

Incidence and Recovery of Postsurgical Heart Block in Pediatric Patients Following Cardiac Surgery for Congenital Heart Disease.

Short Title: Pediatric Postsurgical Heart Block Recovery

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Introduction: A subset of patients who develop post-surgical heart block have recovery of atrioventricular-node function. Factors predicting recovery are not understood. We sought to investigate our center's incidence of post-surgical heart block and examine factors associated with recovery of atrioventricular-node function.

Methods: Patients 0 – 21 years who underwent cardiac surgery between January 2010 – December 2019 at a free-standing children's hospital and experienced postoperative heart block were included. Demographics, clinical and operative variables were analyzed.

Results: Of 6333 surgical hospitalizations, 128 (2%) patients were included. Of the 128 patients included, 90 (70%) had return of atrioventricular-node function, and 38 (30%) had permanent pacemaker placement. Of the 38 patients who underwent pacemaker placement, 6 (15.8%) had recovery of atrioventricular-node function noted on long-term follow-up. Median time to from onset of heart block to late atrioventricular-node recovery was 13 days (IQR 5 – 117). Patients with single-ventricle physiology ($p = 0.04$), greater weight ($p = 0.03$) and shorter cardiopulmonary bypass time ($p = 0.015$) were more likely to have recovery. The use of postoperative steroids was similar between all groups ($p = 0.445$). Infectious or wound complications were similar between pacemaker groups ($p = 1$).

Conclusions: Two percent of patients who underwent cardiac surgery developed postoperative heart block, and 0.6% underwent pacemaker placement. Early recovery of atrioventricular-node was associated with greater weight at time of surgery, single-ventricle physiology and shorter cardiopulmonary bypass time. Late recovery of atrioventricular-node conduction following pacemaker placement occurred in 15.8% of patients.

Keywords: Congenital Heart Surgery; Pediatric Postsurgical Heart Block; Pediatric Pacemaker;

Introduction:

Surgical heart block is a well described complication of cardiac surgery (CS) for congenital heart disease (CHD). Prior reports estimate that atrioventricular (AV) block occurs in 1-6% of patients undergoing CS.^{1, 2} A recent registry study from Pediatric Cardiac Critical Care Consortium found an incidence of postoperative heart block to be nearly 3%. However, almost 94% of these patients had resolution of AV block by postoperative day 10, resulting in 1% of patients receiving a permanent pacemaker (PPM).¹

Postsurgical AV block is a complication with significant morbidity and mortality.^{1, 3, 4} Patients requiring PPM for surgical heart block have an overall 2.1 times longer length of stay (LOS), and increased mortality when adjusting for surgical complexity.³⁻⁵ Placement of pacemaker in pediatric patients can be associated with complications including lead fracture, phrenic nerve capture, pacer induced cardiomyopathy, infectious complications and coronary artery compression.^{6,7} Guidelines suggest that a PPM be placed for postsurgical heart block after 7 days as a class 1 indication.⁸ There is evidence that up to 97% of recovery of AV nodal function occurs within 9 days of surgery with postsurgical heart block following CHD repair.^{1, 2, 9} However, factors predicting late AV nodal function recovery are not well understood. The registry report by Romer et al, suggested that longer cardiopulmonary bypass (CPB) times and specific operations such as the Nikaidoh, double switch procedure, or VSD creation/enlargement were associated with higher risk for needing a PPM.¹ There are reports of late recovery of AV nodal function after surgical heart block, but factors predicting recovery are not well understood.^{2, 10-12} We sought to describe our center's experience with surgical heart block following CS for CHD and examine the factors associated with heart block and recovery of AV nodal function.

Methods:

This is a single center retrospective cohort study that included all patients 0 – 21 years of age who underwent CS for palliation or repair of CHD and developed heart block postoperatively between January 1st 2010 and December 31st 2019 at Children’s Healthcare of Atlanta, a free-standing, university-affiliated quaternary children’s hospital. An internal surgical database was queried, and eligible surgical encounters were identified. The study was approved by the Children’s Healthcare of Atlanta Institutional Review Board (IRB# 00000398). Informed consent was waived.

Demographics (age, weight, gender, and race), clinical characteristics (cardiac intensive care unit length of stay [CICU-LOS], post-operative-LOS, hospital-LOS, duration of mechanical ventilation, genetic syndrome) and operative variables (cardiopulmonary bypass [CPB] time and aortic cross clamp [XC] time) were collected. Patients with postoperative heart block that required ventricular pacing were stratified into 3 main outcome groups; 1) those who had spontaneous recovery of AV nodal function, 2) those who recovered AV nodal function after permanent pacemaker implantation (PPM), and 3) those who had PPM placed but had no recovery of AV nodal function. Recovery of AV nodal function was defined as return to sinus rhythm or first-degree heart block. This definition is similar to what has been used in prior reports. ¹

Statistical Analysis:

Normality was tested for all variables of interest. Descriptive statistics were performed including counts, medians, and interquartile ranges. We used nonparametric methods to determine the difference in medians between continuous variables of the three outcome groups. Exact Fisher and χ^2 tests were performed for differences in categorical variables between

groups. A p -value of less than 0.05 was considered the cutoff for significance. Statistical analyses were performed using SAS Enterprise Guide version 7.15 (SAS Institute, Inc., NC).

Results:

Patient Characteristics:

A total of 6,333 CS for CHD were performed between January 1, 2010, and December 31, 2019. Of this group, 2% (128/6333) patients developed post-surgical heart block, and 0.6% (38/6333) of them underwent PPM placement. There were 6/38 patients (15.8%) who had recovery of AV nodal function following PPM placement. There was no difference in demographics between the three groups with regards to age, race, weight at time of index surgery, gender, preoperative need for antiarrhythmic medications or presence of chromosomal abnormalities (Table 1). For patients who had transient AV block, 91.2% had recovery of AVN function 10 days after developing heart block and 100% at 19 days. A greater proportion of those with single-ventricle physiology with PPM placement and recovery than single-ventricle physiology patients who had heart block requiring PPM and no AV node recovery (50% vs 12.5%, $p = 0.016$) (Table 1). Given the heterogeneity in cardiac diagnoses with few patients in each category, further statistical analysis was not feasible (Table 2).

Surgical Characteristics:

Median CPB time was 121 minutes (IQR 95 – 166) in the transient AV block group, 144 minutes (IQR 120 – 190) in the PPM group without recovery and 138 minutes (IQR 111 – 178) in the PPM group with later recovery of AVN function ($p = 0.015$) (Table 1). Median aortic cross clamp time was 70 minutes (IQR 51 – 110) in the transient AV block group, 91 minutes (IQR 72 – 128) in the PPM group without recovery and 75 minutes (IQR 62 – 144) in the PPM group with later recovery of AVN function ($p = 0.059$) (Table 1).

Medical Characteristics:

There was no difference in the rate of postoperative steroid administration between groups ($p = 0.445$), nor was there a difference in infectious or wound complications ($p = 1$). Furthermore, there was no difference in long term mortality between groups (8%, 19% and 0% respectively, $p = 0.191$). However, the median CICU-LOS in the transient AV block group was 5 days (IQR 3 – 10) compared to 15 days (IQR 7.5 – 36.5) in those who required PPM and did not have recovery of AVN function ($p < 0.0001$) (Table 1).

Recovery of AV nodal function:

There were six patients who had recovery of AV nodal function after placement of PPM. Following the index surgery resulting in heart block, the median duration to PPM placement was at 5.5 days (IQR 4 – 8) in patients who had late AV nodal function recovery versus 9.0 days (IQR 8 – 14) in those who did not have recovery of AV nodal function ($p = 0.006$). Median time from index operation to recovery was 13 days (Range 5 – 117).

In a sub-group analysis of patients stratified by age, those in the children group (aged 1 year to 18 years) who had PPM placed without AVN recovery had lower weight (median 13.5 kg, IQR 11 – 18.2) compared to those who had PPM placed but had recovery of AV nodal function (median 43.15 kg, IQR 28.1 – 58.5). Complication rates between these groups were similar ($p = 1$).

Discussion:

In this study, we demonstrate an incidence of early of post-surgical heart block of 2% at our center, with permanent heart block rate of 0.5%. This aligns with prior reports.^{1, 5} Romer et al

in a large registry study evaluating 15,901 surgical hospitalizations and found that 2.7% of patients experienced post-surgical heart block.¹ In their study cohort, approximately 1% of patients who underwent cardiac surgery required PPM placement compared to our study, where 0.6% of patients underwent PPM placement. Of note, our study is more specific to pediatric cardiac surgery as our cohort contained only three adult patient 18 – 21 years of age, compared to 713 in the Romer study. They identified that longer CPB time was associated with increased risk for needing PPM placement. Our study confirms this finding as well, with the median CPB time of 121 minutes in those with transient heart block compared to 144 and 138 minutes in those who had PPM placed with recovery of AVN function and those who had PPM placed but had no resolution of heart block respectively. Longer aortic cross-clamp time trended towards but was not significantly associated with increased rate of permanent heart block. The etiology for this is not well known but may be related to longer AV node ischemic time, or CPB time may be a surrogate for more difficult operations or ones with more challenging intracardiac visualization.

We also describe the rate of resolution of post-surgical heart block in the largest group of pediatric patients following cardiac surgery, to our knowledge. Of 6333 cardiac surgeries, 128 (2%) were complicated by AV block requiring ventricular pacing, and 38 (0.6%) had a PPM placed. Of the patients that underwent PPM placement (n = 38), 6/38 (15.8%) had resolution of heart block. van Geldorp et al, describe a group of patients with resolution of AV block following initial PPM placement. They examined 2,850 patients who underwent cardiac surgical procedures of whom 59 (2.1%) experienced chronic (>14 days) postoperative heart block. Of this group, 7 patients (7/59, 11.9%) demonstrated resolution of AV block following initial PPM placement.² Notably, that study did not analyze variables that are associated with recovery of AV nodal function. Our findings demonstrate a slightly higher (6/38, 15.8%) rate of recovery of AV nodal function following postoperative heart block. While the patients in our study who had recovery of

AV nodal function after PPM placement had median placement of PPM on postoperative day 5, all but one had recovery 7 days after development of post-surgical AV block. Thus, these patients would have still met the current PACES/HRS recommendation for PPM placement on postoperative day 7.⁸ Interestingly, had we waited for postoperative day 10 to determine the need for PPM implantation, 3 of our 38 patients would not have received PPM. Romer et al. suggested that in their large multicenter cohort, that if AV nodal function recovers after postoperative heart block, this occurs by postoperative day 10 in 94% of patients.¹ Ours is also the first study to evaluate for factors that might predict recovery of AV nodal function. A greater proportion of patients with single-ventricle physiology had recovery of AV nodal function after PPM implantation compared to those who had permanent postoperative AV block. The reasons for this are not entirely clear, but could be due to the fact that Glenn and Fontan procedures do not generally require intracardiac surgery.

Of those in the single-ventricle physiology late recovery group, one patient had VSD enlargement, but the remaining two patients did not have intracardiac surgery (Kawashima and extracardiac Fontan procedures). This is compared to those single-ventricle physiology patients who required permanent pacing, all of whom underwent intracardiac surgery (Ebstein's anomaly of tricuspid valve repair, Fontan with atrioventricular valvuloplasty, Glenn with VSD enlargement and Starnes procedures). Oster et al. studied arrhythmias in single ventricle patients who underwent Norwood operation. They found the only significant factor contributing to heart block in this cohort was a concomitant procedure in addition to the Norwood procedure, with the strongest risk factor being tricuspid valve repair.¹³ Thus, our data suggests that in single ventricle patients, the need for a concomitant procedure in addition to Glenn or Fontan procedure is associated with developing irrecoverable heart block (in addition to the other previously identified high-risk operations like Ebstein repair and Starnes procedure).¹

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188 Limitations:

189 This is a single center retrospective study with its attendant limitations. We did not study
190 operator as a variable. Pacemaker implantation timing was based on surgeon and CICU team
191 preference and not based on a set protocol. For this reason, pacemaker placement could have
192 been performed earlier than guidelines suggest for other reasons (i.e., early unplanned
193 reoperation). The group in whom late AV node recovery was present was small and warrants a
194 larger, multi-center study to better characterize this population.

195

196 **Conclusion:**

197 Post-surgical heart block occurs in 2% of patients undergoing CS for CHD. In our study
198 91% of resolution occurred by post-operative day 10. PPM placement occurred in 0.6% (38/6333)
199 of patients, and permanent postoperative heart block occurred in 0.5% (32/6333) of patients.
200 Higher weight, shorter CPB time, and presence of single ventricle physiology are associated with
201 resolution of post-surgical AV block. Late recovery of AV-node conduction following PPM
202 placement occurred in 15.8% (6/38) patients, is associated with greater age and weight, but is
203 not associated with gender, post-operative steroids, infectious or wound complications.

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Table 1. Patient Characteristics

| Variable | N | Transient AVB (n = 90) | AVB with PM without recovery (n = 32) | AVB with PM with recovery (n = 6) | p-value |
|---|-----|---------------------------|---|---|---------------|
| Age at Surgery (Days) | 128 | 198 (111 – 986) | 198 (72.5 – 667) | 2822 (320 – 4725) | 0.149 |
| Infant (0 – 1 year) | 81 | 58 (64.44%) | 21 (65.63%) | 2 (33.33%) | 0.497 |
| Child (1 – 18 years) | 43 | 29 (31.46%) | 10 (31.25%) | 4 (66.67%) | |
| Adult (> 18 years) | 4 | 3 (3.37%) | 1 (3.13%) | 0 (0%) | |
| Race | | | | | |
| Caucasian | 74 | 52 (58.43%) | 19 (59.38%) | 3 (50%) | 0.199 |
| Black | 45 | 33 (37.08%) | 10 (31.25%) | 2 (33.33%) | |
| Asian | 4 | 1 (1.12%) | 2 (6.25%) | 1 (16.67%) | |
| Native American | 1 | 0 (0%) | 1(3.13%) | 0 (0%) | |
| Other | 3 | 3 (3.37%) | 0 (0%) | 0 (0%) | |
| Gender | | | | | |
| Male | 64 | 42 (46.67%) | 19 (59.38%) | 3 (50%) | 0.449 |
| Female | 64 | 48 (53.33%) | 13 (40.63%) | 3 (50%) | |
| Weight at Surgery (kg) | 128 | 6.6 (4.5 – 13.6) | 6.45 (4.0 – 11.3) | 23.1 (8.3 – 58.0) | 0.087 |
| Weight at Pacemaker Implantation (kg) | 38 | . | 6.4 (3.9 – 11.8) | 23.7 (8.5 – 58.0) | 0.029 |
| Chromosomal abnormality | | | | | |
| No abnormality | 96 | 68 (75.56) | 24 (75) | 4 (66.67) | 0.287 |
| Trisomy 21 | 17 | 14 (15.56) | 2 (6.25) | 1(16.67) | |
| Other | 15 | 8 (8.89) | 6 (18.75) | 1(16.67) | |
| Single Ventricle | | | | | |
| No | 114 | 83 (92.22) | 28 (87.5) | 3 (50.0) | 0.016 |
| Yes | 14 | 7 (7.78) | 4 (12.5) | 3 (50.0) | |
| Preop antiarrhythmic meds | | | | | |
| No | 99 | 69 (76.7) | 24 (75.0) | 6 (100.0) | 0.512 |
| Yes | 29 | 21 (23.3) | 8 (25.0) | 0 (0.0) | |
| Cardiopulmonary Bypass Time (min) | 128 | 121 (95-165.5) | 144.0 (120-190) | 138 (111-178) | 0.015 |
| Aortic Cross Clamp Time (min) | | 70 (51-110) | 91 (72-128) | 74.5 (62-144) | 0.059 |
| CICU Length of Stay (days) † | 128 | 5.0 (3.0-10.0) | 15.0 (7.5-36.5) | 7 (4.0 -48.0) | 0.0001 |
| Post-Operative Steroids | | | | | |
| No | 113 | 78 (86.7%) | 30 (93.7%) | 5 (83.3%) | 0.445 |
| Yes | 15 | 12 (13.3%) | 2 (6.3%) | 1 (16.7%) | |
| Mortality | | | | | |
| Alive | 114 | 83 (92.22%) | 25 (80.6%) | 6 (100%) | 0.191 |
| Demised | 13 | 7 (7.78%) | 6 (19.4%) | 0 (0%) | |
| Results depicted in n (percent), median (interquartile range) | | | | | |
| † significant difference between Group B and A <i>p</i> <0.0001 | | | | | |

Table 2. Primary Cardiac Diagnosis

| Primary Cardiac Diagnosis | N | Transient AV Block (N=90) | AV Block with PM without recovery (N=32) | AV Block with PM with recovery (N=6) |
|--|----------|--------------------------------------|---|---|
| ASD | 4 | 4 | 0 | 0 |
| AVC complete | 17 | 13 | 2 | 2 |
| Anomalous Pulmonary Venous Return | 5 | 4 | 1 | 0 |
| Aortic Valve Disease | 11 | 8 | 3 | 0 |
| Cardiomyopathy | 6 | 5 | 0 | 1 |
| Congenitally corrected – TGA | 2 | 0 | 2 | 0 |
| DORV | 7 | 5 | 2 | 0 |
| Ebstein/Tricuspid valve anomaly | 4 | 1 | 3 | 0 |
| Interrupted Aortic Arch | 4 | 1 | 3 | 0 |
| Miscellaneous | 2 | 1 | 1 | 0 |
| Mitral Valve Disease | 7 | 3 | 3 | 0 |
| PA/VSD | 4 | 4 | 0 | 0 |
| Pulmonary Artery Anomalies | 3 | 3 | 0 | 0 |
| Pulmonary Valve Disease | 3 | 3 | 0 | 0 |
| Pulmonary Vascular Obstructive Disease | 1 | 1 | 0 | 0 |
| Single Ventricle; Heterotaxy | 2 | 1 | 0 | 1 |
| Single Ventricle; Hypoplastic Left Heart | 5 | 4 | 1 | 1 |
| Single Ventricle; Hypoplastic Right Heart | 5 | 3 | 1 | 1 |
| TGA | 3 | 2 | 1 | 0 |
| TOF | 13 | 11 | 2 | 0 |
| VSD | 14 | 9 | 5 | 0 |
| VSD/hypoplastic aortic arch | 5 | 3 | 2 | 0 |

Table 3. Patients with Permanent Pacemaker with and Without Recovery

| Variable | N | AV Block with PM but no recovery (N=32) | AV Block with PM with recovery (N=6) | p-value |
|---|----|---|--|---------|
| Duration from Surgery to PM Placement (Days) | 36 | 9.0 (8.0 – 14.0) | 5.5 (4.0 – 8.0) | 0.006 |
| Patient at Dry Weight at Time of PM Placement | | | | |
| No | 5 | 5 (15.63%) | 0 (0%) | 0.570 |
| Yes | 6 | 27 (84.38%) | 6 (100%) | |
| Infectious or Wound Complications | | | | |
| None | 29 | 24 (75%) | 5 (83.33%) | 1 |
| Sternal Wound | 3 | 3 (9.38%) | 0 (0%) | |
| Infection | 1 | 1 (3.13%) | 0 (0%) | |
| Endocarditis | 4 | 3 (9.38%) | 1 (16.67%) | |
| PM pocket Dehiscence | 1 | 1 (3.13%) | 0 (0%) | |
| Other | | | | |
| Mortality | | | | |
| Alive | 31 | 25 (80.65%) | 6 (100%) | 0.562 |
| Deceased | 6 | 6 (19.35%) | 0 (0%) | |
| Age at Surgery (Days) | 38 | 198 (72.5 – 667) | 2822 (320 – 4725) | 0.041 |
| Weight at Time of Surgery (kg) | 38 | 6.45 (4.0 – 11.3) | 23.15 (6.4 – 58.3) | 0.033 |
| Infant (N=24) | 23 | 4.8 (3.1 – 6.2) | 6.49 (4.7 – 8.28) | 0.382 |
| Child (N=15) | 14 | 13.45 (11 – 17.1) | 43.05 (23.15 – 58.25) | 0.024 |
| Adult (N=1) | 1 | 53.0 (53 – 53) | -- | -- |
| Weight at Pacemaker Placement (kg) | 37 | 6.40 (3.9 – 11.8) | 19.1 (4.7 – 58.0) | 0.0371 |
| Infant | 23 | 4.8 (3.4 – 6.3) | 6.6 (4.7 – 8.5) | 0.359 |
| Child | 14 | 13.0 (11.0 – 17.1) | 43.2 (23.7 – 58.25) | 0.024 |
| Adult | 1 | 53.0 (53 – 53) | -- | -- |

Results depicted in n (percent), median (interquartile range)

Figure 1A. A. Kaplan-Meier plot showing time from onset of AV block to either spontaneous recovery of AV nodal function (red) or placement of PPM (blue).

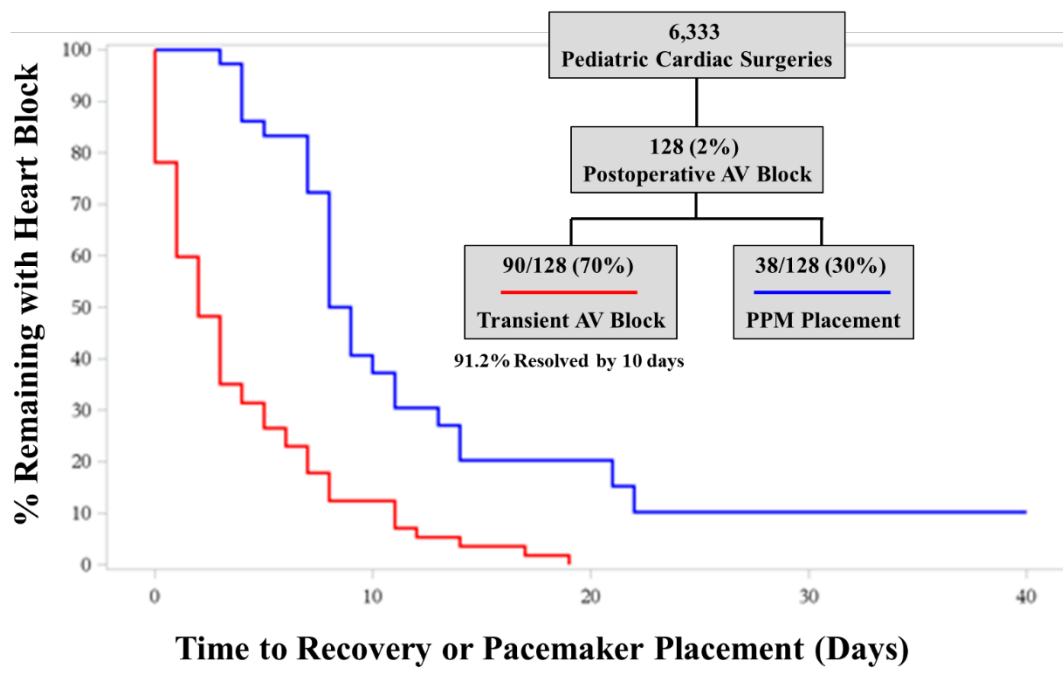
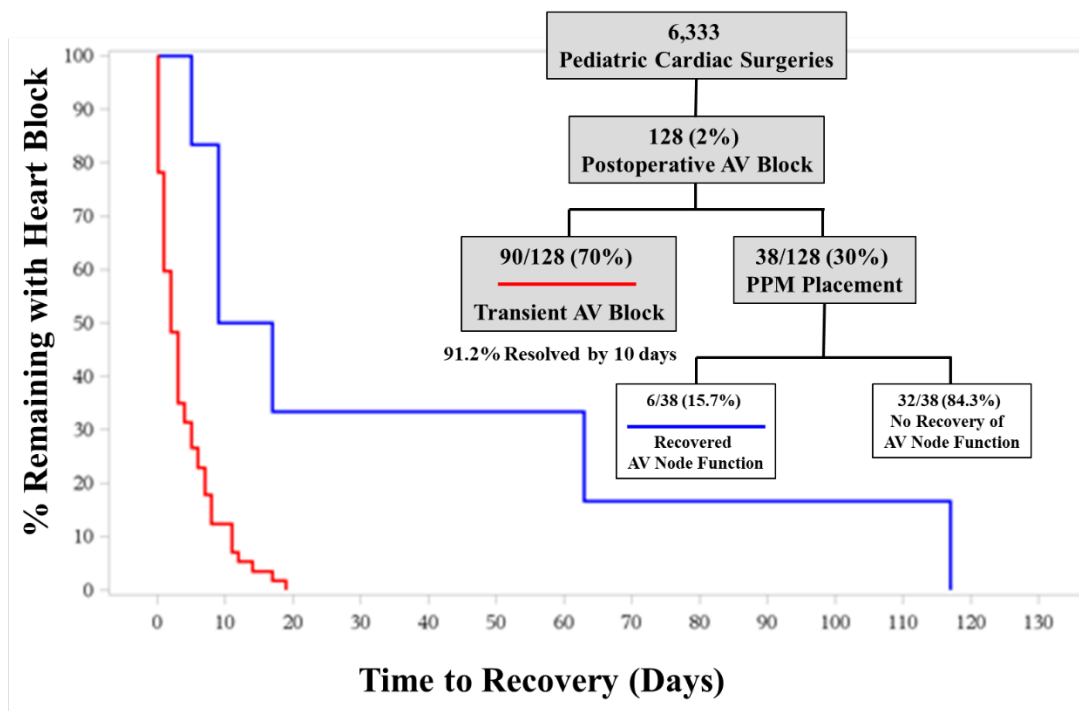


Figure 1B. B. Kaplan-Meier plot showing time from onset of AV block to recovery of AV nodal function without pacemaker (red) or recovery after PPM was placed (blue).



Abbreviations: AV: atrioventricular, PPM: permanent pacemaker.

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258

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261 **Table and Figure Legend:**

262 **Table 1.** Patient Characteristics

263 **Table 2.** Primary Cardiac Diagnosis

264 **Table 3.** Patients with Permanent Pacemaker with and Without Recovery

265 **Figure 1A.** A. Kaplan-Meier plot showing time from onset of AV block to either spontaneous
266 recovery of AV nodal function (red) or placement of PPM (blue).

267 **Figure 1B.** B. Kaplan-Meier plot showing time from onset of AV block to recovery of AV nodal
268 function without pacemaker (red) or recovery after PPM was placed (blue).