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Research Article

Study of Postoperative Pacing in Children and Risk Factors for Permanent Pacemaker Implantation. A Single Center Experience

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Abstract

Aim: Our aim was to identify predictors for Permanent Pacemaker (PPM) implantation.

Methods: We performed a retrospective analysis of patients under 18 years of age who received postoperative pacing through a temporary external pacemaker, between 2002 and 2020. Patients were divided in two groups: 1) permanent, when a PPM was implanted before discharge or 2) temporary if PPM was not implanted. Demographic characteristics, anatomic diagnosis and perioperative variables of the two groups were compared.

Results: Overall, 2.985 patients were operated and 286 (9.6%) received postoperative pacing. Temporary pacing was performed in 245 (8.2%) patients and 41 (1.4%) patients received a PPM. Independence from the temporary external pacemaker was achieved in 91% of patients of the temporary group on day 10. Patients in the permanent group needed pacing from the first hour of admission to PICU much more often than patients in the temporary group (92.7% vs 60.4%, $p < 0.001$). On univariable analysis, increased age ($p = 0.02$) and number of previous surgeries ($p = 0.02$) and segmental anatomy {S,L,L} ($p = 0.04$) were significantly higher in the permanent group. Multivariable logistic regression analysis identified that increased number of previous cardiac surgeries (OR = 1.99, 95% CI = 1. 1.21 - 3.29, $p = 0.007$) was an independent risk factor for PPM implantation.

Conclusion: Patients with need for pacing from the first hour of admission to PICU, persistent need beyond the 10th postoperative day, atrioventricular discordance and especially those who had multiple previous surgeries are more likely to require permanent pacing.

Keywords: *Postoperative Pacing; Permanent Pacemaker Implantation; Children; Heart Surgery; Congenital Heart Disease*

Abbreviations

PPM: Permanent Pacemaker; AVB: Atrioventricular Block; ICU: Intensive Care Unit; RACHS: Risk Adjustment for Congenital Heart Surgery; VSD: Ventricular Septal Defect; TOF: Tetralogy of Fallot; CBP Cardiopulmonary Bypass; LVOT: Left Ventricular Outflow Tract; HOCM: Hypertrophic Obstructive Myocardiopathy

Introduction

Postoperative bradyarrhythmias are caused by a combination of myocardial ischemia, edema and surgical trauma. In certain congenital heart defects, there are preexisting anatomic malformations of the conduction system that predispose to arrhythmias [1].

Atrioventricular Block (AVB) and less commonly sinus node dysfunction are significant postoperative complications. Fortunately, most postoperative bradyarrhythmias resolve spontaneously, with few exceptions. The incidence of PPM implantation in large multicenter studies is approximately 1 - 2% [2-4]. As opposed to adults, chronic pacing in children has potentially severe consequences, due to the lifelong need for artificial heart stimulation, which may affect mechanical heart function, but also due to the need for repeated lead and generator changes and risk of infection [1-5].

Surgical repair of certain congenital heart defects is associated with increased risk for PPM implantation [2-4]. AV valve and aortic valve surgery, ventricular septal defect (VSD) repair (either isolated or in the context of more complex CHD) and relief of Left Ventricular Outflow Tract (LVOT) obstruction are associated with increased risk of surgical injury to the conduction system [7-10]. Patients with specific congenital heart defects such as AV discordance have an inherent risk of heart block [1,8,9]. In addition to the specific heart defect, the duration of cardiopulmonary bypass has been found to be independent risk factors associated with PPM placement [4].

Our hospital is a referral center in Greece for pediatric cardiology and cardiac surgery.

Purpose of the Study

The purpose of this work was to study the characteristics of patients requiring postoperative pacing and to recognize risk factors for PPM implantation.

Methods

The study was approved by the Hospital ethics committee. Due to the retrospective design of this study, consent was not required.

Patients under 18 years of age who underwent surgery between 5/2002 and 5/2020, were identified using the admission log file of the Pediatric Cardiac Surgery Department. Patients who received postoperative pacing therapy were detected through the medical and surgical notes.

Pre-operative clinical factors included demographic characteristics, the presence of genetic syndrome, the primary diagnosis, the cardiac segmental anatomy, the anatomic type of VSD and the number of previous surgeries. Intra-operative data were extracted from the operative reports and consisted of the surgical anatomic findings, the duration of cardiopulmonary bypass and ischemic time, and the RACHS-1 score of the procedure [12]. Post-operatively we recorded for each patient the hourly timeline of pacing for the first two weeks after surgery, the postoperative day of PPM implantation, the duration of hospitalization and any in-hospital mortality.

In terms of the segmental anatomy, Van Praagh's terminology was used, based on 3 segments: Viscero-atrial situs (Solitus, Inversus or Ambiguous), Looping of the heart (D or L loop) and position of the great arteries (S: solitus, D: aorta right anterior, L: aorta left anterior) [11].

PPM indications were in accordance with the recommendations for Permanent Pacing in Children, Adolescents, and Patients with Congenital Heart Disease of the European Society of Cardiology [5]. Patients with third- or second-degree Mobitz II atrioventricular block (AVB) that persist beyond post operative day 10, is a candidate for Permanent Pacemaker implantation.

Inclusion criteria

We included all patients that received postoperative pacing therapy for all types of bradyarrhythmia even relative sinus bradycardia based on patient's hemodynamic status.

Exclusion criteria

We excluded patients with preexisting PPM, patients who required PPM implantation late after discharge from the Hospital and those who received temporary pacing to overdrive a tachyarrhythmia.

Statistical analysis

Continuous variables are presented as mean (± standard deviation) and categorical variables are presented as numbers (with percentages). Bivariate analysis between demographic and clinical characteristics and type of pacemakers (permanent vs. temporary) included chi-square test, chi-square trend test, Fisher's exact test, and independent samples t-test. First, we performed univariate logistic regression analysis and then variables that were significantly different ($p < 0.20$) were entered into the backward stepwise multivariable logistic regression analysis with type of pacemakers (permanent vs. temporary) as the dependent variable. Multivariable logistic regression analysis was performed to eliminate confounding. In multivariable models, we estimated adjusted odds ratios (OR) with 95% confidence intervals (CI) and p-values. All tests of statistical significance were two-tailed, and p-values < 0.05 were considered significant. Statistical analysis was performed with the Statistical Package for Social Sciences software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.).

Results

Demographic and clinical characteristics of patients are presented in table 1. More patients were male (58.2%), mean age was 2.7 years and mean BMI was 15.4 kg/m^2. The main diagnoses were Tetralogy of Fallot (34.4%), Ventricular Septal Defect (19.3%), D-Transposition of Great Arteries (8.1%), and Double Outlet Right Ventricle (5.6%) (Figure 1). The majority of children had {S,D,S} segmental anatomy (86.4%), and the majority of VSDs were conoventricular/membranous (87.3%). A genetic syndrome was found in 12.8% of patients. A previous cardiac surgical procedure had been performed in 25.4%. Most patients were in RACHS-1 category 2 (57.9%) (Figure 2). Pre-operative medication included b blocker (23.4%), Angiotensin-converting-enzyme inhibitors (12.6%), Digoxin (12.9%), Thyroxin (5.8%) and Furosemide (26.3%). However, the majority of operations were elective and chronotropic medications were ceased before surgery. Interestingly, 39 patients (13.6% overall) received steroids after surgery but assessment of the effect of steroids on outcome would require a larger number of subjects and a well designed prospective study.

Variable	Overall (n = 286)	Temporary (n = 245)	Permanent (n = 41)	P-value
Gender				0.31[a]
Male, n (%)	166 (58.2)	143 (58.4)	23 (56.1)	
Female n (%)	119 (41.8)	101 (41.2)	18 (43.9)	
Age (years), mean (SD)	2.7 (3.5)	2.38 (3.37)	4.35 (4.06)	0.02[b]
BMI (kg/m^2) mean (SD)	15.4 (3.1)	15.3 (3.1)	15.7 (3.0)	0.43[b]
Main Diagnosis				0.12[a]
TOF n (%)	98 (34.4)	85 (34.7)	13 (31.7)	
VSD n (%)	55 (19.3)	47 (19.2)	8 (19.5)	
D-TGA n (n%)	23 (8.1)	21 (8.6)	2 (4.9)	
DORV n (%)	16 (5.6)	15 (6.1)	1 (2.4)	
Other n (%)	94 (32.6)	77 (31.4)	17 (41.5)	
VSD type				0.34[a]
Conoventricular-membranous n (%)	185 (87.3)	157 (87.2)	28 (87.5)	
AV canal type n (%)	16 (7.5)	15 (8.3)	1 (3.1)	
Muscular n (%)	11 (5.2)	8 (4.4)	3 (9.4)	
Cardiac segments				0.04[a]
{S,D,S} n (%)	247 (86.4)	213 (86.9)	34 (82.9)	
{S,L,L} n (%)	8 (2.8)	4 (1.6)	4 (9.8)	
{S,D,D} n (%)	26 (9.1)	24 (9.8)	2 (4.9)	
{I,L,L} n (%)	2 (0.7)	2 (0.8)	0 (0)	
{S,L,D} n (%)	2 (0.7)	1 (0.4)	1 (2.4)	
Genetic syndrome				0.8[a]
No n (%)	246 (87.2)	208 (84.9)	38 (92.7)	
Trisomy 21 n (%)	23 (8.2)	21 (8.6)	2 (4.9)	
Di George n (%)	3 (1.1)	3 (1.2)	0 (0)	
Marfan n (%)	2 (0.7)	2 (0.8)	0 (0)	
Other n (%)	8 (2.8)	8 (3.3)	0 (0)	
Previous surgeries				0.02[c]
0 n (%)	212 (74.6)	186 (75.9)	26 (63.4)	
1 n (%)	57 (20.1)	50 (20.4)	7 (17.1)	
2 n (%)	14 (4.9)	7 (2.9)	7 (17.1)	
3 n (%)	1 (0.4)	1 (0.4)	0 (0.0)	
RACHS-1				0.68[c]
1 n (%)	13 (4.6)	13 (5.3)	0 (0.0)	
2 n (%)	165 (57.9)	141 (57.6)	24 (58.5)	
3 n (%)	73 (25.6)	62 (25.3)	11 (26.8)	
4 n (%)	31 (10.9)	25 (10.2)	6 (14.6)	
6 n (%)	3 (1.1)	3 (1.2)	0 (0.0)	
CPB (min) mean (SD)	181.4 (98.9)	181.9 (100.5)	178.1 (90.1)	0.81[b]
Hospital stay (days) mean (SD)	23.8 (18.1)	21.9 (15.3)	35.0 (17.3)	< 0.001[b]
Death				0.09[d]
Yes n (%)	29 (10.2)	28 (11.4)	1 (2.4)	
No n (%)	256 (89.8)	216 (88.2)	40 (97.6)	

Table 1: *Demographic and clinical characteristics of children.*

[a]: Chi-square test, [b]: Independent samples t-test, [c]: Chi-square trend test, [d]: Fisher's exact test.

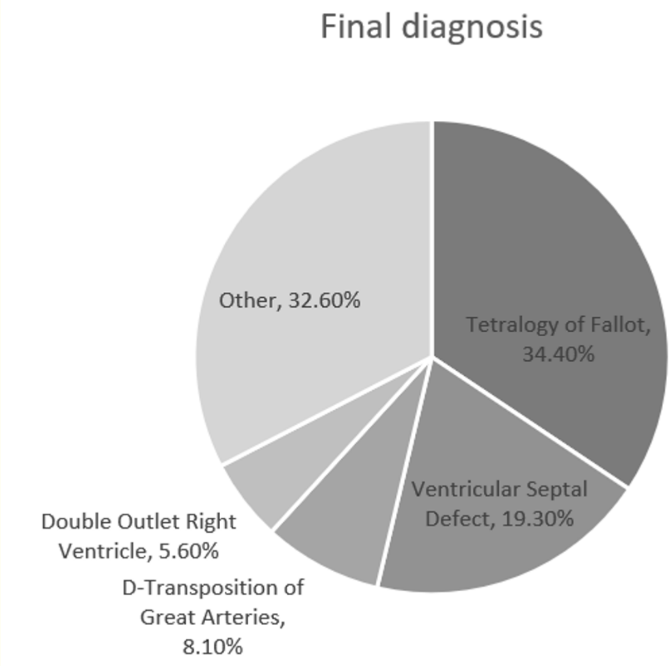

Figure 1: *Final diagnosis.*

Other diagnosis (32.6%) include: Aortic Valve Stenosis (2.8%), Atrial Septal Defect (4.2%), Coarctation of the Aorta (0.7%), Complete Atrioventricular Canal defect (5.3%), Partial Atrioventricular Canal defect (2.1%), L-transposition of the great arteries (1.8%), Single Ventricle Defects (3.5), Total Anomalous Pulmonary Venous Connection (4.9%), Truncus Arteriosus (0.7%), Partial anomalous pulmonary venous connection (0.7%), Atrioventricular septal defect (0.7%), Hypertrophic obstructive cardiomyopathy (1.6%), Mitral Valve Stenosis (1.4), Aortic Valve Regurgitation (1.4%), Anomalous origin of the left coronary artery from the pulmonary artery (0.7%), Double-outlet left ventricle (0.7%), Cor Triatriatum (0.4%) and Interrupted Aortic Arch (0.4%).

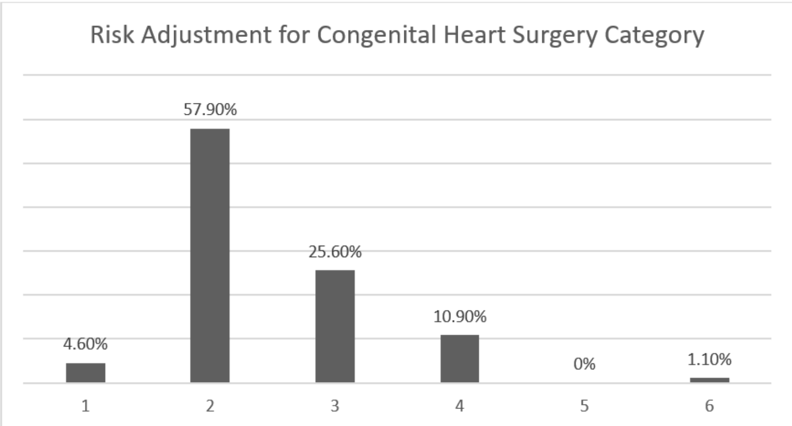

Figure 2: *Severity of illness.*

We found that patients who required permanent pacing were older (p = 0.02). Patients with segmental anatomy {S,L,L} required PPM more often compared to the other segmental combinations (p = 0.04). Patients who required permanent pacemakers had a higher incidence of previous surgeries (p = 0.02). The predominant mode of temporary pacing was DDD (n = 209), while VVI mode was used in 48 and AAI mode was used in 66 patients. More than one type of pacing was used in certain patients. The mean time for insertion of the PPM was 21.7 days, with a range from 3 to 64 days. Twenty nine out of the 286 children died (10.1%). Mortality was higher in the temporary pacing group, but this difference did not reach statistical significance (11.4% vs. 2.4%, p = 0.09). Length of hospital stay was longer in the permanent pacing group (p < 0.001).

The relationship between demographic and clinical characteristics and type of pacemakers are shown in table 1. After univariate logistic regression analysis, {S,L,L} segmental anatomy (0.04), increased age (p = 0.02), and number of previous cardiac surgeries (p = 0.02) were related with increased use of permanent pacemakers. Multivariable logistic regression analysis identified that increased number of previous cardiac surgeries (OR = 1.99, 95% CI = 1. 1.21 - 3.29, p = 0.007) was related with increased use of permanent pacemakers (Table 2).

Variable	Unadjusted OR (95% CI)	P-value	Adjusted OR (95% CI)[a]	P-value
Boys vs. girls	0.92 (0.47-1.80)	0.81	NS	
Age (years)	1.13 (1.05-1.22)	0.002	NS	
Body mass index (kg/m^2)	1.06 (0.96-1.17)	0.24	NS	
{S,D,S} segments vs. other	0.69 (0.28-1.70)	0.69	NS	
VSD type				
AV canal type vs. conoventricular-membranous	0.37 (0.05-2.94)	0.35	NS	
Muscular vs. conoventricular-membranous	2.10 (0.53-8.41)	0.29	NS	
Genetic syndrome vs. no	0.32 (0.07-1.37)	0.13	NS	
Number of previous cardiac surgeries	1.86 (1.14-3.04)	0.014	1.99 (1.21-3.29)	0.007
RACHS-1	1.17 (0.80-1.71)	0.42	NS	
Cardiopulmonary bypass time	1.00 (0.99-1.003)	0.80	NS	

Table 2: *Univariate and multivariable logistic regression analyses with type of pacemaker as the dependent variable (permanent vs. temporary).*

CI: Confidence interval, NS: Not selected by the backward elimination procedure in the multivariate logistic regression analysis with a significance level set at 0.05, OR: Odds ratio, [a]R^2 for the final multivariate model was 14%.

The differences in the usage of external pacemakers between the two groups is shown in figure 3. External pacing was terminated on postoperative day 10, in 91% of patients of the temporary group. Notably, we found a statistically significant difference (60.4% vs 92.7%, p < 0.001) in the need for pacing from the first hour between the two groups.

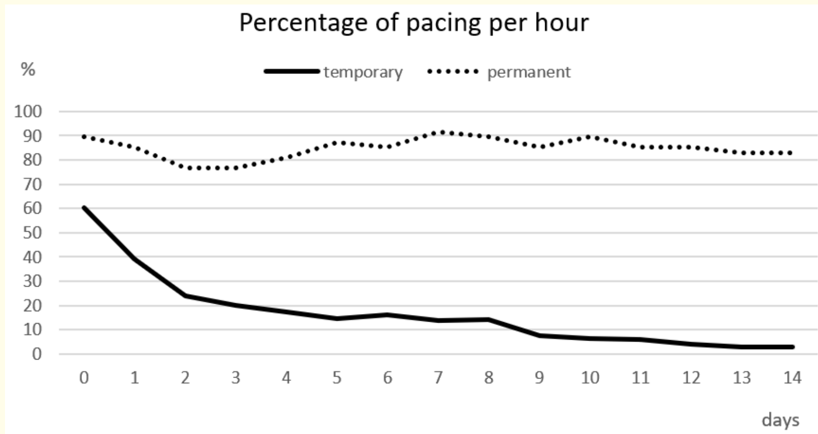

Figure 3: *Usage of external temporary pacemaker during the first two weeks.*

Discussion

In this single center study, we assessed the characteristics of postoperative pacing in children after heart surgery and the risk factors for PPM implantation. We found that previous cardiac surgeries increased the possibility for needing permanent pacemaker implantation. Older age of patients was also associated with higher risk, but this may be interrelated with multiple previous surgeries. Patients with AV discordance (segmental anatomy S,L,L) were also at higher risk for needing permanent pacing. We also noticed that the children who required a PPM implantation were more likely to need external temporary pacing from the first hour of admission in PICU. Finally, we demonstrated that independence from the need of external pacemaker was achieved on the 10th postoperative day in 91% of the patients in the temporary group.

Incidence of PPM implantation after surgery

The overall incidence of post-operative PPM implantation is close to the one reported in the majority of international studies [2-4]. Interestingly the largest multicenter study by Romer., *et al.* describes considerable variation in rates of PPM placement between participating centers [4]. These differences may be attributed to several reasons. Comparison of different practises is particularly challenging but beyond the scope of this study. The percentage of temporary pacing in our study was 8.2% which is notably higher than the incidence of temporary AVB reported in other studies [2-4]. Yet, in our cohort we included patients that received temporary pacing treatment for all types of bradyarrhythmia, even relative sinus bradycardia based on the patient's hemodynamic status.

Time of resolution of bradyarrhythmia

In scientific documents and practice guidelines there is a strong consensus that patients with third- or second-degree Mobitz II, or high-grade atrioventricular block (AVB) after cardiac surgery that persists or is not expected to resolve, should undergo permanent pacemaker implantation. Guidelines published in the United States (ACC/AHA/HRS) in 2008 recommend an observation period of at least 7 days (Class I, Level of Evidence B) [6], whereas guidelines of the European Society of Cardiology published in 2013, recommend the implantation of PPM if advanced AV block is persisting > 10 days postoperatively (Class I, Level of Evidence B) [5].

The most recent and largest patient study from 25 U.S. Centers published by Romer., *et al*. in 2019 found that resolution of temporary atrioventricular block (AVB) occurs in 94% of patients by day 10 [4]. In our cohort, 9% of patients from the temporary group required external pacing beyond day 10. The majority of those patients had Mobitz I AVB, indicating that there was not an absolute indication for permanent pacing and that resolution of AV block might be expected.

Preoperative risk factors

In our study we found a statistically significant predominance of {S,L,L} anatomy (AV and VA discordance) in the permanent group ($p = 0.04$). In addition, we found that older patients were more likely to need permanent pacing therapy. It is possible that this is due to more patients with congenitally corrected Transposition of Great Arteries (ccTGA) or patients who underwent complex surgeries such as Fontan or Rastelli operation who underwent surgery at relatively older age than the rest of our patient group. It is known that the risk of heart block in ccTGA patients increases overtime by approximately 2% per patient-year, even in patients who have not undergone an operation, with an overall incidence ranging between 13% and 38% depending on the presence of associated defects [8]. Therefore, any surgical procedure may affect the already tenuous conduction system in these patients.

Intra-operative risk factors

Neither the duration of cardiopulmonary and cross clamp time nor the category of operation based on the RACHS-1 score were found to be significant determinants of the need for PPM implantation.

The majority of patients had an operation that involved a VSD closure (66.7%). The conduction system is usually closely related to the border of the ventricular defect and, therefore, it is prone to injury during the surgical manipulation [7]. In our study we examined the role of VSD type based on anatomical location and we did not find an association of the type of VSD (conoventricular-membranous, muscular and atrioventricular canal defects) with conduction system injury.

Post-operative risk factors

When we looked into the need for pacing after surgery, we found that patients that required PPM implantation were more likely to need pacing from the first hour after admission to ICU. This finding suggests a close relation between the severity of impairment to the conduction system and the need for permanent pacing. However almost 60% of patients in the temporary group will also require pacing immediately after surgery and, therefore, a period of observation is necessary before proceeding to permanent pacemaker implantation. Sanatani., *et al*. recommend elucidating the pathophysiology of post-operative complications and work towards preventing their occurrence [13]. Perhaps in the future we will be able to identify markers for AVN cells and map the atrioventricular conduction system with high resolution 3-Dimensional imaging [13,14].

Time of insertion-Length of hospital stay-Mortality

The mean time for insertion of the PPM was 21.7 days. The earliest insertion was on postop day 3, in a patient that had permanent epicardial leads implanted during a Rastelli operation. The latest was 64 days after mitral valve replacement in a patient who required postoperative ECMO and his hospital course was complicated with infection. As expected, the length of hospital stay was longer in the permanent group (21.9 versus 35.0 days) due to the longer observation time and the need for reoperation. Mortality was higher in the temporary group although it did not reach statistical significance (11.4% vs. 2.4%, $p = 0.09$). The increased percentage of mortality in the temporary group may be explained by the fact that we included patients that received postoperative pacing for all types of bradyarrhythmia, including bradycardia related to severe hemodynamic instability.

Limitations of the Study

There are several limitations in this study. Due to the retrospective nature of the study, it is subject to some systematic errors in data collection. The study number of patients is relatively small especially in the permanent group. Some of the patients in the temporary group who died and were still paced, might have required permanent pacing. Also, our study included only 3 patients from RACHS categories 5 and 6. Centres with larger numbers may find statistically significant differences in these categories. Finally, this is a single center study and evaluates patients over a long period of time (18 years) during which surgical techniques, technology and overall postoperative management may have changed.

Conclusion

The incidence of permanent pacemaker implantation after cardiac surgery for children under 18 years is 1.4%. Patients with Atrio-Ventricular discordance, multiple previous surgeries and those who need temporary pacing from the first hour of admission in PICU and/or the need for pacing persists beyond 10 days, are more likely to require permanent pacing.

Declarations of Interest

None.

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