Early postoperative arrhythmias after pediatric cardiac surgery

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Objective: Early postoperative arrhythmias are a known complication of cardiac surgery; however, little data exists specific to pediatrics. The purpose of this study was to determine the incidence and risk factors associated with the development of arrhythmias immediately after surgery in a pediatric population.

Methods: Data were collected in a prospective observational format from pediatric patients undergoing cardiac surgery between September 2000 and May 2003. This format included age, anatomy, surgical repair, and serum magnesium and calcium levels, as well as cardiopulmonary bypass and aortic crossclamp times. Patients were continuously monitored, and hemodynamically significant arrhythmias were recorded.

Results: Arrhythmias occurred in 28 of the 189 patients enrolled (15%) including 16 with junctional ectopic tachycardia, 7 with complete atrioventricular block, 4 with ventricular tachycardia, and 1 with re-entrant supraventricular tachycardia. Significant differences were found between the arrhythmia and nonarrhythmia groups with regard to age (22 vs 45 months), cardiopulmonary bypass time (189 vs 109 minutes), and aortic crossclamp time (105 vs 44 minutes); $P < .05$. Magnesium and calcium levels were not significantly different between the groups. Two repairs carried an increased risk: complete atrioventricular septal defect repair, 8 of 11 patients (72%), and the arterial switch 5 of 8 patients (62.5%); $P < .05$. Atrioventricular septal defects had an even higher incidence when controlled for age, bypass time, and crossclamp time (odds ratio = 7.65).

Conclusions: Hemodynamically significant postoperative arrhythmias are a frequent complication of pediatric cardiac surgery. Younger age and longer bypass and crossclamp times are risk factors for arrhythmia. In addition, the repair of atrioventricular septal defects carries an independent risk of arrhythmias.

Arrhythmias in the immediate postoperative period are a widely recognized complication of cardiothoracic surgery in both the adult and pediatric populations. Despite this, the majority of reports relate to their occurrence in adult patients.¹⁻⁵ In pediatric cardiac surgery, there is little information regarding the incidence and risk factors for early postoperative arrhythmias that is not isolated to one type or disease or surgical technique.⁶⁻⁹ The existing data, specific to acute postoperative arrhythmias, reports an incidence of arrhythmias ranging from 27% to 48%.^{6,7} This relatively high incidence may be related to the difficulty in defining an

Abbreviations and Acronyms

ACC	= aortic crossclamp time
CI	= confidence interval
AV	= atrioventricular
AVSD	= atrioventricular septal defect
CPB	= cardiopulmonary bypass
JET	= junctional ectopic tachycardia
OR	= odds ratio
PICU	= pediatric intensive care unit
SVT	= supraventricular tachycardia
VT	= ventricular tachycardia

arrhythmia. These studies have also included relatively benign variations in rate and rhythm, as well as individual premature atrial and ventricular complexes.

Normal values for pediatric heart rates are based on healthy children.¹⁰ It is difficult to apply these values to children who are recovering from the effects of surgery, such as cardiac dysfunction, electrolyte disturbances, catecholamine stimulation, irritative scar and sutures in the myocardium, residual hemodynamic impairment, as well as pain and anxiety.^{6-9,11-14} These, as well as other unknown factors, may predispose children to arrhythmia.

The purpose of this study was to determine the incidence and risk factors associated with the development of arrhythmias in a cardiac surgical population in the immediate postoperative period.

Patients and Methods

This study was an institutional review board–approved, prospective observational study of consecutive pediatric patients who underwent cardiac surgery at Yale–New Haven Children’s Hospital between September 2000 and May 2003. Data collected included the patient’s age at the time of surgery, cardiac diagnosis, surgical repair, cardiopulmonary bypass (CPB) time, aortic crossclamp (ACC) time, as well as ionized calcium and serum magnesium levels on arrival in the pediatric intensive care unit. Exclusion criteria included surgery without CPB, patient age 19 years or older at the time of surgery, and a history of chronic arrhythmias.

For this study, an arrhythmia was defined as an alteration in the heart rate or rhythm that necessitated an intervention, such as a change in medication, use of temporary pacing wires, or electrical cardioversion/defibrillation. This allowed inclusion of all types of supraventricular (SVT) and ventricular tachycardia (VT), as well as disorders of atrioventricular (AV) conduction. For the purpose of this study, junctional ectopic tachycardia (JET) was defined as a narrow complex tachycardia, with AV dissociation or retrograde atrial capture, which was at least 20% faster than the underlying sinus rate. All automatic focus and re-entrant tachycardias were included, as they uniformly required an intervention to correct or limit the hemodynamic effect of the arrhythmia. This definition excluded benign rate and rhythm disturbances that were observed, but not treated, such as alterations in the sinus rate and individual or paired extrasystoles.

The same surgical team performed all procedures during the study without significant change in their surgical technique for individual cardiac diagnoses. All types of corrective and palliative congenital cardiac surgery were performed, excluding cardiac transplantation. Postoperative care was provided in the pediatric intensive care unit (PICU), with management provided by members of pediatric cardiology, pediatric critical care, and pediatric cardiothoracic surgery staff.

All study patients were monitored continuously with a Hewlett-Packard Merlin component system (Hewlett-Packard Company, Palo Alto, Calif). This is a computer-based system linked to a central monitoring station with 24-hour Holter review capability. Identified rhythm disturbances after arrival to the PICU were reviewed and agreed on by both the cardiology and intensive care services. Transient rhythm problems in the operating room that did not recur postoperatively were not included.

The decision to treat rhythms was decided for each individual case at the discretion of the management team. JET was treated in a similar manner to that described by Hoffman and associates¹¹: avoidance of hyperthermia, optimizing sedation, pain control, and limitation of exogenous catecholamines. If the ventricular rate permitted, atrial overdrive pacing through temporary atrial wires was used to restore synchrony. If the ventricular rate was too rapid for effective overdrive pacing, amiodarone infusion was initiated, in addition to the maneuvers described above. Postoperative AV block was treated with temporary AV pacing and observation for 10 days. No patient required electrical cardioversion or defibrillation. The single patient with re-entrant SVT responded to adenosine with no recurrence in the postoperative period, and the patients with VT all received either lidocaine or amiodarone infusion at the discretion of the management team.

Statistical analysis was performed with the SAS statistical software system (© 2004 SAS Institute Inc, Cary, NC). Data were presented as frequencies or mean $\pm$ the standard deviation. The Fisher exact or independent sample *t* test was used to draw comparisons between arrhythmic and nonarrhythmic subjects. After the identification of any significant predictors in the univariate analysis, a multivariable logistic regression was used to determine independent relations of predictors with arrhythmia. Separate models were used to evaluate the independent relation of surgical types with arrhythmia. Other variables, including age, CPB time, and ACC time, were included as continuous covariables. Tests for departure from linearity were conducted to assure adequacy of the linearity assumption. Results of the logistic regression are reported as odds ratios (OR) with 95% confidence intervals (CI).

Results

During the study period, 189 pediatric patients met criteria for enrollment. Patients’ type of surgical repair are listed in [Table 1](#). Patients’ ages ranged from 0 to 216 months (mean 41 months). The CPB time ranged from 18 to 340 minutes (mean 123 minutes) and the ACC time ranged from 0 to 230 minutes (mean 57 minutes).

An arrhythmia was documented in 28 of 189 patients ([Table 2](#)), which represented an overall incidence of 15%. These included 16 (8.5%) patients with JET, 7 (3.7%) with complete AV block, 4 (2.1%) with VT, and a single patient

TABLE 1. Type of surgical repair

Total patients	189
Female	93
Male	96
Septal defect	42
Pulmonary artery conduit	23
Single ventricle palliation: Norwood, Glenn, and Fontan variants	21
TOF repair	17
Pulmonary artery plasty	12
AVSD repair	11
PAVSD repair	9
Subaortic membrane	9
Partial anomalous vein	8
ASO	8
Other	29

TOF, Tetralogy of Fallot; AVSD, atrioventricular septal defect; PAVSD, partial atrioventricular septal defect; ASO, arterial switch operation.

(0.5%) who had re-entrant SVT. Complete AV block was transient in all but a single patient. This patient had undergone a second operation for recurrent subaortic membrane resulting in complete AV block. All episodes of VT occurred within the first 24 hours after surgery, were nonsustained, and responded to medical management. An electrophysiologic study was not deemed necessary in these patients.

TABLE 2. Type of arrhythmia and surgical repair

Arrhythmia (n = 28/189)	Operation	No.
JET (n = 16, 8.5%)	AVSD repair	5
	ASO with VSD	3
	Pulmonary conduit	2
	TOF repair (1 with AVSD)	2 (1 with AVSD)
	ASD	1
	Supravalvular AS/PS	1
	External conduit Fontan	1
	VSD/IAA	1
Complete AV block (n = 7, 3.7%)	AVSD repair	2
	Subaortic membrane resection	4
	VSD	1
VT (n = 4, 2.1%)	ASO (1 with VSD)	2
	LVOT repair	1
	VSD	1
Re-entrant SVT (n = 1, 0.5%)	Pulmonary artery conduit/VSD	1

JET, Junctional ectopic tachycardia; AV, atrioventricular; VT, ventricular tachycardia; SVT, supraventricular tachycardia; AVSD, atrioventricular septal defect; ASO, arterial switch operation; VSD, ventricular septal defect; AS, aortic stenosis; PS, pulmonary stenosis; IAA, interrupted aortic arch; LVOT, left ventricular outflow tract.

Anatomic features and surgical repairs specific to the patients with arrhythmia are illustrated in Table 2. Comparisons between the arrhythmic and nonarrhythmic populations are illustrated in Table 3. A statistically significant difference between the mean values for the arrhythmic and nonarrhythmic groups was found in relation to age at operation (22 vs 45 months), CPB time (189 vs 109 minutes), and ACC time (105 vs 44 minutes) ($P < .05$). Further analysis of these groups revealed no statistical difference between gender or electrolyte values ($P =$ not significant). Of note, the mean ionized calcium levels were normal in both groups, but the mean serum magnesium levels for the arrhythmic (1.50 mg/dL) as well as the nonarrhythmic patients (1.51 mg/dL) were uniformly below the accepted normal range (1.8-2.2 mg/dL) on arrival to the PICU. However, no statistically significant relationship between these electrolyte values and arrhythmia was found. Hypocalcemia and the much more frequent hypomagnesemia were treated with infusions of calcium chloride and magnesium sulfate, respectively, at standard pediatric doses. The practice in the PICU was to give the drugs through a central venous line over a 1-hour infusion time. These values were rechecked serially with recurrent dosing until the levels persistently fell within the normal range for our laboratory.

Further analysis of the data revealed two surgical repairs with a significantly elevated incidence of arrhythmia. AV septal defect (AVSD) repairs were associated with a 72% incidence (8/11) of arrhythmia. These included 6 patients with JET and 2 with complete AV block. Those who underwent the arterial switch operation, with or without ventricular septal defect closure, had a 62.5% incidence (5/8) of arrhythmia, including 3 with JET and 2 with VT.

Multivariable logistic regression analyses identified a significant relation between AVSD and arrhythmia that was independent of the other variables (age, CPB time, and ACC time) and was found to be significant on the initial analysis (OR = 7.65; 95% CI = 1.37, 42.73). Notably, the multivariable association of age and ACC time did not reach independent statistical significance (OR = 1.00; 95% CI = 0.99, 1.01; OR = 1.01; 95% CI = 0.99, 1.02, respectively), whereas CPB time remained a significant predictor of ar-

TABLE 3. Patient characteristics

	No arrhythmia	Arrhythmia
Gender (M/F)	84/75	13/15
Age (mo)	45 ± 29.6	22 ± 39.7*
CPB time (min)	109 ± 29.6	189 ± 106*
ACC time (min)	44 ± 22.2	105 ± 73.6*
Calcium (mg/dL)	4.75 ± .26	4.92 ± .47
Magnesium (mg/dL)	1.51 ± .1	1.50 ± .37

CPB, Cardiopulmonary bypass; ACC, aortic crossclamp. *Boldface indicates $P < .05$.

rhythmia (OR = 1.01; 95% CI = 1.00, 1.02). This indicated a 1% increase in the odds of arrhythmia for each 1-minute increase in CPB time. This translates into an approximate 2-fold increase in the likelihood of arrhythmia for each 1-hour increase in CPB time. After adjustment for age, ACC time, and CPB time, the association between the arterial switch operation and arrhythmia was no longer significant (OR = 1.12; 95% CI = 0.20, 6.33).

Discussion

In this prospective study of pediatric patients, the incidence of hemodynamically significant arrhythmia was 15%. In addition, we found an increased risk of arrhythmia associated with AVSD and arterial switch procedures. These operations also included the above-listed risk factors of young age and longer operative times. However, the AVSD repair was an independent variable predictive of early postoperative arrhythmia.

Studies have been conducted on the rhythm complications related to surgical repair of congenital heart disease.^{5-8,15-20} Most have focused on rhythm disturbances as a late complication of a single diagnosis or procedure,^{5,15-17} whereas others have evaluated the risk of a single rhythm disturbance.^{8,11,12} The goal of this study was to define the overall incidence of significant arrhythmias that require intervention and isolate risk factors for acute postoperative arrhythmias in a pediatric population with congenital heart disease.

The most common arrhythmia encountered in this study was JET, with an incidence of 8.5%. The prior studies showed similar incidences, between 5% and 8%, for JET or JET combined with accelerated junctional rhythm.^{6,7,9} Incidences of surgical complete AV block, both transient and permanent, were reported at 5% and 6%, respectively, whereas this study documented a 3.7% incidence. Rates of VT were low, at less 3%, in all studies other than that of Hoffman and associates,⁹ who reported a much higher incidence of nonsustained VT (15.2%) in postoperative patients, with at 2% incidence of sustained VT. The prior studies have documented a low excess mortality related to early postoperative arrhythmias, ranging between 0% and 1.2%. No deaths related to early postoperative arrhythmia were reported in this study.

The previous studies have recorded higher incidences of arrhythmia (27% and 48%).^{6,7} The difference between these studies lies in the definition of arrhythmia. Both studies chose to include rate and rhythm disturbances without hemodynamic effect, such as setting arbitrary limits to the sinus rate, as well as documenting extrasystoles (atrial or ventricular) as infrequent as 1 per minute.

This study further illustrates that the most consistent risk factors for early postoperative arrhythmias are a younger age at the time of surgery and longer CPB and ACC times. CPB time was an independent variable that increased risk

proportionately with time. Although the arterial switch operation was associated with a higher incidence of arrhythmia, it was not independent of these other factors. In this study, AVSD repairs did carry an independent additional risk. It is not clear why the rate of arrhythmia in our patients with AVSDs was significantly higher than that reported previously for this lesion. The data represent one institution's experience using a standard single-patch repair technique, with no differences in bypass or perfusion from other infantile intracardiac repairs performed during the study. The patients appear to have no long-term sequelae, but certainly JET and temporary complete AV block were more prevalent in this study than has been previously reported for this defect.

This study also evaluated the patients for electrolyte disturbances on arrival in the PICU. Ionized calcium levels were within normal limits in both groups whereas magnesium levels were below the normal range in both groups, without relationship to arrhythmia. Hypomagnesemia is a widely documented consequence to surgery involving CPB in both adult and pediatric patients^{1-8,10-12,14,16-18} and has correlated with a higher incidence of arrhythmia in adult patients. The pediatric literature on hypomagnesemia and arrhythmia is conflicting, and our study did not support any relationship.^{6-8,11,12,14,15-18}

Conclusions

Hemodynamically significant arrhythmias are common, affecting 15% of pediatric patients after cardiovascular surgery. JET is the most common arrhythmia requiring intervention, affecting 8.5% of this population and constituting 57% of the arrhythmias. Patients have an increased risk of arrhythmia if they require surgery at a younger age and if they have long CPB and ACC times.

Two operations commonly performed in this population, complete AVSD repair and the arterial switch operation with ventricular septal defect closure, were found to have an increased incidence of arrhythmia. The association between AVSD repair and arrhythmia was found to be independent of age, CPB time, and ACC time.

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