Predictors for use of temporary epicardial pacing wires after pediatric cardiac surgery

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Objective: The objectives of this study were (1) to determine the use of temporary epicardial pacing wires to diagnose and treat early postoperative arrhythmias in pediatric cardiac surgical patients and (2) to determine the predictive factors for the need of pacing wires for diagnostic or therapeutic purposes.

Methods: We collected preoperative, intraoperative, and postoperative data in a prospective, observational format from patients undergoing pediatric cardiac surgery between August 2010 and January 2011 at a single academic children's hospital.

Results: A total of 157 patients met the inclusion criteria during the study period. Of these 157 patients, pacing wires were placed in 127 (81%). Pacing wires were used in 25 patients (19.6%) for diagnostic purposes, 26 patients (20.4%) for therapeutic purposes, 15 patients (11.8%) for both diagnostic and therapeutic purposes, and 36 patients (28.3%) for diagnostic or therapeutic purposes. Need for cardioversion in the operating room, presence of 2 or more intracardiac catheters, severely reduced ventricular ejection fraction, and elevated serum lactate level at the time of operating room discharge were found to be independent predictors for the use of pacing wires. The only complication noted in the cohort was a skin infection at a pacing wire insertion site in 1 patient. A permanent pacemaker was required in 8 (6.2%) of all patients with temporary pacing wires.

Conclusions: Our data support the use of temporary epicardial pacing wires in approximately 30% of children after congenital heart surgery. We found the need for cardioversion in the operating room, presence of 2 or more intracardiac catheters, severely reduced ventricular ejection fraction, and high serum lactate level at the time of discharge from the operating room to be independent predictors of the use of pacing wires in the early postoperative period. (*J Thorac Cardiovasc Surg* 2012;144:557-62)

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Arrhythmias are a well-known complication after cardiac surgery in children with congenital heart defects.¹⁻⁴ Temporary epicardial pacing wires are used in the perioperative period both for diagnosis of arrhythmias and for treatment of a variety of abnormalities of cardiac rhythm. Some centers have advocated for discontinuing the routine placement of temporary pacing wires.⁵ The argument for this change in practice is that temporary pacing

wires are associated with serious postoperative complications, and the incidence of postoperative arrhythmias and heart block are now low because of improvements in myocardial protection and surgical techniques. The data on the complications associated with the use and removal of pacing wires are limited, with isolated case reports describing events, including cardiac perforation, tamponade, foreign body retention, wire migration, and wire-induced arrhythmias.⁶⁻¹³ In contrast, other centers have demonstrated the routine use of temporary pacing wires without major complications.^{14,15} Attempts to define predictors for the use of pacing wires after pediatric cardiac surgery have also been made.^{14,15} Moltedo and colleagues¹⁴ demonstrated the length of cardiopulmonary bypass (CPB) and aortic cross-clamp time to be predictors of the need for pacing wires after pediatric cardiac surgery. By using hemodynamic improvement as the primary outcome, Ceresnak and colleagues¹⁵ demonstrated that the occurrence of intraoperative arrhythmias, use of circulatory arrest, and Fontan procedure were independent predictors for hemodynamic improvement with postoperative pacing.

Because of the conflicting recommendations and limited published data on this topic, we prospectively evaluated our institutional experience with the use of temporary epicardial pacing wires in pediatric cardiac surgical patients. The purpose of our study was to determine the following:

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass

TEE = transesophageal echocardiogram

(1) the use of pacing wires to diagnose or treat early postoperative arrhythmias, (2) the predictive factors for the need of temporary epicardial wires, and (3) the complications associated with the use or removal of temporary pacing wires.

MATERIALS AND METHODS

We performed a prospective, observational study with patients admitted to Stanford University's pediatric cardiovascular intensive care unit. The institutional review board of the Stanford University Medical Center approved the study, and the need for informed consent was waived. All patients aged 1 day to 18 years undergoing surgical repair or palliation of congenital heart defects from August 2010 to January 2011 at Lucile Packard Children's Hospital were included in the study. The primary outcome variable evaluated in our study was the use of temporary epicardial pacing wires for diagnostic or therapeutic purposes, or both. Patients who underwent ligation of patent ductus arteriosus, repair of coarctation of aorta via lateral thoracotomy, and implantation of a permanent pacemaker as a primary procedure were excluded. The decision to implant temporary atrial or ventricular epicardial pacing wires was made by the cardiac surgical team in the operating room, and the decision to use and remove the pacing wires was made jointly by the cardiac intensive care and surgical teams. The diagnostic uses of pacing wires included evaluation of the cardiac rhythm and the diagnosis of tachyarrhythmias and bradyarrhythmias. The use of pacing wires for diagnostic purposes was typically prompted by inadequate information on surface electrocardiogram recordings. The therapeutic uses of pacing wires included increasing the heart rate to augment blood pressure, establishing atrioventricular synchrony, performing overdrive pacing of junctional rhythms, suppressing ectopy, and terminating tachyarrhythmias. The use of pacing wires for therapeutic purposes was typically due to hemodynamic instability or signs and symptoms of low cardiac output syndrome (eg, inadequate urine output, low mixed venous oxygen saturation, elevated serum lactate, or metabolic acidosis).

Sinus bradycardia, junctional ectopic tachycardia, complete heart block, slow junctional rhythm, supraventricular and ventricular tachycardias, atrial flutter and atrial fibrillation, sinus tachycardia, frequent premature atrial, or ventricular complexes were considered critical arrhythmias. Sinus bradycardia was defined as an inadequate sinus rate for the age and hemodynamic condition of the patient or as a junctional escape rhythm in the absence of atrioventricular block or junctional ectopic tachycardia. The following minimal rates according to age were considered as bradycardia: 120 to 130 beats/min diurnal rate in neonates, less than 120 beats/min in children aged less than 1 year, 110 beats/min in children aged 3 to 4 years, 100 beats/min in children aged 5 to 7 years, less than 90 beats/min in children aged 8 to 11 years, and 85 beats/min in children aged 12 to 15 years.^{3,16,17} Sinus tachycardia was defined as heart rate more than 180 beats/min in children aged less than 2 years and more than 160 beats/min in children aged more than 2 years. Frequent premature supraventricular or ventricular beats were diagnosed if their number exceeded 10 per minute.³

We collected preoperative variables, including age, sex, weight, degree of prematurity, need for preoperative medications, need for antiarrhythmic medications, thyroid disease, preoperative cardiomegaly, cardiac diagnosis, and diagnosis of trisomy 21 and 22q11 microdeletion. Risk adjustment for surgery was performed using the Risk Adjustment for Congenital Heart

Surgery-1 method.¹⁸ Intraoperative data included the procedure performed, CPB time, aortic crossclamp time, need for pacing coming off CPB, need for cardioversion or defibrillation in the operating room, volume of blood products administered, site of incision(s) (atrial, ventricular, or both), intraoperative ST-segment changes, and use of any antiarrhythmic medications. Postoperative variables included serum lactate level; ventricular ejection fraction on immediate postoperative transesophageal echocardiogram (TEE); inotrope score¹⁹; number and location of intracardiac catheters; dexmedetomidine use at the time of onset of arrhythmia; electrolyte abnormality as measured by potassium, calcium, and magnesium levels; serum lactate level; body temperature; arterial pH and inotrope score¹⁹ at the time of onset of any arrhythmia; need and use of pacing wires for diagnostic or therapeutic purposes or both; duration of pacing wire implantation and of mechanical ventilation; and complications associated with use and removal of pacing wires, including death. The cardioplegia in our patients was standardized and induced using a solution of Plegisol (Hospira, Inc, Lake Forest, Ill) (sodium: 110 mEq/L, chloride: 160 mEq/L, potassium: 16 mEq/L, calcium: 2.4 mEq/L, magnesium: 32 mEq/L), with additional additives of potassium chloride (5 mEq/L) and sodium bicarbonate (10 mEq/L). Qualitatively reduced ejection fraction on postoperative TEE as judged by an independent, experienced echocardiographer constituted reduced ejection fraction for the purposes of study. Cardiomegaly was defined as a transverse diameter of the cardiac silhouette greater than or equal to 50% of the transverse diameter of the chest (increased cardiothoracic ratio) and was judged by an independent, experienced radiologist. The complications assessed included transmyocardial migration of a wire, cardiac perforation, pericardial effusion, cardiac tamponade, arrhythmias associated with removal of pacing wires, and retention of pacing wires after attempted removal. Patient charts, telemetry recordings, and electrocardiograms were reviewed for all patients included. In addition, we reviewed chest radiographs to assess the position of temporary pacing wires, as well as all echocardiograms performed after the removal of pacing wires to assess for pericardial effusion.

Statistical Analysis

Continuous variables are presented as median (10th percentile, 90th percentile), and categorical variables are presented as counts and percentages. We performed univariable analyses to examine the associations between the patient characteristics and risk factors and the primary outcome variable. The *P* value was calculated using Pearson's chi-square test or Fisher exact test of independence for categorical variables and Wilcoxon rank-sum test for continuous variables. We also completed a redundancy analysis of the candidate predictors for multivariate logistic regression models along with variable clustering using Hoeffding's D statistic. A multivariable logistic regression analysis was performed to identify possible predictors associated with the need for pacing wires. Variables with a *P* value of .2 or less in the univariate analysis were entered in the multiple regression model. Any variable with 20% or more missing values or that occurred uncommonly (≤ 5 subjects) was not considered for inclusion in the multivariate analyses. The model was expressed in terms of adjusted odds ratio, 95% confidence interval, and *P* value. Backward variable selection was used to help select variables. We performed several additional analyses to explore the findings of the multivariate model and investigate variables not selected. The model's goodness-of-fit was evaluated using the Hosmer-Lemeshow test, and the ability of the model to discriminate between outcomes was assessed using the c-statistic (which is equal to the area under the receiver operating curve). All analyses were performed using STATA/MP, Version 11.1 biostatistical software (StataCorp LP, College Station, Tex).

RESULTS

A total of 157 patients met the inclusion criteria during the study period. Of these 157 patients, pacing wires were

TABLE 1. Incidence of types of cardiac arrhythmias corresponding to use of temporary epicardial pacing wires

Type of arrhythmia	Incidence of arrhythmia	Use of pacing wires			
		Diagnostic	Therapeutic	Both	Either
Junctional ectopic tachycardia	9	5	9	5	9
Complete heart block	7	4	7	4	7
Slow junctional rhythm	5	5	5	5	5
Supraventricular tachycardia	3	2	1	—	3
Atrial flutter/atrial fibrillation	4	2	2	1	3
Sinus bradycardia	2	—	2	—	2
Sinus tachycardia	4	4	—	—	4
Premature atrial complexes	4	3	—	—	3
Premature ventricular complexes	2	—	—	—	—
Ventricular tachycardia/ventricular fibrillation	2	—	—	—	—
Total	42	25	26	15	36

placed in 127 (81%). Among those with the pacing wires, 82 (64.5%) had only atrial pacing wires, 21 (16.5%) had only ventricular pacing wires, and 24 (18.8%) had both atrial and ventricular pacing wires. The incidence of arrhythmias was 33% (42 patients). Pacing wires were used in 25 patients (19.6%) for diagnostic purposes, 26 patients (20.4%) for therapeutic purposes, 15 patients (11.8%) for both diagnostic and therapeutic purposes, and 36 patients (28.3%) for diagnostic or therapeutic purposes (Table 1). Patients' types of surgical repair are listed in Table 2. Patients not receiving temporary pacing wires did well during their postoperative course and did not need any further acute electrophysiologic intervention during their hospital stay. Patients receiving pacing for therapeutic reasons had improvement in hemodynamics after initiation of pacing. Two patients had evidence of slow junctional rhythm during the use of dexmedetomidine. Sequential atrioventricular pacing was used to increase the heart rate to promote hemodynamic stability. The mean $\pm$ standard deviation inotrope score, arterial pH, and body temperature at the time of initiation of pacing in subjects who needed pacing for

therapeutic reasons were 12.4 ± 4.3 , 7.4 ± 0.1 , and $36.3^\circ\text{C} \pm 1.0^\circ\text{C}$, respectively. The mean $\pm$ standard deviation magnesium, potassium, ionized calcium, and serum lactate levels in the same patients at the time of initiation of pacing were 2.5 ± 0.7 mEq/L, 3.6 ± 0.7 mEq/L, 1.3 ± 0.3 mmol/L, and 3.1 ± 0.9 mmol/L, respectively. None of the patients needing pacing had abnormal electrolytes at the time of initiation of pacing, whereas 8 patients had lactate acidosis (≥ 4 mmol/L) at the time of initiation of pacing. The lactic acidosis improved to normal limits in 3 patients within the first 4 hours, 2 patients within the first 8 hours, and 3 patients within the first 12 hours of initiation of pacing.

We divided our cohort into 2 groups: one group in whom pacing wires were used for diagnostic or therapeutic purposes and one group in whom pacing wires were never used. Baseline demographics were similar in both groups (Table 3). On univariate analysis comparing the 2 groups, the variables associated with the use of pacing wires ($P \leq .05$) included preoperative cardiomegaly, need for cardioversion in the operating room, pacing required to come off CPB, presence of 2 or more intracardiac catheters, severely reduced ventricular ejection fraction on the postoperative TEE, elevated serum lactate level, higher inotrope score, and use of antiarrhythmics leaving the operating room (Table 2). Other variables with a P value of .2 or less included in the subsequent multivariate analysis were body weight, mean CPB time, volume of blood products administered in the operating room, and presence of single ventricle physiology. In the multivariate analysis, the need for cardioversion in the operating room, presence of 2 or more intracardiac catheters, severely reduced ventricular ejection fraction on TEE, and elevated serum lactate level at the time of operating room discharge were found to be independent predictors for the use of pacing wires (Table 4). The model had adequate goodness of fit with a nonsignificant Hosmer–Lemeshow $P = .45$. The c-statistic or area under the receiver operating curve was 0.86, indicating that the model had good discrimination. The redundancy analysis of the candidate predictors for multivariate logistic regression

TABLE 2. Type of surgical repair

Total patients eligible for inclusion in the study	157
Patients with no epicardial pacing wires	
Patent ductus arteriosus repair	15
Coarctation of aorta repair	12
Implantation of permanent pacemaker	3
Patients with implantation of epicardial pacing wires	
Single ventricle palliation: Norwood, Glenn, Fontan, central shunt	26
Septal defect (ASD/VSD)	26
TOF repair	22
Atrioventricular septal defect: complete and partial	14
Anomalous pulmonary venous connection: total and partial	8
Arterial switch operation	4
Others*	27

ASD, Atrial septal defect; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

*Others include orthotopic heart transplantation, subaortic membrane resection, mitral valve replacement, Ross procedure, Rastelli procedure, vascular ring repair, septal myectomy, and pulmonary artery plasty.

TABLE 3. Univariable analyses of potential risk factors for the need of diagnostic or therapeutic use of temporary pacing wires

Variable	Need for pacing wires (n = 36)	No need for pacing wires (n = 91)	P value
Age (mo)	7.5 (0.2–117.0)	14.0 (0.2–143.0)	.22
Male sex	44% (16)	52% (47)	.46
Premature (<36 wk)	11% (4)	9% (8)	.74*
Weight (kg)	6.6 (2.8–28.4)	8.4 (3.1–32.4)	.14
Preoperative antiarrhythmics	6% (2)	5% (5)	1.00*
Thyroid disease	0% (0)	2% (2)	1.00*
Preoperative cardiomegaly	89% (32)	71% (63)	.03
Trisomy 21	8% (3)	5% (5)	.69*
DiGeorge syndrome	3% (1)	3% (3)	1.00*
RACHS-I classification (category 4–6)	28% (10)	21% (19)	.4
Single ventricle anatomy	31% (11)	16% (15)	.07
Inotrope score at onset of arrhythmia†	11.8 (7.0–17.5)	10.5 (3.0–17.5)	.05
Mean CPB time (min)	118.5 (0.0–303.0)	98.0 (0.0–215.0)	.18
Aortic crossclamp time (min)	60.0 (0.0–117.0)	42.5 (0.0–113.5)	.28
Pacing required to come off CPB	33% (12)	4% (4)	<.001*
Cardioversion required in OR	33% (12)	7% (6)	<.001
Antiarrhythmics leaving the OR	39% (14)	2% (2)	<.001*
Amount of blood products in OR (mL/kg)	38.5 (15.0–107.0)	26.7 (5.6–97.0)	.08
≥2 intracardiac catheters	33% (12)	9% (8)	<.001
Perioperative ST-segment changes	0% (0)	4% (4)	.58
Postoperative lactate levels	3.4 (2.2–7.0)	2.3 (1.4–4.5)	<.001
Post-bypass TEE reduced ejection fraction	45% (14)	8% (7)	<.001
Ventricular incision	22% (8)	22% (20)	.98
Atrial incision	72% (26)	67% (61)	.57
Atrial and ventricular incisions	19% (7)	11% (10)	.21
Dexmedetomidine use at the time of onset of pacing	6% (2)	0% (0)	.084*
No. of days with pacing wires	10.5 (5.0–49.0)	6.0 (3.0–15.5)	<.001
Days of mechanical ventilation	3.0 (1.0–27.0)	1.0 (1.0–6.0)	<.001
Death	6% (2)	0% (0)	.084*

OR, Operating room; CPB, cardiopulmonary bypass; RACHS-I, Risk Adjustment for Congenital Heart Surgery-1; TEE, transesophageal echocardiogram. *Fisher exact test P value reported. Continuous variables are summarized by the median (10th, 90th percentiles). Categorical variables are summarized as percent (n). †Inotrope score¹⁹: dosages of dopamine + dobutamine (in $\mu\text{g/kg/min}$) + (dosages of epinephrine + norepinephrine + isoproterenol [in $\mu\text{g/kg/min}$] $\times 100$ + dosages of milrinone (in $\mu\text{g/kg/min}$) $\times 15$.

models found no redundant variables. Patients in the group with use of pacing wires remained tracheally intubated and had their pacing wires in place for a longer period of time. There was no difference in the incidence of death in the 2 groups associated with the use or removal of pacing wires. One patient had a skin infection associated with a pacing wire. We observed no other complications associated with use or removal of pacing wires. A permanent pacemaker was required in 8 patients (6%) with temporary pacing wires.

Of all the patients who were admitted to the cardiac intensive care unit with pacing wires, 107 had 0 or 1 intracardiac

catheter, and 20 had 2 or more intracardiac catheters. In the cohort of 107 children with 0 or 1 intracardiac catheter, pacing wires were used for diagnostic purposes in 14 patients (13%), therapeutic purposes in 19 patients (18%), and diagnostic or therapeutic purposes or both in 24 patients (22%). In the cohort of 20 children with 2 or more intracardiac catheters, pacing wires were used for diagnostic purposes in 11 patients (55%), therapeutic purposes in 7 patients (35%), and diagnostic or therapeutic purposes or both in 12 patients (60%) (Figure 1). Atrial arrhythmias were noted in 8 of 20 patients (40%) with 2 or more intracardiac catheters and in 3 of 107 patients (3%) with 0 or 1 intracardiac catheter. Junctional ectopic tachycardia, the other common arrhythmia, was noted in 5 of 20 patients (25%) with 2 or more intracardiac catheters and in 4 of 107 patients (4%) with 0 or 1 intracardiac catheter.

DISCUSSION

Temporary epicardial pacing wires have traditionally been placed in children as a routine practice after most or all intracardiac surgical procedures for congenital heart

TABLE 4. Multivariate model predicting the need for pacing wires

Variable	Adjusted OR	95% CI	P value
Postoperative reduced ejection fraction	4.9	1.2 20.1	.03
Postoperative lactate	1.6	1.1 2.3	.008
Intracardiac lines ≥ 2	4.5	1.1 19.1	.04
Mean CPB time (min)	1.0	1.0 1.0	.08
Cardioversion required in OR	8.2	2.0 33.8	.004

CI, Confidence interval; OR, odds ratio.

FIGURE 1. Comparison of the use of pacing wires as a function of the number of intracardiac catheters.

defects. However, there are limited and conflicting data on the utility, safety, and predictors of the need for pacing wires after cardiac surgery in children. The reported incidence of postoperative arrhythmias ranges from 14% to 29% in pediatric patients with cardiac disease.^{1-4,14,15} Most published studies report higher complexity of surgery, longer CPB time, longer aortic crossclamp time, lower body weight, and repair of atrioventricular septal defects to be associated with arrhythmias in children after intracardiac surgery.^{1-4,14,15} Despite this incidence of arrhythmias, Fishberger and colleagues⁵ advocated against the routine placement of temporary pacing wires after pediatric cardiac surgery. In their cohort of 1193 surgical procedures, temporary pacing wires were implanted in 14 children (1.2%) and used in only 4 patients (0.3%). In contrast, Moltedo and colleagues¹⁴ reported the use of temporary pacing wires in 35% of their patients for diagnostic or therapeutic reasons.¹⁴ By using hemodynamic improvement as the primary outcome, Ceresnak and colleagues¹⁵ found pacing wires to be useful in 20% of a cohort of 117 patients, and a total of 35 patients (30%) were paced.

Although the incidence of arrhythmias was 33% in our cohort, 20% of our patient population received temporary pacing. Pacing wires were used in 28% of our patients for diagnostic or therapeutic purposes. Greater disease complexity as defined by higher Risk Adjustment for Congenital Heart Surgery-1 category (groups 4–6), younger age, smaller size, need for greater blood product transfusion in the operating room, and single ventricle anatomy were not found to be independent predictors for the need of pacing wires. Although we suspected that electrolyte abnormalities would be present at the time of the onset of arrhythmias,^{1,20,21} we found normal levels of potassium, ionized calcium, and magnesium at the time of initiation of pacing. Lactic acidosis improved with initiation of pacing in our cohort, reiterating the fact that the use of pacing wires is associated with hemodynamic improvement.¹⁵ The presence of 2 or more intracardiac catheters was independently associated with the use of pacing wires. Although intracardiac catheters

are relatively safe,^{22,23} they may be associated with mechanical irritation and increased ectopy, which may have contributed to arrhythmias in this patient population.

Study Limitations

Our study has several limitations. First, this is a single-center study and the results may not be generalizable to all centers, because surgical and postoperative medical management vary from one institution to another. Second, the decision to use pacing wires for diagnostic or therapeutic purposes was made by the treating physicians, and this may have introduced some ascertainment bias in the study. Third, the patients whose pacing wires were used had higher serum lactate levels and evidence of worse ventricular function after surgery, suggesting they were sicker than the patients who did not have their pacing wires used. Fourth, because of insufficient end points, we could not evaluate the use of atrial and ventricular pacing wires separately. Despite these limitations, our study helps to lay the foundation for future prospective, randomized multicenter trials of temporary pacing wire use.

CONCLUSIONS

Our data support the use of temporary epicardial pacing wires in approximately 30% of children after congenital heart surgery. We found the need for cardioversion in the operating room, presence of 2 or more intracardiac catheters, severely reduced ventricular ejection fraction, and high serum lactate level at the time of discharge from the operating room to be independent predictors of the use of pacing wires in the early postoperative period.

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