



Early arrhythmia burden in pediatric cardiac surgery fast-track candidates: Analysis of incidence and risk factors

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ABSTRACT

An increasing number of pediatric heart centers are utilizing early extubation protocols to “fast-track” patients after congenital heart surgery. Early postoperative arrhythmias are an important recognized complication of pediatric heart surgery, but the arrhythmia burden among candidates for extubation immediately after bypass surgery is unknown. This study evaluated the incidence and risk factors associated with postoperative arrhythmias in surgical fast-track candidates.

Postoperative rhythm status and potential perioperative risk factors were retrospectively analyzed in all patients undergoing surgery for congenital heart disease from 2012 to 2014 who were considered early extubation candidates. Overall, 199 operations in 196 individual patients (30 days–19 years) were included. The overall incidence of arrhythmias was 9% (18/199). The most common arrhythmia was junctional ectopic tachycardia (5%; 10/199), followed by atrial tachycardia (1.5%; 3/199) and complete heart block (1.5%; 3/199). Two patients with junctional ectopic tachycardia had permanent complete heart block. Compared to patients with no arrhythmias, patients with arrhythmias were more likely to be younger (0.5 vs. 2.4 years, $U = 783$, $p < 0.001$) and to weigh less (6.0 vs. 12 kg, $U = 853$, $p < 0.005$). Surgical repairs with the highest incidence of arrhythmia were tetralogy of Fallot-type (6/18, 33%; $p = 0.017$), followed by repair of atrioventricular canal (5/18, 28%, $p = 0.022$) and ventricular septal defect repair (4/18, 22%, $p = 0.758$). In an unadjusted analysis, younger patient age, STAT category 4 procedures, and increasing cross-clamp time were significantly associated with the occurrence of arrhythmias. Amiodarone and procainamide were the most common drugs used for junctional ectopic tachycardia and atrial tachycardia. There were no deaths related to postoperative arrhythmias.

Early postoperative arrhythmias are common among fast-track candidates. Patient age and operation complexity may predict risk of early arrhythmia. These data provide important information to help guide programmatic and clinical decision-making when contemplating fast tracking children after congenital heart surgery.

1. Introduction

Early postoperative arrhythmias are an important and recognized complication of pediatric congenital heart surgery [1, 2]. Arrhythmias such as junctional ectopic tachycardia (JET) affect up to 5% of patients undergoing cardiac surgery and may cause an increased hospital length of stay (HLOS), increased healthcare costs, and may even lead to early

post-operative death [1–3]. Complications due to arrhythmias are due to inadequate cardiac output either due to loss of atrio-ventricular synchrony or a rapid ventricular response. Most postoperative arrhythmias are associated with surgery around the sinus or the atrio-ventricular (AV) node or related to atriotomy or ventriculotomy incisions or perioperative ischemia [4–6]. Electrolyte abnormalities and disturbances in acid base balance in the immediate postoperative

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period have also been cited as important contributors to arrhythmias [1, 7].

Fast-track protocols including extubation in the operating room or soon thereafter are increasingly common in congenital heart centers, and offer potential benefits such as shorter HLOS [8, 9]. The feasibility of early extubation (EE) has been demonstrated for a variety of congenital heart operations across a wide range of complexity [8, 10, 11]. In many centers, EE is one component of a larger fast-track protocol or inpatient clinical pathway that defines clinical criteria for advancing a patient (e.g.: timing of line removal, feeding, drain removal) towards hospital discharge. Although the goal of fast-tracking cardiac surgical candidates is to reduce perioperative morbidity, reintubation due to arrhythmia-related hemodynamic instability is sometimes necessary and leads to a deviation from the fast-track pathway. The incidence of post-operative arrhythmias in the population of fast-track candidates is unknown. In order to better understand related risk factors in the modern era of fast-tracking in congenital heart surgery, it is important to define the incidence of arrhythmias in a contemporary pediatric population. The aims of this study were to evaluate the incidence of, and potential risk factors for, in-hospital postoperative arrhythmias following congenital heart surgery for children considered fast-track candidates in an institution with an established EE protocol.

2. Material and Methods

This study was approved as a retrospective analysis by the University of North Carolina Institutional Review Board. The study population consisted of consecutive patients > 30 days and < 19 years who underwent surgery for congenital heart disease using cardiopulmonary bypass (CPB) at North Carolina Children's Hospital (UNC) from January 1, 2012 to December 31, 2014. High risk Society of Thoracic Surgeons/European Association for Cardio thoracic Surgery (STAT) mortality category 5 patients were not considered for EE and were excluded from the cohort. Other fast-track exclusion criteria were: intubated prior to travel to operating room, returned from operating room with open chest, and/or pre- or post-operative use of extracorporeal membrane oxygenation (ECMO). All patients > 30 days undergoing operations in STAT categories 1–4 were generally considered candidates for a fast-track protocol, including extubation immediately after surgery. Single-shot caudal anesthesia was given preoperatively for all candidates for EE when anatomically practical. Standard maintenance of anesthesia for EE candidates included volatile agents with limited narcotics. At the conclusion of the case, extubation was attempted in all patients who demonstrated appropriate gas exchange and respiratory effort in the absence of major intraoperative complications or ongoing bleeding. The final decision regarding EE was made after a multi-disciplinary team discussion including surgeon, anesthesiologist, and ICU attending. Early extubation was defined as extubation in the operating room or immediately on arrival to the ICU by the anesthesia team. The fast-track candidate patients who were not extubated early were extubated using a traditional PICU model: extubation timing based on the clinical judgment of the PICU physicians when the patients have met age-appropriate respiratory parameters.

Data collection was accomplished by review of medical and pharmacy records. Demographic and perioperative variables collected included cardiac diagnoses, preoperative co-morbidities, type of surgical repair, CPB and cross-clamp times, HLOS, presence and type of arrhythmia, morbidity, and hospital mortality. Serum electrolyte concentrations (sodium, potassium, magnesium, and calcium) were routinely determined in the postoperative period at regular intervals and abnormalities were corrected to maintain cardio-protective electrolyte serum concentrations. The vasoactive inotrope score (VIS) was recorded for the first 24 h postoperatively and calculated according to the methods of Gaies et al.: $VIS = \text{Dopamine dose } (\mu\text{g/kg/min}) + \text{Dobutamine dose } (\mu\text{g/kg/min}) + 100 \times \text{epinephrine dose } (\mu\text{g/kg/min}) + 10 \times \text{Milrinone dose } (\mu\text{g/kg/min}) + 10,000 \times \text{Vasopressin}$

$\text{dose } (\text{U/kg/min}) + 100 \times \text{Norepinephrine dose } (\mu\text{g/kg/min})$ [12, 13].

All patients were monitored throughout their entire hospitalization with a three-channel standard 12-lead electrocardiographic recorder that was linked to continuous full disclosure telemetry. Cardiac arrhythmias that were identified by the primary team were confirmed by the pediatric electrophysiologist (SF). For this study, an arrhythmia was defined as an abnormal rhythm that was present for over 30 s anytime during the patient's postoperative inpatient course. Isolated or paired premature atrial contractions (PACs), premature junctional complexes (PJC)s or premature ventricular contractions (PVCs) were not included if they were infrequent (< 10 per minute).

For patients utilizing temporary pacing, underlying rhythm checks were performed every 12 h. The timing of onset, duration, type of arrhythmia, intervention and response was documented for every arrhythmia. The data collection period was from the time of the surgical procedure to discharge from the hospital. Patients were classified as having more than one arrhythmia only if an additional arrhythmia was distinctly different from the first arrhythmia.

Electrical pacing was preferred over pharmacologic therapy when possible. DC cardioversion was used for atrial flutter or ventricular tachycardia and intravenous adenosine was administered in AV nodal dependent tachycardia.

Statistical analysis was performed using SPSS for Windows, v24 (IBM Corp, New York, USA). Comparisons between continuous variables with and without arrhythmias were made with the Mann Whitney U test. Categorical data were compared with the chi-squared test and Fisher's exact test when appropriate. Due to the small number of arrhythmia events, multivariable logistic regression analysis was not conducted. Instead, an unadjusted odds ratio was calculated for parameters that were found to be significant by univariate analysis in order to quantify potential risk factors for postoperative cardiac arrhythmias for future modeling efforts.

3. Results

Overall, 196 patients who underwent 199 consecutive operations using CPB for congenital heart surgery met criteria for inclusion. There were 94 (48%) males and 102 (52%) females. The overall incidence of arrhythmias was 9% (18/199). The incidence of each specific cardiac arrhythmia after CPB surgery is presented in Table 1. The most common arrhythmia was JET. Two patients with JET had permanent complete heart block (CHB). The median duration of an arrhythmia was 22 h. Amiodarone followed by procainamide were the drugs used preferentially in our institution for JET and atrial tachycardia. There were no deaths related to postoperative arrhythmias. Table 2 presents the surgical case mix with incidences of postoperative cardiac arrhythmias corresponding to type of surgical repair. Surgical repair with highest incidence of arrhythmia (33%) was noted in TOF-type repairs.

Table 3 presents the potential risk factors for arrhythmias and perioperative details. Compared to patients with no arrhythmias, patients with arrhythmias were younger (0.5 vs. 2.4 years, $U = 783$, $p < 0.001$) and weighed less (6.0 vs. 12 kg, $U = 853$, $p < 0.001$). Arrhythmias were more frequent following operations with longer CPB times (97 vs. 124, $U = 1077$, $p < 0.05$) and longer cross-clamp times (45 vs 74, $U = 926$, $p < 0.005$). Highest VIS in first 24 h postoperatively and presence of electrolyte abnormalities were not

Table 1
Incidences of types of cardiac arrhythmias.

Type of arrhythmia	Incidence	%
Junctional ectopic tachycardia (JET)	10/199	5
Atrial tachycardia	3/199	1.5
Complete heart block (CHB)	3/199	1.5
JET + CHB	2/199	1

Table 2
Case mix (N = 199).

Case type	Arrhythmia n = 18 (%)	No arrhythmia n = 181 (%)	Total n = 199 (%)
ALCAPA	0 (0)	1 (0.6)	1 (0.5)
Anomalous origin of coronary artery from the Aorta	0 (0)	1 (0.6)	1 (0.5)
ASD	0 (0)	24 (13)	24 (12)
Primum ^a	0 (0)	0 (0)	0 (0)
Secundum	0 (0)	17 (9)	17 (9)
Sinus venosus	0 (0)	7 (4)	7 (4)
VSD (includes ASD/VSD)	4 (22)	35 (19)	39 (20)
ASD/VSD	2 (11)	9 (5)	11 (6)
ASD/VSD/RVOT reconstruction	0 (0)	1 (0.6)	1 (0.5)
ASD/VSD/pulmonary valvuloplasty	0 (0)	1 (0.6)	1 (0.5)
VSD repair	2 (11)	24 (13)	26 (13)
AV repair	0 (0)	1 (0.6)	1 (0.5)
AV replacement (AVR)	0 (0)	6 (3)	6 (3)
AVR, isolated	0 (0)	3 (2)	3 (2)
AVR + Asc. Ao replacement	0 (0)	1 (0.6)	1 (0.5)
AVR + Konno	0 (0)	1 (0.6)	1 (0.5)
AVR + RV to PA conduit	0 (0)	1 (0.6)	1 (0.5)
AVSD	5 (28)	15 (8)	20 (10)
Complete	3 (17)	8 (4)	11 (6)
Partial	2 (11)	6 (3)	8 (4)
AVSD, DORV	0 (0)	1 (0.6)	1 (0.5)
Bi-directional Glenn (BDG)	0 (0)	15 (8)	15 (8)
BDG +/- atrial septectomy	0 (0)	13 (7)	13 (7)
BDG + Fontan	0 (0)	1 (0.6)	1 (0.5)
BDG + MV repair	0 (0)	1 (0.6)	1 (0.5)
Fontan	1 (6)	7 (4)	8 (4)
HOCM (septal myectomy)	0 (0)	2 (1)	2 (1)
Intracardiac tumor/mass resection	0 (0)	2 (1)	2 (1)
LV to PA conduit	0 (0)	1 (0.6)	1 (0.5)
MV repair or replacement	2 (11)	4 (2)	6 (3)
MV repair	0 (0)	2 (1)	2 (1)
MV replacement	2 (11)	2 (1)	4 (2)
Pulmonary artery/RVOT reconstruction	0 (0)	2 (1)	2 (1)
Ross operation	0 (0)	5 (3)	5 (3)
RV to PA conduit placement or replacement	0 (0)	23 (13)	23 (12)
Scimitar repair	0 (0)	1 (0.6)	1 (0.5)
Sub AS resection	0 (0)	13 (7)	13 (7)
Sub AS	0 (0)	3 (2)	3 (2)
Sub AS + MV repair	0 (0)	1 (0.6)	1 (0.5)
Sub AS + VSD	0 (0)	7 (4)	7 (4)
Sub AS + RVOT reconstruction with TAP	0 (0)	2 (1)	2 (1)
Supravalvar AS repair	0 (0)	3 (2)	3 (2)
TOF-type repair	6 (33)	20 (11)	26 (13)
TOF	3 (17)	16 (9)	19 (10)
DORV	3 (17)	4 (2)	7 (4)

N represents 199 individual operations on 196 different patients. ^aPrimum ASD included under transitional AVSD. Abbreviations: ALCAPA, anomalous origin of the left coronary artery from the pulmonary artery; AS, aortic stenosis; ASD, atrial septal defect; AV, aortic valve; AVSD, atrioventricular septal defect; DORV, double-outlet right ventricle; HOCM, hypertrophic obstructive cardiomyopathy; LV, left ventricle; MV, mitral valve; PA, pulmonary artery; RV, right ventricle; RVOT, right ventricular outflow tract; TAP, trans-annular patch; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

statistically different among patients with and without arrhythmias. Early extubation was less prevalent among patients with arrhythmias in the early (first 48 h) postoperative period, compared to patients who did not experience arrhythmias (39% vs. 69%, p = 0.018), and patients with arrhythmias were significantly more likely to be reintubated during his or her hospitalization (22% vs. 2%, p = 0.003). In the

Table 3
Study population characteristics and perioperative details (N = 199).

Patient characteristics	Arrhythmias n = 18 (%)	No arrhythmias n = 181 (%)	p-Value
Preoperative			
Male:female	10:8 (56)	86:95 (48)	0.623
Race			
Caucasian	11 (61)	104 (58)	0.622
African American	5 (28)	50 (28)	
Hispanic	2 (11)	13 (7)	
Other	0 (0)	14 (7)	
Age (yrs)	0.5 (0.3–0.9)	2.4 (0.7–8.8)	< 0.0001
Weight (kg)	5.9 (4.6–7.9)	12.4 (6.8–29.6)	0.001
Single ventricle	1 (6)	17 (9)	1.0
Preoperative co-morbidities ^a	2 (11)	15 (8)	0.656
Chromosomal abnormalities	6 (33)	30 (17)	0.104
Operative			
STAT category			
1	4 (22)	70 (39)	0.083
2	6 (33)	59 (33)	
3	3 (17)	37 (20)	
4	5 (28)	15 (8)	
Regional anesthesia used			
Caudal	8 (44)	86 (48)	0.866
Spinal	0 (0)	2 (1%)	
CBP time (min)	123 (112–187)	97 (70–144)	0.018
Cross-clamp time (min)	74 (56–128)	45 (16–80)	0.002
Extubated early	7 (39)	124 (69)	0.018
Perioperative			
Chest tube days	6 (3–8)	2 (2–3)	< 0.0001
Highest inotrope score < 24 h post-operatively	6 (5–8)	6 (4–8)	0.787
Corrected electrolyte abnormalities	2 (11)	22 (12)	1.0
Outcomes			
Major complications ^b	6 (33)	5 (3)	< 0.0001
Need for reintubation	4 (22)	4 (2)	0.003
ICU LOS (days)	9.5 (5.5–25)	2 (1–3)	< 0.0001
Hospital LOS (days)	16 (11–51)	5 (4–8)	< 0.0001
Deaths	1 (6)	1 (0.6)	0.173

Data are presented as n (%) for discrete variables and median (IQR) for continuous variables. ^aPreoperative co-morbidities included: pre-existing gastrostomy tube, tracheostomy, or colostomy. ^bMajor complications included: bleeding requiring re-exploration, stroke, cardiac tamponade, bowel perforation, and sepsis.

Table 4
Potential risk factors for early postoperative arrhythmia^a.

Variable	Unadjusted odds ratio	95% CI	p value
Age (years)	0.799	0.651–0.980	0.031
Gender	0.724	0.273–1.92	0.516
Weight (kg)	0.941	0.884–1.001	0.055
Chromosomal abnormalities	2.517	0.876–7.231	0.087
Single ventricle lesion	0.567	0.071–4.532	0.593
Cardiopulmonary bypass time (per 10 min. increase)	1.057	0.992–1.126	0.089
Cross-clamp time (per 10 min. increase)	1.133	1.033–1.242	0.008
STAT category 1	0.453	0.143–1.432	0.178
STAT category 2	1.034	0.370–2.890	0.949
STAT category 3	0.778	0.214–2.831	0.704
STAT category 4	4.256	1.336–13.563	0.014

^a Binary logistic regression for individual variables was used to obtain unadjusted OR.

unadjusted logistic regression analysis, younger age, longer cross-clamp time and STAT category 4 operations were each associated with a

significant risk for developing post-operative arrhythmias (Table 4).

4. Discussion

Arrhythmias are a known risk factor for postoperative morbidity and mortality after pediatric cardiac surgery [1, 2]. To date, most studies have focused on a specific type of arrhythmia or evaluated the incidence of late arrhythmias after surgery [3]. There is a relative paucity of literature on early postoperative arrhythmias, particularly among the fast-track population of pediatric heart surgery patients [4]. In the current study, we report the incidence, type, probable risk factors and duration of early postoperative arrhythmias after congenital heart surgery among a population of fast-track candidates who were generally expected to do well postoperatively.

The majority of prior studies include higher-risk populations, such as neonates and patients undergoing STAT category 5 operations. In the last decade, the reported incidence of postoperative arrhythmias in congenital cardiac surgery has ranged from 14% to as high as 79% [1, 2, 14, 15]. The wide range of incidences in these reports may be related to differences in the definitions used for arrhythmias, the duration of time the patient was monitored, and the operative case-mix in each study. Rekawek and colleagues and Delaney et al. reported only on those arrhythmias that necessitated intervention, which comprised 14 and 15% of their cohorts, respectively [1, 15]. Alp et al. reported an arrhythmia incidence of 44% but included isolated frequent ectopic beats noted post-operatively [14]. Also, Grosse-Wortmann et al. included any rhythm abnormalities including those after discharge that were noted on ambulatory monitoring, resulting in their reported prevalence of 79% [2].

In the current study, like many prior reports, patients with arrhythmias were more likely to be younger and to weigh less [1, 2, 5]. Repairs around the crux of the heart like VSD, AV canal and TOF repairs are associated with a high incidence of JET, presumably due to irritation to the conduction system at the time of surgery [4]. Here, JET was the most common type of arrhythmia observed (6%). This is similar to the reported incidence of 5 to 9% noted in other recent studies [1, 15, 16]. Other studies have noted an increase incidence in supra-ventricular arrhythmias in patients with an ASD, VSD, AV canal or TOF repair [6, 15]. Grosse-Wortmann and colleagues reported a higher incidence of abnormal junctional rhythms (9%) in patients undergoing VSD repairs, and especially sub-arterial VSD repairs [2].

The incidence of permanent CHB in this study (2.5%) was comparable with other large series that report incidences of 2–4% [1, 15]. No study patient developed ventricular tachycardia (VT). This finding was in keeping with the decreasing trend in post-operative VT seen after cardiac surgery over the last 10 yrs. [1, 5] However, our findings may in part be due to the exclusion of high-risk STAT category 5 operations from this cohort. Interestingly, two patients in our cohort with JET developed CHB. This is in contrast to the study by Paech et al. that stated that patients with CHB did not have JET and though transient heart block was noted in patients with JET, none of these patients went on to have permanent heart block [17]. Several others have also noted an association between JET and transient postoperative CHB [18–20]. We have noted that permanent damage to the Hisian system during radiofrequency ablations is preceded by a very rapid accelerated junctional rhythm followed by heart block. Post-operative JET is proposed to be due to indirect or direct damage to the para-Hisian tissue with consequent abnormal automaticity. While retrograde conduction might be preserved allowing for atrial activation during JET, it seems logical that if the damage does not recover, there may be potential for complete heart block. Amiodarone and procainamide, respectively, are preferred drugs for JET and atrial tachycardia at our institution. Similar patterns of use of these two drugs have been noted by other groups [15, 21, 22].

In examining our patient population for risk factors associated with the development of the arrhythmia, we found no independent

association between prolonged CPB time, higher dose of inotropic agent, or electrolyte imbalances in the immediate post-operative period and the diagnosis of any arrhythmia. Although this analysis suggested higher odds of developing an arrhythmia with decreasing age, increasing cross-clamp time, and STAT category 4 cases, these effects could not be independently assessed due to a low total incidence number limiting our ability to conduct a meaningful multivariable logistic regression analysis. Our findings are somewhat consistent with a 2012 study by Alps and colleagues who reported no association between CPB or cross-clamp times and risks for arrhythmia [14]. The evidence is variable however, and other recent studies by Delaney and Valasangiaco and colleagues report an association between arrhythmias and longer CPB times [1, 7, 15].

Although we are encouraged by our findings, this study does have several limitations that will warrant further investigation. First, it is difficult to make comparisons to other studies of postoperative arrhythmias when our current cohort excluded the most complex patients. Inclusion criteria in the current study were selected in order to focus on the most robust population, i.e.: those patients thought most likely to succeed in remaining extubated after surgery. Also, we did not compare patients extubated early with those extubated later. In the current study, extubation in the OR was associated with a lower incidence of arrhythmia, but this finding may point to appropriate patient selection, rather than a true protective effect. Although arrhythmia was not the reason for reintubation in any of the patients in this series, medical management and additional hospital days were required for arrhythmia treatment. Also, significantly more major complications were seen among patients who had early postoperative arrhythmias, compared to those patients who did not. Finally, the low incidence of arrhythmia limited our ability to account for confounding in our risk factor analysis. However, these initial findings warrant further investigation in larger, multi-institutional studies.

5. Conclusion

Early postoperative arrhythmias following surgery for congenital heart disease are not uncommon, even among fast-track candidates. The incidence of postoperative arrhythmia in this potentially more robust population is clinically significant and has an impact on key outcome measures including length of stay and complications, which add significantly to medical costs. Younger patient age, longer cross-clamp time, and increased operation complexity may be important risk factors for early postoperative arrhythmias. As the practice of fast-tracking more complex pediatric cardiac surgical patients spreads to developing countries and resource-limited programs, it is important to understand the burden and impact of arrhythmia management on this specific patient population.

Declarations of Interest

None.

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References

- [1] Delaney JW, Moltedo JM, Dziura JD, Kopf GS, Snyder CS. Early postoperative arrhythmias after pediatric cardiac surgery. *J Thorac Cardiovasc Surg* 2006;131:1296–300.
- [2] Grosse-Wortmann L, Kreitz S, Grabitz RG, Vazquez-Jimenez JF, Messmer BJ, von Bernuth G, et al. Prevalence of and risk factors for perioperative arrhythmias in neonates and children after cardiopulmonary bypass: continuous holter monitoring before and for three days after surgery. *J Cardiothorac Surg* 2010;5:85.

- [3] Mildh L, Hiiippala A, Rautiainen P, Pettila V, Sairanen H, Happonen JM. Junctional ectopic tachycardia after surgery for congenital heart disease: incidence, risk factors and outcome. *Eur J Cardiothorac Surg* 2011;39:75–80.
- [4] Dodge-Khatami A, Miller OI, Anderson RH, Goldman AP, Gil-Jaurena JM, Elliott MJ, et al. Surgical substrates of postoperative junctional ectopic tachycardia in congenital heart defects. *J Thorac Cardiovasc Surg* 2002;123:624–30.
- [5] Hoffman TM, Bush DM, Wernovsky G, Cohen MI, Wieand TS, Gaynor JW, et al. Postoperative junctional ectopic tachycardia in children: incidence, risk factors, and treatment. *Ann Thorac Surg* 2002;74:1607–11.
- [6] Pfammatter JP, Bachmann DC, Wagner BP, Pavlovic M, Berdat P, Carrel T, et al. Early postoperative arrhythmias after open-heart procedures in children with congenital heart disease. *Pediatr Crit Care Med* 2001;2:217–22.
- [7] Valsangiacomo E, Schmid ER, Schupbach RW, Schmidlin D, Molinari L, Waldvogel K, et al. Early postoperative arrhythmias after cardiac operation in children. *Ann Thorac Surg* 2002;74:792–6.
- [8] Beamer S, Ferns S, Edwards L, Gunther G, Nelson J. Early extubation in pediatric heart surgery across a spectrum of case complexity: Impact on hospital length of stay and chest tube days. *Prog Pediatr Cardiol* 2017;45:63–8.
- [9] Mitnacht AJ, Hollinger I. Fast-tracking in pediatric cardiac surgery—the current standing. *Ann Card Anaesth* 2010;13:92–101.
- [10] Mitnacht AJ, Thanjan M, Srivastava S, Joashi U, Bodian C, Hossain S, et al. Extubation in the operating room after congenital heart surgery in children. *J Thorac Cardiovasc Surg* 2008;136:88–93.
- [11] Winch PD, Nicholson L, Isaacs J, Spanos S, Olshove V, Naguib A. Predictors of successful early extubation following congenital cardiac surgery in neonates and infants. *Heart Lung Circ* 2009;18:271–6.
- [12] Gaies MG, Gurney JG, Yen AH, Napoli ML, Gajarski RJ, Ohye RG, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med* 2010;11:234–8.
- [13] Wernovsky G, Wypij D, Jonas RA, Mayer Jr. JE, Hanley FL, Hickey PR, et al. Postoperative course and hemodynamic profile after the arterial switch operation in neonates and infants. A comparison of low-flow cardiopulmonary bypass and circulatory arrest. *Circulation* 1995;92:2226–35.
- [14] Alp H, Narin C, Baysal T, Sarigul A. Prevalence of and risk factors for early postoperative arrhythmia in children after cardiac surgery. *Pediatr Int* 2014;56:19–23.
- [15] Rekawek J, Kansy A, Miszczak-Knecht M, Manowska M, Bieganowska K, Brzezinska-Paszke M, et al. Risk factors for cardiac arrhythmias in children with congenital heart disease after surgical intervention in the early postoperative period. *J Thorac Cardiovasc Surg* 2007;133:900–4.
- [16] Batra AS, Chun DS, Johnson TR, Maldonado EM, Kashyap BA, Maiers J, et al. A prospective analysis of the incidence and risk factors associated with junctional ectopic tachycardia following surgery for congenital heart disease. *Pediatr Cardiol* 2006;27:51–5.
- [17] Paech C, Dahnert I, Kostelka M, Mende M, Gebauer R. Association of temporary complete AV block and junctional ectopic tachycardia after surgery for congenital heart disease. *Ann Pediatr Cardiol* 2015;8:14–9.
- [18] Ayyildiz P, Kasar T, Ozturk E, Ozyilmaz I, Tanidir IC, Guzelbas A, et al. Evaluation of permanent or transient complete heart block after open heart surgery for congenital heart disease. *Pacing Clin Electrophysiol* 2016;39:160–5.
- [19] Murray LE, Smith AH, Flack EC, Crum K, Owen J, Kannankeril PJ. Genotypic and phenotypic predictors of complete heart block and recovery of conduction after surgical repair of congenital heart disease. *Heart Rhythm* 2017;14:402–9.
- [20] Weindling SN, Saul JP, Gamble WJ, Mayer JE, Wessel D, Walsh EP. Duration of complete atrioventricular block after congenital heart disease surgery. *Am J Cardiol* 1998;82:525–7.
- [21] Chang PM, Silka MJ, Moromisato DY, Bar-Cohen Y. Amiodarone versus procainamide for the acute treatment of recurrent supraventricular tachycardia in pediatric patients. *Circ Arrhythm Electrophysiol* 2010;3:134–40.
- [22] Bar-Cohen Y, Silka MJ. Management of postoperative arrhythmias in pediatric patients. *Curr Treat Options Cardiovasc Med* 2012;14:443–54.