Pediatr Cardiol 23:598–604, 2002
DOI: 10.1007/s00246-001-0079-y

Pediatric Cardiology

The Incidence of Arrhythmias in a Pediatric Cardiac Intensive Care Unit

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Abstract. A pediatric cardiac intensive care unit (CICU) manages critically ill children and adults with congenital or acquired heart disease. These patients are at increased risk for arrhythmias. The purpose of this study was to prospectively evaluate the incidence of arrhythmias in a pediatric CICU patient population. All patients admitted to the CICU at the Cardiac Center at The Children's Hospital of Philadelphia between December 1, 1997, and November 30, 1998, were evaluated prospectively from CICU admission to hospital discharge via full disclosure telemetry reviewed every 24 hours. Arrhythmias reviewed included nonsustained and sustained ventricular tachycardia (VT), nonsustained and sustained supraventricular tachycardia (SVT), atrial flutter and fibrillation, junctional ectopic tachycardia, and complete heart block. We reviewed 789 admissions consisting of 629 patients (age range, 1 day–45.5 years; median, 8.1 months). Hospital stay ranged from 1 to 155 days (total of 8116 patient days). Surgical interventions (n = 602) included 482 utilizing cardiopulmonary bypass. During the study period, there were 44 deaths [44/629 patients (7.0%)], none of which were directly attributable to a primary arrhythmia. The operative mortality was 5.1%. Overall, 29.0% of admissions had one or more arrhythmias the most common arrhythmia was nonsustained VT (18.0% of admissions), followed by nonsustained SVT (12.9% of admissions). Patients admitted to a pediatric CICU have a high incidence of arrhythmias, most likely associated with their underlying pathophysiology and to the breadth of medical and surgical interventions conducted.

Key words: Congenital heart disease — Acquired heart disease — Arrhythmia — Intensive care — Cardiac surgery

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The cardiac intensive care unit (CICU) at our institution is a 20-bed facility caring for children with congenital and acquired heart disease as well as for adults with congenital heart disease. All neonates with complex heart disease, irrespective of gestational age or birth weight, are admitted to the CICU. Neonates with minor congenital heart defects who are hospitalized for expectant observation or for other associated illnesses are typically admitted to the neonatal ICU. Patients with congenital or acquired heart disease are admitted to the CICU following cardiac surgery, certain catheterization procedures, noncardiac surgery, pre- and posttransplantation, and for the evaluation and management of cardiac disease and associated illnesses. These patients represent a high-risk population for arrhythmias due to their underlying pathophysiology.

It is widely recognized that pediatric patients commonly experience arrhythmias both early and late after cardiac surgical procedures [1–8, 11–17, 19–21, 23, 25, 28–32, 34]. Atrial arrhythmias and sinus node dysfunction are associated with atrial-level baffle procedures such as the Mustard or Senning operation for transposition of the great arteries [14, 21, 29, 30] and the Fontan operation [1, 5, 8, 11, 13, 19, 20]. Ventricular arrhythmias are common in patients fol-

Table 1. Arrhythmia definitions [27]

Arrhythmia type	Definition
Supraventricular tachycardia	
Nonsustained	3–10 beats
Sustained	>10 beats
Atrial flutter	Rapid and regular atrial rhythm with characteristic flutter waves
Atrial fibrillation	Chaotic, irregular atrial electrograms
Ventricular tachycardia	
Nonsustained	3–30 beats
Sustained	>30 beats
Junctional ectopic tachycardia	>170 bpm
	Baseline QRS complex
	AV dissociation
	Ventricular rate > atrial rate
Complete heart block	AV dissociation
	Atrial rate > ventricular rate

AV, atrioventricular; bpm, beats per minute.

lowing tetralogy of Fallot repair [6, 7, 12, 15, 16, 23, 25, 34] or the Ross procedure for left ventricular outflow tract disease [2]. Junctional ectopic tachycardia is commonly noted after ventricular septal defect (VSD) closure either in isolation or as part of a more complicated congenital heart disease as well as in patients who undergo the Fontan operation [31].

Complete heart block (CHB) may be seen after any surgery that may injure the His–Purkinje system, such as a VSD closure, or in patients undergoing a subaortic resection or a myectomy [3, 17, 32]. Similarly, many acquired cardiac disease states, such as myocarditis or cardiomyopathy, are associated with the occurrence of rhythm disturbances [9, 26, 33]. The purpose of this study was to determine the incidence of arrhythmias in a large CICU population.

Methods

Patient Population

All patients admitted to the CICU at The Children's Hospital of Philadelphia from December 1, 1997, to November 30, 1998, were consecutively entered into the study. All patients were followed daily from CICU admission through hospital discharge. Patients that were readmitted to the CICU after transfer to the step-down unit during the same hospitalization were only counted once in the analysis. This study is descriptive in nature and was approved by the institutional review board.

Data Acquisition

Telemetry/Arrhythmia Definitions(Table 1) [27]. All patients were monitored using full-disclosure telemetry (*Hewlett Packard*, *Andover*, *MA*, *USA*) during their hospitalization until discharge. This system stores the information for 24 hours and allows a beat-by-beat analysis for each patient. All alarms as well as heart rate trends were examined. The recordings were reviewed every 24 hours by one of the investigators, with the final coding of any arrhythmia being accomplished by an attending electrophysiologist.

Demographic, Medical History, and Hospitalization Data. A record review was accomplished to determine patient and procedures-related data. Demographic and medical history data collected included the patient's age, the underlying cardiac diagnosis, prior history and treatment of arrhythmias, and prior cardiac surgeries. The operative note was reviewed for those who had cardiac surgery during the study period to determine the details of the procedure and cardiopulmonary bypass (if utilized).

Pharmacologic Treatment of Arrhythmias

Pharmacologic treatment of a particular arrhythmia or, in some cases, multiple arrhythmias in a given patient was based on the physiologic status of the individual, the hemodynamic impact of the rhythm disturbance, and physician preference. These circumstances were recorded from the pharmacologic report for each patient.

Results

Patient Population

During the study period, there were 789 admissions (629 patients) to the CICU. Of these, 594 (75.3%) were for cardiac surgery, 162 (20.5%) were for nonsurgical reasons, and 33 (4.2%) were for management of primary arrhythmia. The age range of the patients was from 1 day to 45.5 years (median age, 8.1 months). The total length of stay ranged from 1 to 155 days, for a total of 8116 patient days reviewed.

Prior History of Arrhythmia

A prior history of arrhythmia was recorded in the medical record in 38/789 admissions (4.8%). Three of these patients had more than one arrhythmia. Sixteen patients had a history of supraventricular tachycardia (SVT), of which 6 were treated (3 with digoxin, 2 with

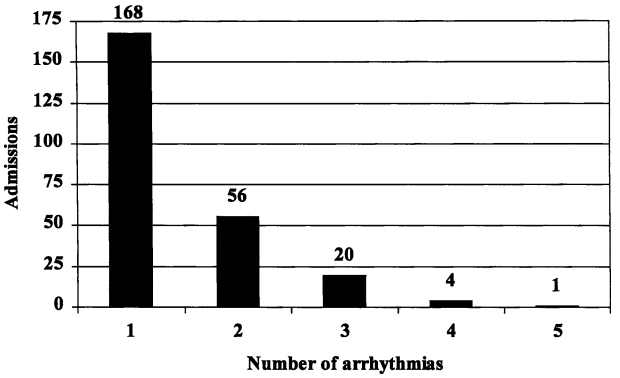

Fig. 1. Frequency of arrhythmias per admission.

amiodarone, and 1 with radiofrequency ablation), and 11 patients had a history of VT, of which 6 were treated (4 with mexiletine, 1 with phenytoin, and 1 with amiodarone). Other preadmission arrhythmias included 3 patients with atrial flutter, 3 with junctional ectopic tachycardia (JET), 3 with complete heart block (CHB), 2 with atrial fibrillation, 2 with junctional rhythm, and 1 with ectopic atrial tachycardia.

Overall Incidence of Arrhythmias

The incidence of a particular rhythm disturbance was based on a total of 789 admissions. Of these, 229 (29.0%) admissions, encompassing 203 patients, had, 1 or more arrhythmias. Many admissions experienced more than one arrhythmia type (Fig. 1). All patients that had sustained VT or SVT documented during a particular admission also had experienced nonsustained VT or SVT, respectively. Therefore, 23 admissions experienced both sustained and nonsustained VT, and 29 admissions experienced both sustained and nonsustained SVT. In other words, 16.2% of those admissions with nonsustained VT also experienced sustained VT, and 28.4% of those admissions with nonsustained SVT also experienced sustained SVT. A total of 361 arrhythmias occurred in the 229 admissions (203 patients). Table 2 indicates the incidence of various arrhythmias and the range and median age of each group. Despite the broad age range of patients for all types of arrhythmias, atrial fibrillation was commonly noted in the immediate postnatal period (median, 3 days), and JET was commonly seen in those patients younger then 2 months of age (median, 1.8 months). All arrhythmias commonly occurred in patients younger than 6 months of age with two exceptions—namely, nonsustained VT, which was commonly seen in those in early childhood (median, 1.5 years), and atrial flutter, which was seen in those in early adolescence (median, 11.2 years).

Admissions for Treatment of Primary Arrhythmia

There were 33 admissions for treatment of primary arrhythmia to the CICU during the study period. The age range of this group was 1 day to 35.5 years (median, 2.2 years). The majority of the patients (21/33) had a structurally normal heart, with 6 having VT, 5 SVT, 4 atrial flutter, 4 CHB, and 2 sinus bradycardia for age. Two patients had CHB associated with unrepaired congenital heart disease, and 10 patients were admitted with congenital heart disease after surgical palliation or repair in the past. Of these, 5 had atrial flutter (3 of whom also had atrial fibrillation) and 5 had CHB.

Admissions for Nonsurgical Reasons

There were 162 admissions for nonsurgical management of congenital or acquired heart disease and associated illnesses. The patients ranged in age from 1 day to 45.0 years (median, 1.5 years). Table 3 summarizes the incidence of arrhythmias per subset of heart disease, including those with and without prior cardiac surgery. The term cardiomyopathy refers to a poorly functioning, dilated left ventricle diagnosed by a shortening fraction of less than 25%.

Admissions for Cardiac Surgery

There were 594 admissions for 602 cardiac surgeries with CICU recovery postoperatively. Cardiopulmonary bypass was used in 482 of the operations. The age range of the patients was from 1 day to 45.5 years (median, 6.7 months). The incidence of postoperative arrhythmias for common operations, defined as 10 or more in a year, is detailed in Table 4.

Mortality

During the study period, there were 44 deaths [44/629 patients (7.0%)], none of which were directly attributable to a primary arrhythmia. However, 1 patient had ventricular fibrillation while being placed on extracorporeal membrane oxygenation and was defibrillated successfully, and 1 patient had electromechanical dissociation prior to death. The risk-unadjusted operative mortality for patients admitted to the CICU after surgery was 5.1% (31/602).

Table 2. Incidence of arrhythmia type per admission

Arrhythmia type	Number of admissions	Age range (median)	Incidence (%)	%receiving pharmacologic treatment
Nonsustained VT	142	1 day – 45.0 years (1.5 years)	18.0	31.7
Sustained VT	23	1 day – 43.6 years (2.7 months)	2.9	56.5
Nonsustained SVT	102	1 day – 45.5 years (2.6 months)	12.9	16.7
Sustained SVT	29	1 day – 45.5 years (2.3 months)	3.7	34.5
Atrial flutter	9	1 day – 35.5 years (11.2 years)	1.1	88.9
Atrial fibrillation	4	1 day – 28.1 years (3 days)	0.5	75.0
JET	33	1 day – 10.5 years (1.8 months)	4.2	27.3
CHB	19	1 day – 15.7 years (5.0 months)	2.4	N/A[a]

CHB, complete heart block, JET, junctional ectopic tachycardia; SVT, supraventricular tachycardia; VT, ventricular tachycardia.
[a]Eleven of 19 received temporary or permanent pacing, 4 with postoperative CHB had resolution of this arrhythmia at 1–16 days (median 1.5 days), and 4 had CHB without need for therapeutic intervention.

Table 3. Incidence of arrhythmias in nonsurgical admissions ($n = 162$)

	Nonsustained VT (%)	Sustained VT (%)	Nonsustained SVT (%)	Sustained SVT (%)	Atrial flutter (%)	Atrial fibrillation (%)	JET (%)	CHB (%)
Heart disease (no prior surgery)								
Structural heart disease ($n = 45$)	15.6	2.2	15.6	4.4	0.0	0.0	0.0	0.0
Cardiomyopathy ($n = 25$)	52.0	4.0	20.0	0.0	0.0	0.0	0.0	0.0
Primary PHTN ($n = 9$)	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heart disease (prior surgery)								
Biventricular repair ($n = 61$)	16.4	0.0	14.8	6.6	0.0	1.6	0.0	0.0
Single ventricle palliation ($n = 22$)	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0

CHB, Complete heart block; JET, junctional ectopic tachycardia; PHTN, pulmonary hypertension; SVT, supraventricular tachycardia; VT ventricular tachycardia.

Pharmacological Treatment of Arrhythmias

The percentage of admissions treated for a particular arrhythmia is listed in Table 2. This study was not designed to determine efficacy of antiarrhythmic therapy, although the treatment frequency may imply the perceived hemodynamic impact of arrhythmias in the CICU.

Discussion

The CICU patient population is extremely prone to develop arrhythmias not only from underlying cardiac disease but also from the various surgical interventions, therapeutic modalities, and disturbance of acid/base and electrolyte status that each patient may experience during hospitalization. Although this study was conducted in a dedicated pediatric CICU, the information provided may be pertinent to those patients cared for in multidisciplinary pediatric or neonatal ICUs that also care for cardiology and cardiothoracic surgery patients. We believe that it is important to have the ability to analyze 24 hours of alarms and heart rate trends. This technology translates into intense surveillance of rhythm and obligates the practitioner to be aware of those at high risk for arrhythmias.

Cardiac Physiology and Surgical Procedures

Ventricular arrhythmias were commonly seen during the study period, followed by atrial rhythm disturbances, JET, and CHB. Both physiologic and surgical manipulations predispose to arrhythmias. Several

Table 4. Incidence of postoperative arrhythmias in common operations

	Nonsustained VT (%)	Sustained VT (%)	Nonsustained SVT (%)	Sustained SVT (%)	Atrial flutter (%)	Atrial fibrillation (%)	JET (%)	CHB (%)
Reparative operations								
VSD ($n = 53$)	18.9	5.7	18.9	1.9	0.0	0.0	13.2	1.9
ASD ($n = 51$)	23.5	2.0	7.8	0.0	2.0	0.0	0.0	0.0
TOF ($n = 35$)	20.0	0.0	11.4	5.7	0.0	0.0	14.3	2.9
Aortic valve ($n = 30$)	33.3	6.7	20.0	10.0	0.0	0.0	0.0	0.0
AVC repair ($n = 21$)	4.8	0.0	19.0	0.0	0.0	0.0	0.0	4.8
Arterial switch ($n = 15$)	20.0	0.0	20.0	6.7	0.0	0.0	0.0	0.0
TAPVR repair ($n = 11$)	18.2	9.1	9.1	9.1	0.0	0.0	36.4	0.0
Single ventricle reconstruction								
Stage I ($n = 42$)	19.0	4.8	21.4	7.1	0.0	0.0	7.1	0.0
Blalock–Taussig shunt ($n = 11$)	9.1	0.0	27.3	0.0	0.0	0.0	9.1	0.0
BDG/hemi-Fontan ($n = 40$)	5.0	0.0	10.0	2.5	2.5[a]	0.0	2.5	2.5[a]
Fontan ($n = 45$)	11.1	0.0	13.3	2.2	0.0	0.0	6.6	0.0
Others								
Coarctation ($n = 23$)	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PDA ligation ($n = 29$)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uncommon operations								
Combined operations ($n = 196$)	22.4	6.1	11.8	4.1	0.0	0.0	4.6	2.0

ASD, atrial septal defect; AVC, atrioventricular canal; BDG, bidirectional Glenn; CHB, complete heart block, JET, junctional ectopic tachycardia; PDA, patent ductus arteriosus; SVT, supraventricular tachycardia; TAPVR, total anomalous pulmonary venous return; TOF, tetralogy of Fallot; VSD, ventricular septal defect; VT, ventricular tachycardia.

[a]This patient had a Fontan takedown, tricuspid valve replacement, and a hemi-Fontan.

[b]These operations encompass those with < 10 per year and include truncus arteriosus repair, vascular ring ligation, interrupted aortic arch repair, aortopulmonary window repair, mitral and tricuspid valve annuloplasty and replacement, pulmonary artery plasty, aortic arch reconstruction, mechanical assist device placement, right ventricular muscle bundle resection, supravalvar pulmonary valve repair, and thoracic organ transplantation.

examples of such alterations that induce rhythm disturbances exist. Patients who exhibit ventricular pressure and/or volume overload or have surgical procedures that directly involve the ventricle (eg., ventriculotomy) are theoretically at increased risk to have arrhythmias. For example, those patients that had tetralogy of Fallot repair are known to be predisposed to develop VT during their lifetime [6, 7, 12, 15, 16, 23, 25, 34]. Similarly, in the immediate postoperative period, aortic valve disease, treated mainly by the Ross procedure in our institution, may lead to ventricular arrhythmias [2]. Additionally, patients that have cardiomyopathies regardless of etiology have a multitude of arrhythmias that include ventricular dysrhythmias as well [9, 26, 33].

Atrial arrhythmias are also associated with various surgical procedures. Atrial level switch procedures [14, 21, 29, 30] are associated with sinus node dysfunctions, as is the Fontan procedure [5, 24]. However, atrial flutter and other supraventricular arrhythmias can be noted in these operations [1, 8, 11, 19].

Junctional ectopic tachycardia arises from the atrioventricular junction and may have a major impact on the postoperative recovery period due to the increased heart rate and the loss of atrioventricular synchrony. Patients that undergo tetralogy of Fallot repair, ventricular septal defect closure, atrioventricular canal repair, or the Fontan procedure are considered at increased risk for JET [31].

Complete heart block may be secondary to inadvertent damage to the atrioventricular node or the His–Purkinje system [3, 17, 32]. In those with postoperative CHB, some have eventual return of normal conduction, and in one report the conduction was normal by postoperative day 9 in most cases [32]. In those that develop postoperative CHB, temporary pacing is often utilized to optimize hemodynamics.

Inotropic Support

Inotropic support is the mainstay of treatment of patients with low cardiac output that resulted either from surgical intervention that included cardiopulmonary bypass or as a component of the underlying heart disease. These continuous infusions are used to

either bridge a patient to recovery or, in some instances, to bridge a patient to transplantation once all other medical or surgical options are exhausted. Some of these medications may be quite arrhythmogenic, especially in the vulnerable myocardium; for example, dobutamine hydrochloride, epinephrine, norepinephrine bitartrate, and phenylephrine hydrochloride are all associated with the possible development of arrhythmia [22].

Electrolyte and Acid/Base Status

Electrolyte and Acid/Base Status anomalies may predispose patients to arrhythmias [10, 18]. The patients in this study had an extreme mix of diagnoses and were subject to multiple medical and interventional modalities with obvious risk of alterations in electrolyte status. The quantification of electrolyte disturbance would be quite difficult in this study due to multiple patient days and a multitude of patients that had several types of arrhythmias. Although this study is not designed to confirm the dogma that electrolyte replacement in cardiac patients may prevent and/or control arrhythmias, we advocate and strongly encourage careful electrolyte surveillance and replacement as dictated by the clinical scenario.

Limitations

The study is limited by the fact that electrolytes and inotropic support are not detailed for each patient, both of which may have a major impact on the frequency and severity of arrhythmias seen. Therefore, a complete risk factor analysis could not be undertaken. With these limitations in mind, this study aids the practitioner in assessing the risk of arrhythmia in cardiac patients either in the general CICU population or following a particular surgical intervention. No prospective study to date has been performed in this detailed, beat-by-beat manner to determine the incidence of arrhythmias recorded in a pediatric cardiac critical care unit. This descriptive study not only provides information to the practioner but also provides a framework to build upon for future research in the field.

Conclusions

Approximately 29% of all admissions to the CICU at our institution exhibited at least one arrhythmia. These patients are at high risk for arrhythmia due to their breadth of anatomic and physiologic heart disease as well as to their multiple therapeutic and surgical interventions. Nonsustained ventricular tachycardia was the most common arrhythmia seen in our patient population during the study period across all diagnostic groups, being noted in 18.0% of all admissions. Although arrhythmias are commonly seen, the long-term sequelae are unknown. Future research is merited regarding the predictors and long-term consequences of perioperative rhythm disturbances.

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