scientific reports

OPEN

Revisiting risk factors and incidence of postoperative tachyarrhythmias in pediatric cardiac surgery

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Postoperative tachyarrhythmias are a significant complication following pediatric congenital heart surgery. This study revisits the incidence and risk factors for postoperative tachyarrhythmias, focusing on congenital heart disease with a higher propensity for arrhythmias. We aim to determine if surgical and perioperative improvements have mitigated these risks. The findings may inform clinical practices and guide the development of preventive strategies. This retrospective cohort study was conducted at a tertiary university hospital, including pediatric patients under 18 years of age who underwent elective surgeries for ventricular septal defect (VSD) and/or right ventricular outflow tract (RVOT) obstruction variants between February 2018 and October 2021. Exclusion criteria included preexisting arrhythmias requiring treatment and intraoperative mortality. Data were collected from medical records. The primary outcome was the incidence and risk factors of postoperative tachyarrhythmias. Independent risk factors for these tachyarrhythmias were identified using multivariable logistic regression. Among the 385 patients included, with a median age of 24.8 months, 49 (12.7%) patients developed postoperative tachyarrhythmias, predominantly junctional ectopic tachycardia (JET; $n = 46$). The highest incidence was observed in patients with DORV with VSD (41.4%) and AVSD (26.7%). Independent risk factors included younger age, with each 6-month increase in age reducing the odds by 10% (adjusted OR 0.90, 95% CI 0.84–0.98, $p = 0.009$); prolonged CPB duration, with a 44% increase in odds per 30-minute increment (adjusted OR 1.44, 95% CI 1.20–1.73, $p < 0.001$); and the use of del Nido cardioplegia (adjusted OR 2.36, 95% CI 1.01–5.52, $p = 0.047$). Patients with postoperative tachyarrhythmias required significantly longer durations of mechanical ventilation, as well as extended intensive care unit and hospital stays. Postoperative tachyarrhythmias remain a significant concern in pediatric congenital heart surgery, especially in younger patients and those with complex heart defects. Strategies to reduce CPB duration and manage systemic hyperinflammation may lower the risk. Further research is needed to explore inflammatory processes in the development of these arrhythmias.

Keywords Pediatric cardiac surgery, Postoperative tachyarrhythmias, Congenital heart defects, Junctional ectopic tachycardia, Cardiopulmonary bypass

Abbreviations

AF	Atrial fibrillation
AFL	Atrial flutter
AT	Atrial tachycardia
AVSD	Atrioventricular septal defect
AVNRT	Atrioventricular nodal reentrant tachycardia
CHD	Congenital heart disease
CPB	Cardiopulmonary bypass
DORV	Double outlet right ventricle
ICU	Intensive care unit
JET	Junctional ectopic tachycardia
NETs	Neutrophil extracellular traps
PA	Pulmonary atresia
PS	Pulmonic stenosis
RVOT	Right ventricular outflow tract

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SD	Standard deviation
STROBE	Strengthening the reporting of observational studies in epidemiology
TOF	Tetralogy of fallot
VSD	Ventricular septal defect
VIS	Vasoactive-inotropic score
VT	Ventricular tachycardia
VF	Ventricular fibrillation

Congenital heart disease (CHD) represents the most common birth defect worldwide, with an incidence of 17.9 per 1,000 live births[1]. A substantial proportion of these patients will require surgical intervention, at some stage during their lives[2]. Postoperative tachyarrhythmias are a significant complication following congenital heart surgery in pediatric patients[3], contributing to increased morbidity, prolonged hospital stays, and elevated healthcare costs. Despite continued advancements in surgical techniques, the management of cardiopulmonary bypass (CPB), and perioperative care, the incidence of postoperative tachyarrhythmias remains a notable concern.

Postoperative tachyarrhythmias are frequently observed following surgeries for ventricular septal defect (VSD), tetralogy of Fallot (TOF), and pulmonic stenosis (PS)[3–5]. These arrhythmias, particularly junctional ectopic tachycardia (JET), can complicate recovery, leading to hemodynamic instability and extended intensive care unit (ICU) stays. Understanding the risk factors associated with these arrhythmias is crucial for developing targeted strategies to minimize their occurrence and improve patient outcomes.

This study aims to revisit the incidence and risk factors for postoperative tachyarrhythmias in pediatric patients undergoing congenital cardiac surgery with CPB. We place a particular focus on CHD that are specifically high risk for developing tachyarrhythmias. By re-evaluating the current landscape, we seek to determine whether improvements in surgical and perioperative management have effectively mitigated the risk of these arrhythmias or if significant challenges remain. Our findings may provide insights that inform future clinical practices and guide the development of more effective preventive strategies.

Methods

Study design and population

This study was conducted as a single-center, retrospective cohort analysis at a tertiary university hospital. The study protocol received approval from the Siriraj Institutional Review Board (IRB) (Si 868/2021). Given the retrospective design, the requirement for informed consent was waived by Siriraj IRB. The study population comprised patients under the age of 18 who underwent elective surgical procedures for ventricular septal defect (VSD) and/or right ventricular outflow tract (RVOT) obstruction variants between February 2018 and October 2021. Patients with preexisting arrhythmias requiring treatment or those who did not survive the operation were excluded from the analysis. The study was conducted in accordance with the Declaration of Helsinki and adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies[6].

Data collection

Data were extracted from medical records including demographic information, comorbidities, diagnoses, procedures, echocardiogram results, medications, cardiopulmonary bypass (CPB) details, laboratory values, respiratory support details, and lengths of stay in the intensive care unit (ICU) and hospital.

The vasoactive-inotropic score (VIS) was calculated using the following formula: dopamine dose (mcg/kg/min) + dobutamine dose (mcg/kg/min) + (100 x epinephrine dose (mcg/kg/min)) + (100 x norepinephrine dose (mcg/kg/min)) + (10 x milrinone dose (mcg/kg/min)) + (10,000 x vasopressin dose (U/kg/min))[7].

Definition of postoperative tachyarrhythmias

Postoperative tachyarrhythmia was defined as any sustained arrhythmia requiring treatment from the time of ICU admission until hospital discharge. Tachyarrhythmias were classified as junctional ectopic tachycardia (JET), atrioventricular nodal reentry tachycardia (AVNRT), atrial fibrillation (AF), atrial flutter (AFL), atrial tachycardia (AT), ventricular tachycardia (VT), and ventricular fibrillation (VF). Standard definitions were used for each type of tachyarrhythmia. Treatment options for tachyarrhythmias included antiarrhythmic medication, electrical cardioversion/defibrillation, overdrive pacing, and conventional treatments such as correction of electrolyte or metabolic disturbances, reduction of inotropes, surface cooling, and optimized sedation and analgesia. In cases where multiple tachyarrhythmias occurred, the arrhythmia requiring specific treatment (e.g., antiarrhythmic drug, cardioversion) was considered.

Detection and documentation of tachyarrhythmias were performed using continuous electrocardiographic monitoring connected to a central monitoring station with memory capabilities. Data on the onset, type, and treatment of arrhythmias were collected. The treatment decisions were made by the cardiac ICU management team, including cardiac surgeons and pediatric cardiologists, following standard clinical guidelines.

Statistical analysis

The reported incidence of tachyarrhythmias following pediatric congenital cardiac surgery ranged from 10 to 15%[8,9]. Based on an assumed 15% incidence, the sample size calculation indicated that a minimum of 196 patients was required to achieve a 95% confidence interval (CI) with a 5% margin of error.

Categorical variables were presented as numbers and percentages, while the normality of continuous data was assessed using the Shapiro-Wilk test. Normally distributed variables were expressed as mean and standard deviation (SD), and non-normally distributed variables were reported as median and interquartile range (IQR).

For between-group comparisons, categorical variables were analyzed using the chi-square test or Fisher's exact test. Continuous variables were assessed using the independent Student's t-test for normally distributed data, and Mann–Whitney U test or Kruskal-Wallis test with post hoc Dunn's correction for non-normally distributed data, as appropriate. A p-value of < 0.05 was considered statistically significant.

Variables from the univariable analysis with a p-value of < 0.05 were included in the multivariable analysis In the regression model, CPB time was categorized in 30-minute increments, and age was categorized in 6-month increments. To assess collinearity among variables, the Pearson pairwise correlation coefficient was used; any variables with an r-value greater than 0.7 were considered to exhibit multicollinearity and were therefore excluded from the analysis. Multivariable logistic regression, employing a backward selection process, was used to develop the final model. The model's fit was assessed using the Hosmer–Lemeshow test, where a p-value greater than 0.05 was considered to indicate a good fit. The model's predictive accuracy was evaluated using the Area Under the Receiver Operating Characteristic (AUROC) curve. Our dataset had a minor degree of missing data. These missing data were assumed to be missing completely at random (MCAR) and were addressed using multiple imputation with the Markov chain Monte Carlo technique. All statistical analyses were performed using PASW Statistics for Windows, version 18.0 (SPSS Inc., Chicago, IL, USA), and graphs were generated using GraphPad Prism version 10 (GraphPad Software, Boston, MA, USA).

Results

We included 385 patients who met the inclusion criteria, consisting of 215 males (55.8%) with a median age of 24.8 months (range: 1.0-213.7 months). The most common primary diagnosis was VSD, affecting 171 patients (44.4%), followed by TOF in 104 patients (27.0%), AVSD in 30 patients (7.8%), DORV with VSD in 29 patients (7.5%), VSD with PS in 25 patients (6.5%), and PA with VSD in 18 patients (4.7%) (Table 1).

Incidence and characteristics of postoperative tachyarrhythmias

A total of 49 patients (12.7%) developed postoperative tachyarrhythmias. The tachyarrhythmias included junctional ectopic tachycardia (JET; *n* = 46), atrioventricular nodal reentrant tachycardia (AVNRT; *n* = 1), atrial flutter (AFL; *n* = 1), and ventricular tachycardia (VT; *n* = 1). The incidence of these tachyarrhythmias

	***n* = 385**
Age (mo)	24.8 (10.5,56.4)
Male	215 (55.8)
Weight (kg)	9.7 (6.2,15.4)
Primary diagnosis	
VSD	171 (44.4)
TOF	104 (27.0)
AVSD	30 (7.8)
DORV VSD	29 (7.5)
VSD/PS	25 (6.5)
PA/VSD	18 (4.7)
DCRV VSD	3 (0.8)
dTGA VSD PS	3 (0.8)
ccTGA	2 (0.5)
Operation	
VSD closure	
Simple closure	185 (48.1)
+ infundibulectomy	27 (7.0)
+ RVOT/PV reconstruction	31 (8.1)
+ infundibulectomy and RVOT/PV reconstruction	71 (18.4)
+ PA plasty	3 (0.8)
+ subaortic resection	13 (3.4)
Rastelli's operation	21 (5.5)
AVSD repair	29 (7.5)
AVSD repair, infundibulectomy	1 (0.3)
LV-aortic baffle	4 (1.0)

Table 1. Demographic data and patient characteristics. Data are presented as n (%) or median (IQR). *AVSD* atrioventricular septal defect, *ccTGA* congenitally corrected transposition of the great arteries, *DCRV* double-chambered right ventricle, *dTGA with VSD and PS* dextro-transposition of the great arteries with ventricular septal defect and pulmonary stenosis, *DORV with VSD* double outlet right ventricle with ventricular septal defect, *PA with VSD* pulmonary atresia with ventricular septal defect, *RVOT* right ventricular outflow tract, *TOF* tetralogy of Fallot, *VSD* ventricular septal defect, *VSD with PS* ventricular septal defect with pulmonary stenosis, *PV* pulmonary valve.

varied by diagnosis, with the highest incidence observed in patients with DORV with VSD (41.4%) and AVSD (26.7%). The lowest incidence was seen in patients with VSD alone (5.3%) (Fig. 1). AVNRT, identified in a patient with TOF, was effectively treated with adenosine; while unstable AFL, also in a TOF patient, required cardioversion. Stable VT occurred in a patient following VSD repair and was managed successfully through the correction of a pulmonary hypertensive crisis. Most cases of JET were managed with conventional strategies, including therapeutic cooling, reduction of inotropic support, and optimization of sedation using fentanyl, dexmedetomidine, or midazolam. Overdrive pacing was required in two cases of JET that were refractory to these initial measures.

The median onset of tachyarrhythmias was approximately 8 h postoperatively, with a range extending from the first hour after ICU admission to the fourth postoperative day. The majority of tachyarrhythmias manifested within the initial 48 h following surgery, with a notable clustering on the first postoperative day (Fig. 2A). The median duration of the tachyarrhythmias was 11.5 h, varying a few minutes to several days postoperatively (Fig. 2B).

Factors associated with postoperative tachyarrhythmias and patient outcomes

The analysis of perioperative characteristics demonstrated significant differences between patients who developed postoperative tachyarrhythmia and those who did not (Table 2). Patients with tachyarrhythmia were notably younger (median age 18.8 vs. 25.3 months, $p = 0.009$). Preoperative beta-blocker use was higher among the tachyarrhythmia group (34.7% vs. 17.6%, $p = 0.005$). Intraoperatively, patients with tachyarrhythmia experienced significantly longer operative times (190.0 vs. 155.0 min, $p < 0.001$), CPB times (121.5 vs. 90.0 min, $p < 0.001$), and aortic cross-clamp times (84.5 vs. 65.0 min, $p < 0.001$). The tachyarrhythmia group also had a higher usage of del Nido cardioplegia (22.4% vs. 9.2%, $p = 0.006$). Additionally, VIS upon ICU admission was higher in the tachyarrhythmia group (12.0 vs. 7.0, $p < 0.001$).

To adjust for confounding factors, we performed a multivariable analysis (Table 3). Due to significant correlations between CPB time and both aortic cross-clamp time ($r = 0.947$, $p < 0.001$) and operative time ($r = 0.955$, $p < 0.001$), the latter two parameters were removed from the analysis. CPB time was retained because it directly reflects the duration of associated physiological stress and systemic hyperinflammation. Multivariable analysis identified longer CPB time and younger age as independent risk factors for arrhythmia. Each 30-minute increase in CPB time was associated with a 44% increase in the odds of tachyarrhythmias (adjusted OR 1.44, 95%CI 1.20–1.73, $p < 0.001$), while each 6-month increase in age reduced the odds by 10% (adjusted OR 0.90, 95% CI 0.84–0.98, $p = 0.009$). The use of del Nido cardioplegia was also independently associated with increased risk (adjusted OR 2.36, 95%CI 1.01–5.52, $p = 0.047$). Although VIS upon ICU admission approached significance, it did not meet the statistical threshold (adjusted OR 1.02, 95%CI 0.99–1.05, $p = 0.055$). The Hosmer and Lemeshow test indicated good model fit ($p = 0.274$), and the Receiver Operating Characteristic (ROC) curve for the multivariable analysis in the final model demonstrated good predictive ability (AUROC 0.775; $p < 0.001$; 95%CI 0.711–0.838) (Fig. 3).

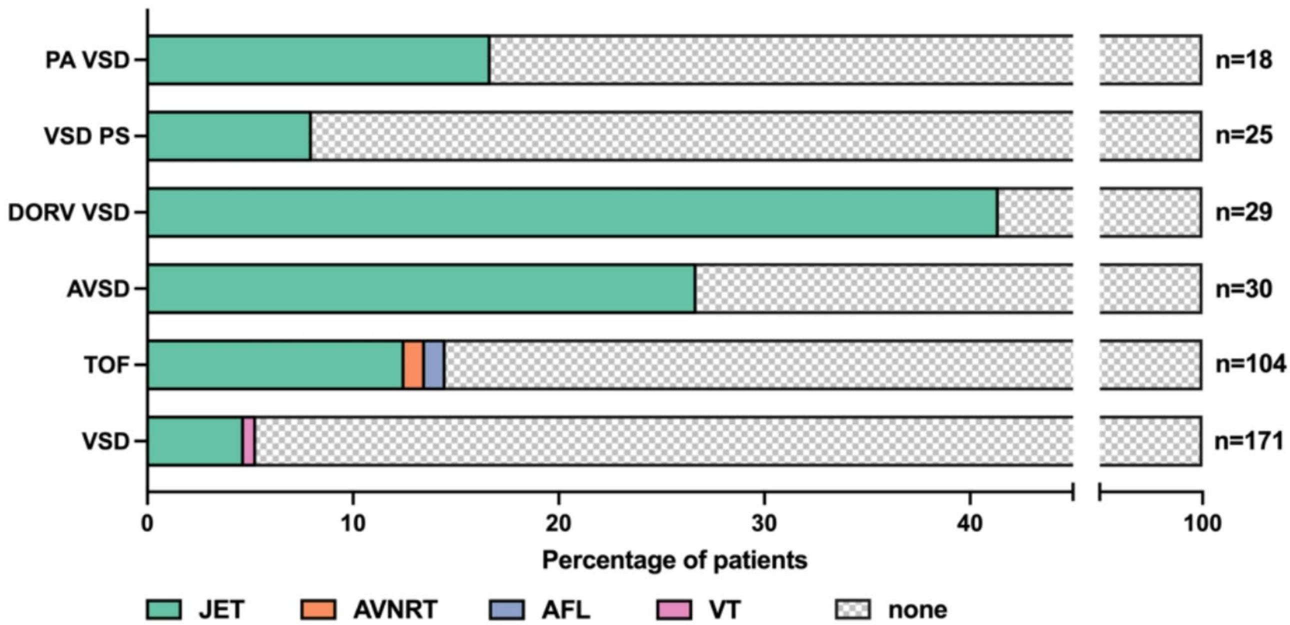

Fig. 1. Distribution of postoperative tachyarrhythmias by type and diagnosis in pediatric patients undergoing congenital heart surgery. *AVSD* atrioventricular septal defect, *AFL* atrial flutter, *AVNRT* atrioventricular nodal reentrant tachycardia, *DORV with VSD* double outlet right ventricle with ventricular septal defect, *JET* junctional ectopic tachycardia, *PA with VSD* pulmonary atresia with ventricular septal defect, *TOF* tetralogy of Fallot, *VT* ventricular tachycardia, *VSD* ventricular septal defect.

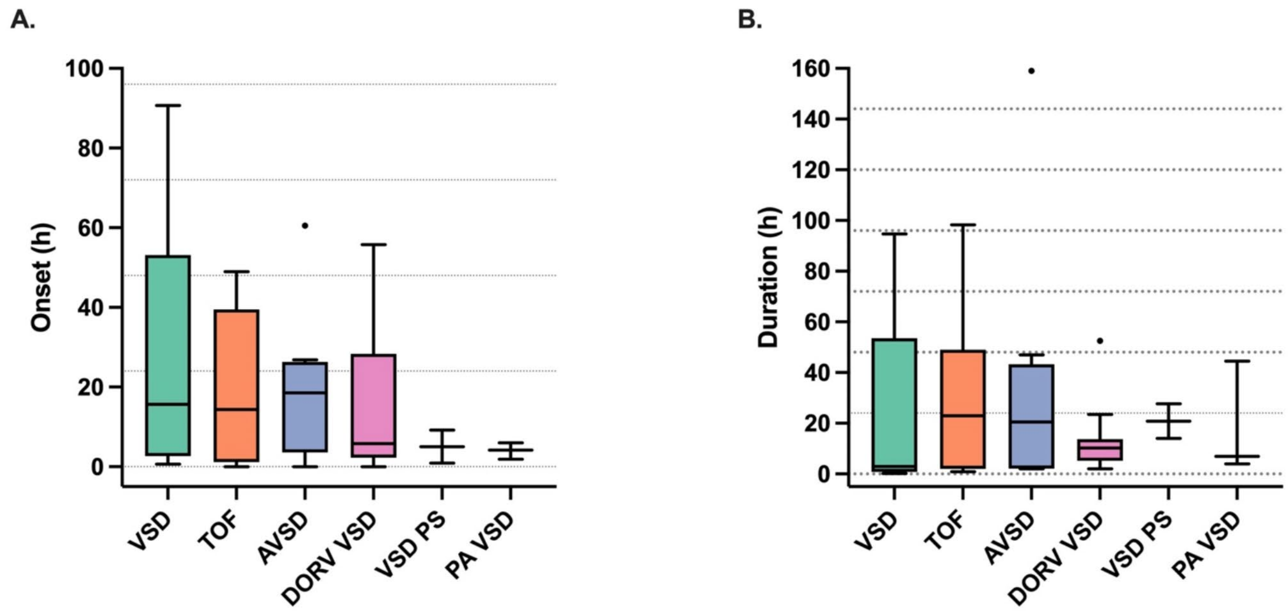

Fig. 2. Onset (**A**) and duration (**B**) of postoperative tachyarrhythmias across different congenital heart defects. *AVSD* atrioventricular septal defect, *DORV with VSD* double outlet right ventricle with ventricular septal defect, *PA with VSD* pulmonary atresia with ventricular septal defect, *TOF* tetralogy of Fallot, *VSD* ventricular septal defect, *VSD with PS* ventricular septal defect with pulmonary stenosis.

Because DORV with VSD and AVSD showed a significantly higher incidence of postoperative tachyarrhythmias compared to isolated VSD, we further investigated whether these diagnoses were associated with younger age or prolonged CPB time, both identified as independent risk factors in our multivariable analysis. As shown in Fig. 4A., CPB time was significantly longer in patients with DORV with VSD (median 120 min, $p < 0.0001$) and AVSD (median 119.5 min, $p < 0.0001$) compared to isolated VSD (median 68 min). In contrast, age was similar across these diagnoses (Fig. 4B).

In terms of postoperative outcomes (Table 4), patients who developed tachyarrhythmias had significantly higher postoperative VIS (19.0 vs. 6.0, $p < 0.001$), longer mechanical ventilation times (43.1 vs. 6.0 h, $p < 0.001$), prolonged ICU stay (96.3 vs. 43.7 h, $p < 0.001$), and extended hospital stay (7.0 vs. 6.0 days, $p < 0.001$). Although mortality was higher in the tachyarrhythmia group (6.3% vs. 0.3%, $p = 0.007$), the causes of death were not directly attributable to the tachyarrhythmias.

Discussion

This study examined the incidence and characteristics of postoperative tachyarrhythmias in pediatric patients undergoing congenital cardiac surgery with CPB. We found that 12.7% of patients developed postoperative tachyarrhythmias, with JET being the most prevalent type. The highest incidence was observed in patients with DORV with VSD, and AVSD. These tachyarrhythmias typically manifested within the first 48 h following surgery. Independent risk factors identified for the development of postoperative tachyarrhythmias included younger age, prolonged CPB duration, and the use of del Nido cardioplegia.

The incidence of postoperative tachyarrhythmias observed in our study aligns with previous literature[8,9], although it is slightly elevated. This increase is likely due to our targeted analysis of CHD that are specifically high-risk for developing tachyarrhythmias. These findings are particularly significant as they underscore the persistent nature of postoperative tachyarrhythmias, despite advancements in surgical techniques, CPB management, and anesthetic practices.

Over 90% of postoperative tachyarrhythmias in our cohort were JETs, which have been associated with surgical procedures involving VSD closure[10,11]. This correlation is likely due to the surgical trauma inflicted on the conduction system at the crux of the heart during such operations[12]. JET is the most common arrhythmia in this context because of its multifactorial pathophysiology. Several mechanisms have been proposed to explain its predominance, including mechanical trauma or stretch of the atrioventricular (AV) junction, local hemorrhage, and ischemia-reperfusion injury during prolonged CPB. Surgical trauma, particularly at the AV node and the surrounding tissue, can disrupt the ionic integrity of cell membranes, contributing to arrhythmogenesis[13]. Additionally, increased sympathetic tone after surgery may exacerbate this vulnerability[13]. Local edema or ischemia in AV node or bundle of His, relief of right ventricular outflow tract obstruction, and electrolyte imbalances may also play a role[4,14].

The higher incidence of JETs observed in patients with DORV with VSD and AVSD, compared to those with isolated VSD, reflects the greater anatomical and surgical complexity of these conditions. Repairs for DORV and AVSD often require intricate procedures, such as correcting malalignment, patching multiple septal defects, and reconstructing atrioventricular valves. These complexities typically result in prolonged CPB and aortic cross-

	Total ($n = 385$)	Tachyarrhythmia Yes ($n = 49$)	 No ($n = 336$)	p-value
Age (mo)	24.8 (10.5,56.4)	18.8 (6.4,39.9)	25.3 (11.0,60.3)	0.009*
Male	215 (55.8)	28 (57.1)	187 (55.7)	0.85
Weight (kg)	9.7 (6.2,15.4)	8.2 (5.3,12.0)	9.8 (6.4,15.0)	0.056
Preoperative				
Medication				
Beta-blocker	76 (19.7)	17 (34.7)	59 (17.6)	0.005*
Digoxin	102 (26.5)	9 (18.4)	93 (27.7)	0.17
Diuretics	162 (49.9)	24 (49.0)	168 (50.0)	0.89
ACEI/ARB	70 (18.2)	5 (10.2)	65 (19.3)	0.16
Sildenafil	4 (1.0)	1 (2.0)	3 (0.9)	0.42
Inotropes	9 (2.3)	3 (6.1)	6 (1.8)	0.09
PHT	114 (30.9)	17 (36.2)	97 (30.1)	0.40
Heart failure	24 (6.2)	6 (12.2)	18 (5.4)	0.06
Previous sternotomy	11 (2.9)	2 (4.1)	9 (2.7)	0.64
Intraoperative				
Ventriculotomy	89 (23.1)	13 (26.5)	76 (22.6)	0.54
Operative time (min)	165.0 (130.0,215.0)	190.0 (175.0,253.8)	155.0 (130.0,210.0)	< 0.001*
CPB time (min)	98.0 (67.5,133.5)	121.5 (99.3,181.0)	90.0 (65.0,128.0)	< 0.001*
Aortic cross-clamp time (min)	68.0 (44.0,91.0)	84.5 (64.3,130.3)	65.0 (42.0,89.0)	< 0.001*
DHCA use	2 (0.5)	0 (0)	2 (0.6)	1.00
Cardioplegia type				
Cold blood	343 (89.1)	38 (77.6)	305 (90.8)	0.006*
del Nido	42 (10.9)	11 (22.4)	31 (9.2)	0.006*
Lowest core temperature (°C)	31.8 (29.6,32.4)	31.0 (28.3,32.3)	31.9 (29.7,32.5)	0.044*
Anesthetic maintenance				
Isoflurane	223 (8.4)	31 (66.0)	213 (63.6)	0.75
Sevoflurane	108 (28.3)	14 (29.8)	97 (29.0)	0.91
Propofol	27 (7.0)	2 (4.2)	25 (7.4)	0.56
Combined propofol + volatile anesthetics	24 (6.3)	0 (0)	24 (7.1)	0.056
Adjunct dexmedetomidine	55 (14.3)	7 (14.3)	48 (14.3)	1.00
VIS upon ICU admission	7.5 (5.0,12.5)	12.0 (7.5,19.5)	7.0 (3.0,10.0)	< 0.001*
Postoperative				
Electrolytes				
Na	143.7 ± 3.3	143.6 ± 3.0	143.7 ± 3.3	0.79
K	3.5 ± 0.5	3.5 ± 0.6	3.5 ± 0.5	0.37
Ca	4.8 ± 0.6	4.8 ± 0.5	4.8 ± 0.6	0.79
Mg	3.6 ± 0.9	3.6 ± 0.9	3.7 ± 1.0	0.97
HCO_3	22.4 ± 2.7	22.4 ± 2.6	22.4 ± 2.7	0.88
pH	7.36 ± 0.08	7.36 ± 0.0.06	7.36 ± 0.09	0.94

Table 2. Univariable analysis of perioperative characteristics. Data are presented as n (%), mean ± SD, or median (IQR). *ACEI/ARB* angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers, *CPB* cardiopulmonary bypass, *DHCA* deep hypothermic circulatory arrest, *PHT* pulmonary hypertension, *VIS* vasoactive-inotropic score.

clamp times, which are well established risk factors for postoperative arrhythmias following congenital cardiac surgery[3,5,15–17]. Extended CPB and aortic cross-clamp times exacerbate ischemia-reperfusion injury, leading to the release of inflammatory mediators that can destabilize cardiomyocyte membrane potentials, thereby predisposing patients to JET and facilitating the formation of micro-reentry circuits within the atrium and AV node[18].

Additionally, younger age has consistently been identified as a significant risk factor for postoperative arrhythmias, including JET, as reported in the literature[3,5,16,17] and confirmed by our findings. The immature conduction tissue in pediatric patients is particularly susceptible to ischemic and inflammatory insults. The rarity of JETs in adult CHD further highlights the increased vulnerability of smaller pediatric heart to surgical trauma[19].

	Adjusted OR (95%CI)	*p*-value
CPB time (per 30-min increment)	1.44 (1.20–1.73)	< 0.001*
Age (per 6-mo increment)	0.90 (0.84–0.98)	0.009*
del Nido cardioplegia	2.36 (1.01–5.52)	0.047*
VIS upon ICU admission	1.02 (0.99–1.05)	0.055

Table 3. Multivariable analysis of perioperative characteristics. Hosmer and Lemeshow Test $p = 0.274$. *CPB* cardiopulmonary bypass, *ICU* intensive care unit, *OR* odds ratio, *VIS* vasoactive-inotropic score.

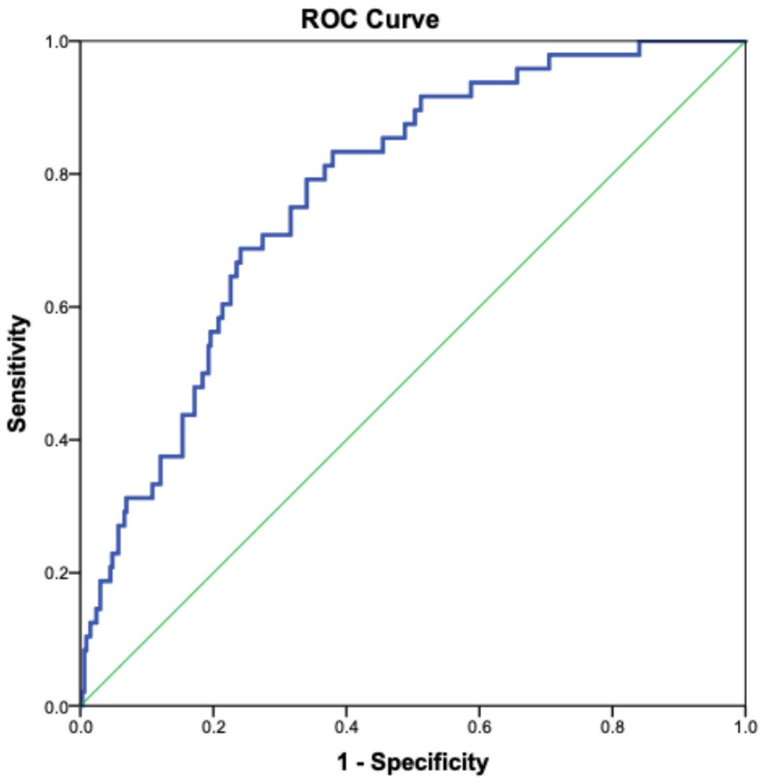

Fig. 3. Receiver operating characteristic (ROC) curve for multivariable analysis in the final model (AUROC 0.775; $p < 0.001$; 95%CI 0.711–0.838).

Del Nido cardioplegia, although widely recognized for its myocardial protective properties in pediatric cardiac surgery, was found to be associated with a nearly two-fold increase in the odds of postoperative tachyarrhythmias in our study. While del Nido cardioplegia has demonstrated efficacy in reducing ventricular arrhythmias in adult cardiac surgery[20,21], its protective effect in pediatric populations remains debatable[22,23]. The cardioplegia solution may reduce postoperative tachyarrhythmias by shortening aortic cross-clamp and CPB times[24]. It also stabilizes the myocardium through components such as lidocaine, which increases refractory period[25], and mannitol, which mitigates oxidative stress and reduces myocardial edema[26].

Although JET is self-limiting, it profoundly exacerbates healthcare resource utilization and hospital expenses due to extended mechanical ventilation duration, prolonged ICU and hospital stays. This not only burdens the healthcare system but also impacts patient well-being and intensifies emotional distress for parents. The persistent incidence of postoperative tachyarrhythmias, particularly JET, despite advances in care, indicates that risk factors such as prolonged CPB time and younger patient age continue to be significant. Thus, we speculated that the heightened systemic inflammatory response observed in younger patients[27] and those with prolonged CPB times represents a modifiable risk factor for these tachyarrhythmias. Emerging evidence linking CPB-induced neutrophil extracellular traps (NETs) with postoperative atrial fibrillation in adult cardiac surgery[28] suggests a potential avenue for further investigation into the role of inflammatory processes in postoperative tachyarrhythmias within the pediatric population.

This study has several limitations. First, this is a retrospective study conducted at a single center which may limit the external validity of the results. The surgical techniques, perioperative management, and use of del Nido cardioplegia may vary across institutions, potentially affecting the incidence and characteristics of postoperative tachyarrhythmias. While our cohort size was sufficient for meaningful analysis, the relatively small number of events (49 patients with postoperative tachyarrhythmias) posed a potential risk of overfitting

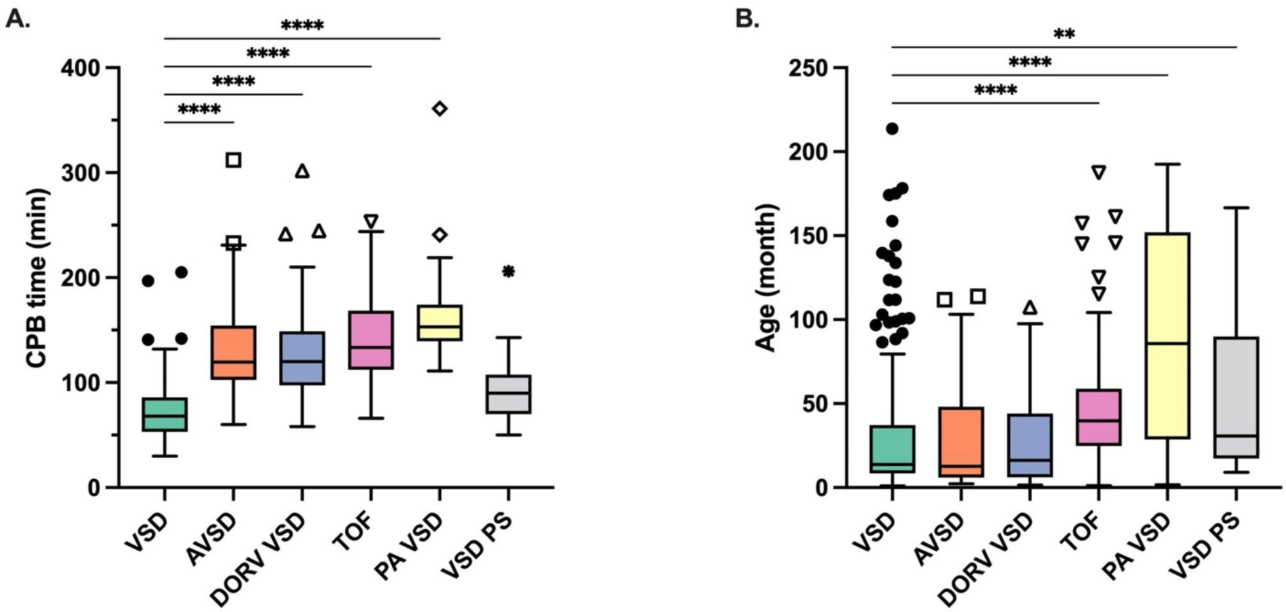

Fig. 4. Comparison of CPB time (**A**) and age (**B**) across different congenital heart defects. *AVSD* atrioventricular septal defect, *DORV with VSD* double outlet right ventricle with ventricular septal defect, *PA with VSD* pulmonary atresia with ventricular septal defect, *TOF* tetralogy of Fallot, *VSD* ventricular septal defect, *VSD with PS* ventricular septal defect with pulmonary stenosis.

		Tachyarrhythmia		
	Total (*n* = 385)	Yes (*n* = 49)	No (*n* = 336)	*p*-value
Postoperative VIS	7.5 (2.5,15.5)	19.0 (9.3,35.0)	6.0 (2.5,12.0)	< 0.001*
Mechanical ventilation time (h)	7.0 (3.9,26.8)	43.1 (7.5,113.3)	6.0 (3.7,21.9)	< 0.001*
ICU LOS (h)	45.5 (22.8,91.1)	96.3 (91.0,175.1)	43.7 (22.6,72.0)	< 0.001*
Hospital LOS (d)	6.0 (5.0,8.5)	7.0 (6.0,12.0)	6.0 (5.0,8.0)	< 0.001*
Mortality	4 (1.0)	3 (6.3)	1 (0.3)	0.007

Table 4. Postoperative outcomes. Data are presented as median (IQR). *ICU* intensive care unit, *LOS* length of stay, *VIS* vasoactive-inotropic score.

in the multivariable model. To mitigate this limitation, we selected variables based on clinical and theoretical relevance, while avoiding collinearity. Nonetheless, we acknowledge the need for validation in larger, multicenter cohorts to ensure the robustness and generalizability of our findings.

Conclusions

Our study reported a notable incidence of postoperative tachyarrhythmias in pediatric patients undergoing congenital cardiac surgery, with JET being the most common. The highest rates were observed in patients with DORV with VSD, and AVSD. Independent risk factors included younger age, prolonged CPB duration, and the use of del Nido cardioplegia. Despite advancements in surgical techniques and perioperative care, the incidence of these arrhythmias remains significant, highlighting the need for ongoing vigilance and targeted interventions. Strategies to reduce CPB times and mitigate systemic hyperinflammation, especially in younger patients, may help lower the risk. Further research is needed to explore the role of inflammatory responses in the development of postoperative tachyarrhythmias in this population.

Data availability

The dataset generated and/or analysed during the current study are not publicly available due to the hospital policy but are available from the corresponding author on reasonable request.

Received: 27 August 2024; Accepted: 24 February 2025
Published online: 01 March 2025

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Author contributions

S.L.: Methodology, Project administration, Writing – review & editing. N.S.: Data curation, Writing – original draft. W.M.: Conceptualization, Methodology, Data curation, Visualization, Formal analysis, Writing – review & editing. All authors reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This study was approved by the Institutional Review Board with an exemption of consent.

Additional information

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