

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

3 **Short Title:** Pediatric Postsurgical Heart Block Recovery

4

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26 **Abstract:** (Word Count: 250)

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

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

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

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

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

49 **Introduction:**

50 Surgical heart block is a well described complication of cardiac surgery (CS) for congenital
51 heart disease (CHD). Prior reports estimate that atrioventricular (AV) block occurs in 1-6% of
52 patients undergoing CS. ^{1, 2} A recent registry study from Pediatric Cardiac Critical Care
53 Consortium found an incidence of postoperative heart block to be nearly 3%. However, almost
54 94% of these patients had resolution of AV block by postoperative day 10, resulting in 1% of
55 patients receiving a permanent pacemaker (PPM). ¹

56 Postsurgical AV block is a complication with significant morbidity and mortality. ^{1, 3, 4}
57 Patients requiring PPM for surgical heart block have an overall 2.1 times longer length of stay
58 (LOS), and increased mortality when adjusting for surgical complexity. ³⁻⁵ Placement of
59 pacemaker in pediatric patients can be associated with complications including lead fracture,
60 phrenic nerve capture, pacer induced cardiomyopathy, infectious complications and coronary
61 artery compression. ^{6,7} Guidelines suggest that a PPM be placed for postsurgical heart block after
62 7 days as a class 1 indication. ⁸ There is evidence that up to 97% of recovery of AV nodal function
63 occurs within 9 days of surgery with postsurgical heart block following CHD repair. ^{1, 2, 9} However,
64 factors predicting late AV nodal function recovery are not well understood. The registry report by
65 Romer et al, suggested that longer cardiopulmonary bypass (CPB) times and specific operations
66 such as the Nikaidoh, double switch procedure, or VSD creation/enlargement were associated
67 with higher risk for needing a PPM. ¹ There are reports of late recovery of AV nodal function after
68 surgical heart block, but factors predicting recovery are not well understood. ^{2, 10-12} We sought to
69 describe our center's experience with surgical heart block following CS for CHD and examine the
70 factors associated with heart block and recovery of AV nodal function.

71

72 **Methods:**

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

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

89 Statistical Analysis:

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

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

96 **Results:**

97 Patient Characteristics:

98 A total of 6,333 CS for CHD were performed between January 1, 2010, and December 31,
99 2019. Of this group, 2% (128/6333) patients developed post-surgical heart block, and 0.6%
100 (38/6333) of them underwent PPM placement. There were 6/38 patients (15.8%) who had
101 recovery of AV nodal function following PPM placement. There was no difference in
102 demographics between the three groups with regards to age, race, weight at time of index surgery,
103 gender, preoperative need for antiarrhythmic medications or presence of chromosomal
104 abnormalities (Table 1). For patients who had transient AV block, 91.2% had recovery of AVN
105 function 10 days after developing heart block and 100% at 19 days. A greater proportion of those
106 with single-ventricle physiology with PPM placement and recovery than single-ventricle
107 physiology patients who had heart block requiring PPM and no AV node recovery (50% vs 12.5%,
108 $p = 0.016$) (Table 1). Given the heterogeneity in cardiac diagnoses with few patients in each
109 category, further statistical analysis was not feasible (Table 2).

110 Surgical Characteristics:

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

117 Medical Characteristics:

118 There was no difference in the rate of postoperative steroid administration between groups
119 ($p = 0.445$), nor was there a difference in infectious or wound complications ($p = 1$). Furthermore,
120 there was no difference in long term mortality between groups (8%, 19% and 0% respectively, p
121 = 0.191). However, the median CICU-LOS in the transient AV block group was 5 days (IQR 3 –
122 10) compared to 15 days (IQR 7.5 – 36.5) in those who required PPM and did not have recovery
123 of AVN function ($p < 0.0001$) (Table 1).

124 Recovery of AV nodal function:

125 There were six patients who had recovery of AV nodal function after placement of PPM.
126 Following the index surgery resulting in heart block, the median duration to PPM placement was
127 at 5.5 days (IQR 4 – 8) in patients who had late AV nodal function recovery versus 9.0 days (IQR
128 8 – 14) in those who did not have recovery of AV nodal function ($p = 0.006$). Median time from
129 index operation to recovery was 13 days (Range 5 – 117).

130 In a sub-group analysis of patients stratified by age, those in the children group (aged 1
131 year to 18 years) who had PPM placed without AVN recovery had lower weight (median 13.5 kg,
132 IQR 11 – 18.2) compared to those who had PPM placed but had recovery of AV nodal function
133 (median 43.15 kg, IQR 28.1 – 58.5). Complication rates between these groups were similar ($p =$
134 1).

135

136 **Discussion:**

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

139 in a large registry study evaluating 15,901 surgical hospitalizations and found that 2.7% of patients
140 experienced post-surgical heart block. ¹ In their study cohort, approximately 1% of patients who
141 underwent cardiac surgery required PPM placement compared to our study, where 0.6% of
142 patients underwent PPM placement. Of note, our study is more specific to pediatric cardiac
143 surgery as our cohort contained only three adult patient 18 – 21 years of age, compared to 713
144 in the Romer study. They identified that longer CPB time was associated with increased risk for
145 needing PPM placement. Our study confirms this finding as well, with the median CPB time of
146 121 minutes in those with transient heart block compared to 144 and 138 minutes in those who
147 had PPM placed with recovery of AVN function and those who had PPM placed but had no
148 resolution of heart block respectively. Longer aortic cross-clamp time trended towards but was
149 not significantly associated with increased rate of permanent heart block. The etiology for this is
150 not well known but may be related to longer AV node ischemic time, or CPB time may be a
151 surrogate for more difficult operations or ones with more challenging intracardiac visualization.

152 We also describe the rate of resolution of post-surgical heart block in the largest group of
153 pediatric patients following cardiac surgery, to our knowledge. Of 6333 cardiac surgeries, 128
154 (2%) were complicated by AV block requiring ventricular pacing, and 38 (0.6%) had a PPM placed.
155 Of the patients that underwent PPM placement (n = 38), 6/38 (15.8%) had resolution of heart
156 block. van Geldorp et al, describe a group of patients with resolution of AV block following initial
157 PPM placement. They examined 2,850 patients who underwent cardiac surgical procedures of
158 whom 59 (2.1%) experienced chronic (>14 days) postoperative heart block. Of this group, 7
159 patients (7/59, 11.9%) demonstrated resolution of AV block following initial PPM placement. ²
160 Notably, that study did not analyze variables that are associated with recovery of AV nodal
161 function. Our findings demonstrate a slightly higher (6/38, 15.8%) rate of recovery of AV nodal
162 function following postoperative heart block. While the patients in our study who had recovery of

163 AV nodal function after PPM placement had median placement of PPM on postoperative day 5,
164 all but one had recovery 7 days after development of post-surgical AV block. Thus, these patients
165 would have still met the current PACES/HRS recommendation for PPM placement on post-
166 operative day 7. ⁸ Interestingly, had we waited for postoperative day 10 to determine the need for
167 PPM implantation, 3 of our 38 patients would not have received PPM. Romer et al. suggested
168 that in their large multicenter cohort, that if AV nodal function recovers after postoperative heart
169 block, this occurs by postoperative day 10 in 94% of patients. ¹ Ours is also the first study to
170 evaluate for factors that might predict recovery of AV nodal function. A greater proportion of
171 patients with single-ventricle physiology had recovery of AV nodal function after PPM implantation
172 compared to those who had permanent postoperative AV block. The reasons for this are not
173 entirely clear, but could be due to the fact that Glenn and Fontan procedures do not generally
174 require intracardiac surgery.

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

187

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.

204

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 p<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

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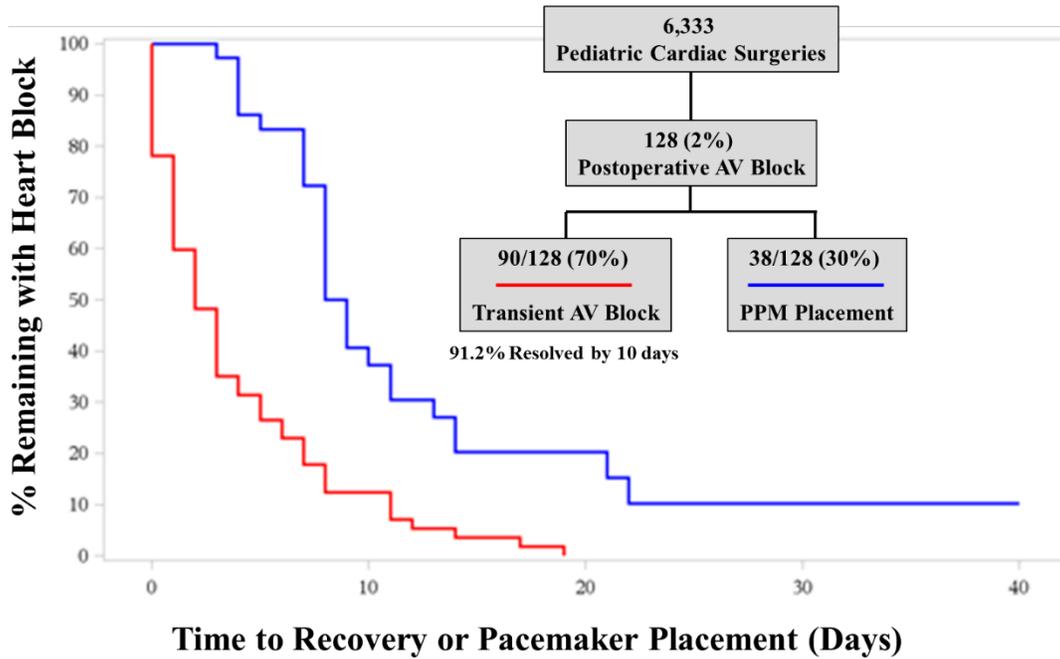
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Table 3. Patients with Permanent Pacemaker with and Without Recovery

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)	--	--

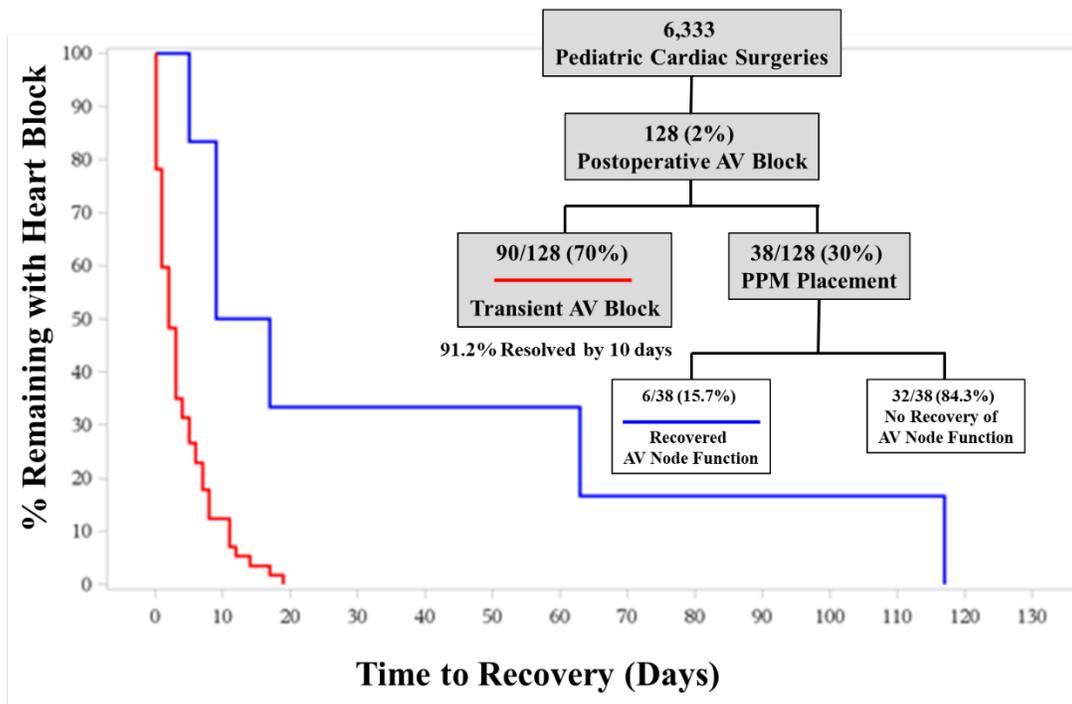
Results depicted in n (percent), median (interquartile range)

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



214

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



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218 Abbreviations: AV: atrioventricular, PPM: permanent pacemaker.

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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).