kg, and fentanyl 1–2 μg/kg, and maintained with sevoflurane, fentanyl and vecuronium. Midazolam 0.2–0.3 mg/kg, vecuronium 0.1–0.2 mg/kg, and fentanyl 2–10 μg/kg were added to the CPB circuit. Neostigmine was not administered for reversal of muscle relaxation. The anesthetics and their doses were chosen by each anesthesiologist, with the exception of fentanyl which, in patients of the fast-track care group, was limited to doses imposed by our fast-track care protocol.

Patient monitoring

The systemic arterial pressure was continuously monitored via a peripheral catheter, and the central venous pressure via a catheter placed in the superior vena cava from an internal jugular vein. Electrocardiogram, pulse oximetry and capnogram were routinely monitored. The arterial blood was sampled for measurements of blood gases. No pulmonary artery or left atrial catheter was used, and transesophageal echocardiograms were not systematically recorded.

Respiratory care and sedation

The patients were transferred to the PICU immediately after the operation, while intubated and ventilated by pressure control, pressure support, or time cycle pressure-limited mode. They were extubated when (1) awake and breathing spontaneously with a (a) >5 ml/kg tidal volume, (b) <60 rpm respiratory rate, (c) $\leq$10 cm H_2O-positive inspiratory support pressure, and (d) <0.6 inspired oxygen fraction (FIO_2), (2) hemodynamically stable with a <10 inotropic score [16], and (3) no major postoperative bleeding was observed. Following extubation, oxygen was administered via a nasal cannula, as needed. Fentanyl was administered by continuous intravenous or subcutaneous infusion for analgesia in a standard dose of 0.4–1.2 μg/kg/h, and midazolam 0.05–0.2 mg/kg/h, dexmedetomidine 0.2–1.2 μg/kg/h, or both, were administered for sedation, as needed.

Fast-track care

Around January 2006, we started to introduce fast-track care, consisting of early (1) postoperative extubation, (2) removal of all indwelling lines, and (3) initiation of enteral feeding. Early extubation was facilitated by (1) lowering the intraoperative doses of fentanyl to 20–30 μg/kg, (2) limiting the use of postoperative vecuronium to intermittent boluses that were administered when needed instead of continuous infusions, and (3) setting the final pulse oximeter saturation (SpO_2) target at 92–95%, instead of >95%, before the institution of fast-track care. The earliest possible removal of indwelling lines was guided by attending intensivists and surgeons, and tube enteral feeding was encouraged as early as 48 h postoperatively.

Perioperative data collection

Perioperative data were collected by retrospectively reviewing the hospital records. Cardio-respiratory measurements were made preoperatively, upon admission to the ICU, and 24, 48, 72, and 120 h later. The preoperative data included (1) age at surgery, (2) birth weight, (3) weight at surgery, (4) sex, (5) gestational age, (6) history of prematurity (<37th week of gestational age), (7) non-cardiac malformations or genetic syndromes, and (8) need for preoperative intravenous inotropic support, mechanical ventilation, and hypoxic gas therapy. The intraoperative data included (1) duration of CPB and aortic cross-clamp time, (2) use of circulatory arrest, (3) duration of procedure and anesthesia, (4) doses of sevoflurane, fentanyl, and vecuronium, (5) epinephrine use, (6) delayed sternal closure and percutaneous cardiopulmonary support, and (7) fluid balance. The postoperative respiratory observations included (1) duration of mechanical ventilation and time needed to reach a fraction of inspired oxygen (FIO_2) <0.6, (2) success rate of extubation within <24 h after surgery, (c3 use of muscle relaxants or continuous intravenous sedatives, (4) use, dose, and concentrations of inhaled nitric oxide, (5) use of non-invasive positive pressure ventilation, and (6) complications, including re-intubation, atelectasis, pneumonia, pleural effusion, and pulmonary hypertensive crisis, defined as a sudden decrease in SpO_2 and systemic arterial pressure in combination with sudden increases in central venous pressure, or a sign of right heart dysfunction on echocardiograms. The postoperative measurements of hemodynamic support included (1) inotropic score [dopamine (μg/kg/min) + dobutamine (μg/kg/min) + epinephrine (μg/kg/min × 100)] and (2) doses of dopamine (μg/kg/min), dobutamine (μg/kg/min), and epinephrine (μg/kg/min) [16]. Outcome measures included (1) the Neonatal Therapeutic Intervention Score [17, 18], based on observations made on the first day in the PICU, (2) in-hospital mortality, and (3) postoperative clinical observations, including (a) length of stay in PICU and of inotrope therapy, (b) placement of arterial, peripheral, or central venous catheters, urinary catheter, or drainage tube, (c) time to onset of enteral nutrition or oral feeding, (d) time to recovery of preoperative body weight, (e) body weight at the time of discharge from PICU, and (f) incidence of postoperative renal failure requiring peritoneal dialysis or other major organ dysfunction [19, 20]. All patients underwent pre- and postoperative cerebral echography, interpreted by experienced neonatologists, to exclude the postoperative development of cerebrovascular complications, intracranial bleeding in particular.

Outcome assessment

The primary outcome assessed in this study was postoperative morbidity, including postoperative duration in mechanical ventilation or ICU stay. The surrogate outcomes were other postoperative parameters associated with morbidity, including postoperative requirement for

Table 1 Baseline characteristics of the study groups and preoperative management

Characteristics	Group F ($n = 16$)	Group C ($n = 35$)	p
Age at surgery (days)	12.3 ± 5.7	12.9 ± 6.1	0.73
Birth weight (g)	2,934 ± 349	2,979 ± 545	0.76
Weight at surgery (g)	2,818 ± 360	2,920 ± 515	0.48
Male/female	10:6	26:9	0.61
Gestational age (weeks)	38.6 ± 1.9	38.6 ± 1.7	0.92
<37 weeks of gestational age	1 (6)	4 (11)	0.98
Congenital disease			
Down's syndrome	0	1 (3)	0.87
Di George syndrome	1 (6)	1 (3)	0.74
Genito-urinary anomalies	0	1 (3)	0.87
Other dysmorphism or anomaly	1 (6)	2 (6)	0.98
Preoperative			
Dopamine	0	18 (51)	0.003
Mechanical ventilation	6 (38)	27 (77)	0.02
Hypoxic gas therapy	6 (38)	11 (31)	0.73
Prostaglandin therapy	12 (75)	31 (89)	0.66

Values are presented as the mean ± standard deviation (SD), or as the number of observations, with the percentage in parenthesis

Group F, Fast-track care; group C, control patients, operated on prior to the introduction of fast-track care

hemodynamic support or recovery of nutritional status or pulmonary and other organ dysfunctions.

Statistical analysis

The data are expressed as mean ± standard deviation (SD), median (range), or numbers (%) of observations. The baseline characteristics of both groups of patients were compared using Student's *t* test, the Mann–Whitney *U* test, or repeated measures analysis of variance for continuous variables, and chi-square test for categorical variables. A p value <0.05 was considered to be statistically significant.

Table 2 Congenital heart defects in each study group

Congenital heart defects	Group F ($n = 16$)	Group C ($n = 35$)
Transposition of the great arteries	10	18
Interrupted aortic arch complex	3	7
Coarctation of aorta complex	1	8
Truncus arteriosus	1	0
Double outlet right ventricle	0	1
Double inlet left ventricle	0	1
Pulmonary stenosis	1	0

Values are presented as the number of observations

Results

Patient population

The study included 16 consecutive neonates who underwent corrective operations between January 2006 and September 2009 (fast-track group, group F), and 35 consecutive neonates who were operated on between January 1997 and December 2005, prior to the introduction of fast-track care (controls, group C). The baseline characteristics of each study group are summarized in Table 1. The mean gestational age, age at operation, birth weight, and weight at surgery were similar in both groups. No patient presented with intraventricular hemorrhage, necrotizing enterocolitis, or infectious complications.

The congenital heart defects operated on in each group are shown in Table 2. The defects were complex in all patients, including transposition of the great arteries ($n = 28$), interrupted aortic arch complex ($n = 10$), and coarctation of the aorta complex ($n = 9$) as most frequent diagnoses. A single patient in group F and five patients in group C presented with non-cardiac malformations or genetic syndromes (Table 1).

Preoperative management

The main interventions used preoperatively are shown in Table 1. No patient in group F was administered dopamine while >50% of patients in group C received dopamine ($p = 0.003$). No patient was treated with epinephrine. The use of mechanical ventilation was also significantly lower in group F patients than in group C patients ($p = 0.02$).

Intraoperative observations

Table 3 summarizes the measurements and observations made intraoperatively. The duration of the CPB, aortic cross-clamp, and overall operation was similar in both

Table 3 Intraoperative observations

Intraoperative observations	Group F ($n = 16$)	Group C ($n = 35$)	p
Duration (min)			
Cardiopulmonary bypass	199 ± 73	197 ± 77	0.95
Aortic cross-clamp	92 ± 53	91 ± 42	0.94
Operation	358 ± 96	374 ± 143	0.68
Anesthesia	485 ± 120	449 ± 119	0.34
Fentanyl (μg/kg)	30 ± 12	65 ± 34	<0.001
Vecuronium (mg/kg)	2.1 ± 1.2	2.4 ± 1.3	0.35
Epinephrine	5 (31.3)	20 (57.1)	0.36
Fluid balance (ml)	464 ± 467	70 ± 235	<0.001
Delayed sternal closure	4 (25.0)	20 (57.1)	0.07
Percutaneous cardiopulmonary support	0	3 (8.6)	0.63

Values are presented as the mean ± SD or as the number (%) of observations in the corresponding group

Table 4 Postoperative respiratory measurements

Postoperative respiratory measurements	Group F ($n = 16$)	Group C ($n = 35$)	p
Days of mechanical ventilation, median (range)	2 (1–49)	9 (1–65)	<0.001
Extubation within <24 h	9 (56.3)	0	<0.001
Re-intubation	2 (12.5)	8 (22.9)	0.83
Vecuronium	0	31 (88.6)	<0.001
Use of continuous intravenous sedatives	7 (43.7)	32 (91.4)	0.04
Days to <0.6 fraction of inspired oxygen	1.1 ± 1.6	5.2 ± 6.2	0.008
Use of nitric oxide	3 (18.9)	20 (57.1)	0.10
Non-invasive positive pressure ventilation	8 (50.0)	8 (22.9)	0.05
Respiratory complications			
Atelectasis/pneumonia	4 (25.0)	8 (22.9)	0.58
Pleural effusion	3 (18.8)	2 (5.7)	0.26
Pulmonary hypertensive crisis	0	3 (8.3)	0.92

Values are presented as the mean ± SD or as the number of observations in the corresponding group, with the percentage in parenthesis

groups. The mean intraoperative dose of fentanyl was approximately 50% lower in group F patients than group C patients ($p < 0.001$), although the mean doses of sevoflurane and vecuronium administered and the proportions of patients who received epinephrine were similar in both groups. The intraoperative fluid balance was markedly greater in group F patients than in group C patients. The sternum was left open after surgery in 20 of 35 patients (57.1%) in group C versus four of 16 patients (25.0%) in group F ($p = 0.06$). Percutaneous cardiopulmonary support was used in three hemodynamically unstable group C patients versus no patient in the group F (not significant).

Postoperative lung and hemodynamic function

The postoperative respiratory variables are summarized in Table 4. The arterial partial oxygen pressure/FIO_2 ratio was similar in both groups. In the first 120 postoperative hours, SpO_2 was significantly lower, time to reach an FIO_2 <0.6 was shorter (Table 4), and supplemental oxygen, expressed by FIO_2, was lower in group F patients than in group C patients. Nearly 90% of the patients in group C received vecuronium during mechanical ventilation versus 0% of patients in group F (Table 4). The use of continuous intravenous sedatives was significantly lower in group F patients than in group C patients ($p = 0.04$), and the median duration of mechanical ventilation was 7 days shorter for group F patients than for group C patients. When we limited the analysis to patients who were not mechanically ventilated preoperatively, the duration of postoperative mechanical ventilation was also 6 days shorter in group F patients than in group C patients (7.3, range 1–49 vs. 13.3, range 4–30 days, respectively; $p = 0.02$). Likewise, the median duration of mechanical ventilation limited to survivors was significantly shorter in group F (2 days, range 1–49) than in group C (12.5 days, range 2–65) ($p < 0.001$). Furthermore, six of 16 patients (56.2%) in group F were extubated within <24 h compared with no patient in group C ($p < 0.001$). The use of non-invasive, nasal, continuous positive airway pressure and the rates of re-intubation and nitric oxide administration were similar in both groups. In patients treated with nitric oxide, the concentration was significantly smaller (0.67 ± 2.6 vs. 6.0 ± 7.0 ppm; $p = 0.005$) and treatment duration was shorter (0.36 ± 0.93 vs. 2.94 ± 4.16 days; $p = 0.02$) in group F patients than in group C patients.

The hemodynamic variables, including mean arterial pressure and central venous pressure, were similar in both groups throughout the study period. The inotropic scores in the group F versus group C patients were 7.0 ± 4.8 versus 14.2 ± 9.8 on admission to the PICU ($p = 0.007$), 4.9 ± 3.6 versus 13.6 ± 9.8 at 24 h ($p = 0.001$), 3.4 ± 2.8 versus 12.4 ± 10.0 at 48 h ($p < 0.001$), 1.8 ± 2.5 versus 10.1 ± 10.0 at 72 h ($p = 0.002$), and 0.36 ± 1.4 versus 7.5 ± 15.6 at 120 h ($p = 0.001$) after the index operation. The median duration of postoperative inotrope therapy was 5 days shorter for group F patients than for group C patients ($p = 0.003$; Table 5).

Other postoperative observations and outcomes

The postoperative characteristics and clinical outcomes of each study group are summarized in Table 5. The Neonatal Therapeutic Intervention Scores measured on admission to the PICU were similar in both patient groups and were consistent with a high immediate postoperative morbid risk. No group F patient died in the postoperative period versus five patients (14.3%) in group C ($p = 0.26$). Of these five patients, one with transposition of the great arteries died in the immediate postoperative period from pulmonary hypertensive crisis, three died due to low cardiac output, and one died due to pulmonary hemorrhage. The latter four patients had been placed on percutaneous cardiopulmonary support.

The median length of stay in the PICU was 10 days shorter for group F patients than for group C patients ($p = 0.007$); this increased to 11.5 days (ranges 8–69 vs. 14–68 days, respectively) after exclusion of the non-survivors from the analysis ($p = 0.001$). Indwelling lines, including vascular catheters, drainage tubes, and urinary catheters, were in place for shorter lengths of time in group F patients than in group C patients, and the duration of peritoneal dialysis was significantly shorter in the former, as was the time to onset of enteral nutrition, oral intake, and to recovery of preoperative body weight (Table 5).

The incidence of postoperative pulmonary complications was similar in both groups, that of organ dysfunction tended to be lower in group F ($p = 0.14$), and the number of failing organs was significantly lower ($p = 0.02$) in group F than in group C (Table 4).

Discussion

The results of this analysis indicate that the postoperative outcome of neonates who underwent corrective cardiac surgery with fast-track management aimed at providing simple care was favorable. Simple interventions, such as early tracheal extubation and withdrawal of indwelling lines and catheters, were achieved safely. Moreover, fast-

Table 5 Postoperative observations and outcomes in each study group

Postoperative observations and outcomes	Group F ($n = 16$)	Group C ($n = 35$)	p
Neonatal Therapeutic Intervention Score[a]	52.9 ± 7.4	53.6 ± 6.4	0.53
Deaths	0	5 (14.3)	0.26
Median time, days (range)			
Stay in intensive care unit	16 (8–69)	26 (3–68)	0.007
Inotrope therapy	4 (2–33)	9 (1–31)	0.003
Catheterization			
Arterial	5 (2–40)	12 (1–66)	0.004
Peripheral venous	15 (6–180)	27 (2–116)	0.11
Central venous	5 (4–12)	12 (1–63)	<0.001
Urinary	4 (2–25)	11 (1–68)	<0.001
Drainage tube placement	4 (4–12)	8 (1–34)	0.19
Peritoneal dialysis	1 (0–19)	4 (0–24)	0.04
To onset of enteral nutrition	1 (1–3)	6 (1–29)	<0.001
To onset of oral feeding	5 (0–110)	15 (3–69)	<0.001
To recovery of preoperative body weight	16 (7–34)	29 (8–103)	0.003
Weight on discharge from intensive care (g)	2,752 ± 363	2,808 ± 611	0.74
Organ dysfunction	0	12 (34.3)	0.14

Unless specified otherwise, values are the mean ± SD or the number of observations in the corresponding group, with the percentage in parenthesis

[a] On admission to pediatric intensive care unit

track care was associated with less hemodynamic or respiratory support, better nutritional status, and shorter time in ICU than standard care.

The mortality associated with corrective heart surgery, including after the repair of complex defects, has decreased markedly over the years [2, 8, 9]. The emphasis has therefore shifted towards lowering morbidity and medical costs [6, 8]. The introduction of early extubation is an important step in that direction, also in pediatric cardiac surgery [5, 9, 21]. Previous reports have suggested that neonates, particularly when they are low weight, premature, or both, are at risk of poor outcomes after the correction of congenital heart defects [3, 6]. These patients are vulnerable to surgical stress due to the immaturity of the major organs, including the heart, lungs, kidneys, or coagulation system, which exposes them to perioperative organ failures as well as to cerebral hemorrhage or enterocolitis [2, 6, 7]. However, Chang et al. [21] have recently suggested that delaying surgical interventions, while awaiting organ maturation, is not recommended since surgery after prolonged preoperative medical management is not associated with better postoperative outcomes in low-birth-weight neonates. Others have reported that an early, complete repair of complex lesions during infancy are associated with an acceptable mortality of between 10 and 22% [6, 22] and that delaying surgery is likely to result in a higher perioperative morbidity [2, 9]. This improvement in outcome from early surgical intervention may be due to improvements in surgical techniques, perfusion technology, filtration techniques, and perioperative care [7, 23].

Early extubation has advantages, including (1) lower rates of tracheal tube- or ventilator-associated complications, such as airway irritation, accidental extubation, laryngo-tracheal trauma, pulmonary hypertensive crisis, mucous plugging of tracheal tubes, barotrauma, pneumonia, atelectasis, and acute lung injury; (2) lower parental stress; (3) less need for pharmacological interventions, including sedatives and inotropes, and associated indwelling lines; (4) earlier patient mobilization; (5) earlier initiation of enteral feeding and improvement in nutritional status; (6) earlier discharge from ICU or hospital and lower costs [5, 10, 11, 15, 24]. Our results suggest that early extubation could be associated with improved outcomes even in the neonatal population. The early restoration of organ function, including cardiac anatomy and physiology after a surgical intervention, is beneficial for the postnatal maturation of neonatal organs [6, 21], particularly in low-weight babies who are at risk of severe secondary organ injury [2, 7, 9].

The doses of narcotics are an important determinant of early extubation [15, 24]. The use of high-dose opioid techniques during anesthesia and in the postoperative period was previously advocated to modulate the stress response, maintain a stable hemodynamic function, and prevent stress-mediated postoperative morbidity [14, 25]. Results from more current studies, however, have suggested improvements in outcomes after cardiac surgery with low-dose opiates anesthesia [10, 15], even in infants at high risk of complications, including pulmonary hypertension [11, 13, 26]. Opiates, particularly when administered in high doses, may cause respiratory depression, gut paralysis, and acute withdrawal phenomenon, which may delay the postoperative recovery [5]. The postoperative use of muscle relaxants can also delay recovery due to prolonged ventilator dependency.

The lower SpO_2 target, which were decreased to 92–95% in our contemporary protocol, is an another factor that facilitates early extubation. The SpO_2 goal is included in the changes that have made a great impact on the practice of neonatal respiratory intensive care in this decade. Neonatologists have been avoiding high SpO_2 goals, as significant adverse pulmonary events can occur when exposing neonates to oxygen saturations above 95% [27, 28]. Our results confirm the safety of lowering the SpO_2 target after cardiac surgery. Its decrease was associated with an early lowering of FIO_2, which contributed to a shorter time to extubation and, perhaps, to the protection of the lungs against oxygen toxicity.

Enteral nutrition is considerably facilitated by early extubation [29], combined with changes in early feeding protocol. Feeding obstacles after cardiac surgery are common in neonates, affecting growth, wound healing, and immune functions and promoting postoperative morbid complications [29, 30]. Although we did not measure the caloric intake or balance, early enteral feeding after surgical repair assists in the early recovery of nutritional status, gut integrity and motility, and immune status [30, 31], as expressed by an earlier body weight recovery observed in this study.

Study limitations

This study is limited by its retrospective design and the heterogeneity of the congenital heart diseases it included. The categorization of the population in two groups according to surgical periods complicates the interpretation of the study results because of the technical improvements taking place over time, although neither the surgeon nor the general patient management, including CPB management, changed during the study period. Second, we can not exclude the possibility that frequent preoperative interventions in group C might directly or indirectly have affected lower postoperative morbidity. However, we still found a significant difference in the number of ventilator days between the two study groups when we limited the analysis to patients who had not been ventilated preoperatively (6 days shorter in group F vs. group C). Third, we did not measure the compliance to fast-track care in a clinical situation, which might influence its success rate as well as patient outcomes. This study is descriptive in terms of the choice made by the pediatric cardiac intensivists and does not necessarily state that the newly introduced fast-track management is the only cause that leads particular outcomes. Fourth, we included only patients undergoing complete surgical repairs. Whether our results can be extrapolated to palliative operations is unknown. Finally, a prospective, multicenter study including a larger number of patients is needed to clarify the effectiveness of the type of care being performed in our institute to neonates undergoing heart surgery.

In conclusion, fast-track management of neonates with the aim of providing simple care for neonates who underwent repair of congenital biventricular heart defects was safely implemented and was associated with better postoperative recovery.

Acknowledgments This study was supported by unrestricted institutional financial support.

Conflict of interest The authors have no conflict of interest to disclose.

References

1. Kirklin JK, Blackstone EH, Kirklin JW, Mc Kay R, Pacifico AD, Bageron LM. Intracardiac surgery in infants under 3 months: incremental risk factors for hospital mortality. Am J Cardiol. 1981;48:500–6.
2. Reddy VM, McElhhinney DB, Sagrado T, Parry AJ, Teitel DF, Hanley FL. Results of 102 cases of complete repair of congenital heart defects in patients weighing 700 to 2500 grams. J Thorac Cardiovasc Surg. 1999;117:324–31.
3. Pawade A, Waterston K, Laussen P, Karl TR, Mee RBB. Cardiopulmonary bypass in neonates weighing less than 2.5 kg: analysis of risk factors for early and late mortality. J Card Surg. 1993;8:1–8.
4. Castaneda AR, Mayer JE, Jonas RA, Lock JE, Wessel DL, Hickey PR. The neonate with critical congenital heart disease: repair—a surgical challenge. J Thorac Cardiovasc Surg. 1989;98:869–75.
5. Laussen PC, Roth SJ. Fast tracking: efficiently and safely moving patients through the intensive care unit. Prog Pediatr Cardiol. 2003;18:149–58.
6. Bové T, Francois K, De Groote K, Suys B, De Wolf D, Verhaaren H, Matthys D, Moerman A, Poelaert J, Vanhaesebroeck P, Van Nooten G. Outcome analysis of major cardiac operations in low weight neonates. Ann Thorac Surg. 2004;78:181–7.
7. Roussin R, Belli E, Bruniaux J, Demontoux S, Touchot A, Planche C, Serraf A. Surgery for transposition of the great arteries in neonates weighing less than 2,000 grams: a consecutive series of 25 patients. Ann Thorac Surg. 2007;83:173–7.
8. Lange R, Schreiber C, Gunther T, Wottke M, Haas F, Meisner F, Hess J, Holper K. Results of biventricular repair of cardiac malformations: definitive corrective surgery? Eur J Cardiothorac Surg. 2001;20:1207–13.
9. Oppido G, Napoleone CP, Formigari R, Gabbieri D, Pacini D, Franscaroli G, Gargirlo G. Outcome of cardiac surgery in low birth weight and premature infants. Eur J Cardiothorac Surg. 2004;26:44–53.
10. Neirotti RA, Jones D, Hackbarth R, Fosse GP. Early extubation in congenital heart surgery. Heart lung Circ. 2002;11:157–61.
11. Heinle JS, Diaz LK, Fox LS. Early extubation after cardiac operations in neonates and young infants. J Thorac Cardiovasc Surg. 1997;114:413–8.
12. Shuller JL, Bovil JG, Mijveld A, Patrick MR, Marcelletti C. Early extubation of the trachea after open heart surgery for congenital heart disease. A review of 3 years' experience. Br J Anesth. 1984;56:1101–8.
13. Davis S, Morley S, Mee RBB, Harrison AM. Factors associated with early extubation after cardiac surgery in young children. Pediatr Crit Care Med. 2004;6:63–8.
14. Hickey P, Hansen D, Wessel D, Lang P, Jonas R, Elison E. Blunting of stress responses in the pulmonary circulation of infants by fentanyl. Anesth Analg. 1985;64:1137–42.
15. Kloth RL, Baum VC. Very early extubation in children after cardiac surgery. Crit Care Med. 2002;30:787–91.
16. Rhodes JF, Blaufox AD, Seiden HS, Asnes JD, Gross RP, Rhodes JP, Griepp RB, Rossi AF. Cardiac arrest in infants after congenital heart surgery. Circulation. 1999;100[19 Suppl]:II194–9.
17. Keene AR, Cullen DJ. Therapeutic intervention scoring system: update 1983. Crit Care Med. 1983;11:1–3.
18. Gray LE, Richardson DK, McCormick MC, Workman-Daniels K, Goldman DA. Neonatal therapeutic intervention scoring system: a therapy-based severity-of-illness index. Pediatrics. 1992;90:561–7.
19. Wilkinson JD, Pollack MM, Glass NL, Kanter RK, Katz RW, Steinhart CM. Mortality associated with multiple organ system failure and sepsis in pediatric intensive care unit. J Pediatr. 1987;111:324–8.
20. Goldstein B, Giroir B, Randilph A, International Consensus Conference on Pediatric Sepsis. International pediatric sepsis consensus conference: definitions for sepsis and organ dysfunction in pediatrics. Pediatr Crit Care Med. 2005;6:2–8.
21. Chang AC, Hanley FL, Lock JE, Castaneda AR, Wessel DL. Management and outcome of low birth weight neonates with congenital heart disease. J Pediatr. 1994;124:461–6.
22. Rossi AF, Seiden HS, Sadeghi AM, Nguyen KH, Quintana CS, Gross RP, Griepp RB. The outcome of cardiac operations in infants weighing two kilograms or less. J Thorac Cardiovasc Surg. 1998;116:28–35.
23. Beyens T, Biarent D, Bouton JM, Demanet H, Viart P, Dessy H, Deville A, Lamote J, Deuvaert FE. Cardiac surgery with extracorporeal circulation in 23 infants weighing 2500 g or less: short to intermediate outcome. Eur J Cardiothorac Surg. 1998;14:165–72.
24. Mittnacht AJC, Thanjan M, Srivastava S, Joashi U, Bodian C, Hossain S, Kin N, Hollinger I, Nguyen K. Extubation in the operating room after congenital heart surgery in children. J Thorac Cardiovasc Surg. 2008;136:88–93.
25. Anand KJS, Hickey PR. Halothane-morphine compared with high-dose sufentanil for anesthesia and postoperative analgesia in neonatal cardiac surgery. N Engl J Med. 1992;326:1–9.
26. Gruber EM, Laussen PC, Casta A, Zimmerman AA, Zurakowski D, Reid R, Odegard KC, Chakravotri S, Davis PJ, McGowan FX Jr, Hickey PR, Hansen DD. Stress response in infants undergoing cardiac surgery: a randomized study of fentanyl bolus, fentanyl infusion, and fentanyl–midazolam infusion. Anesth Analg. 2001;92:882–90.

27. Anonymous (no authors listed). Supplemental Therapeutic Oxygen for Prethreshold Retinopathy Of Prematurity (STOP-ROP), a randomized, controlled trial. I: primary outcomes. Pediatrics. 2000;105:295–310.
28. Askie LM, Henderson-Smart DJ, Irwig L, Simpson JM. Oxygen-saturation targets and outcomes in extremely preterm infants. N Engl J Med. 2003;349:959–67.
29. Kogon BE, Ramaswarmy V, Todd K, Plattner C, Kirshbom PM, Kanter KR, Simsic J. Feeding difficulty in newborns following congenital heart surgery. Congenit Heart Dis. 2007;2:332–7.
30. Schwalbe-Terilli CR, Hartman DH, Nagle ML, Gallagher PR, Ittenbach RF, Burnham NB, Gaynor JW, Ravishankar C. Enteral feeding and caloric intake in neonates after cardiac surgery. Am J Crit Care. 2009;18:52–7.
31. Owen JL, Musa N. Nutrition support after neonatal cardiac surgery. Nutr Clin Pract. 2009;24:242–9.