Cardiology in the Young

cambridge.org/cty

Incidence and recovery of post-surgical heart block in children following cardiac surgery

Rohit Madani[1], Elizabeth Aronoff[2], Jessica Posey[1], Mohua Basu[3], Tawanda Zinyandu[4], Paul Chai[5], Robert Whitehill[1], Kevin O. Maher[1] and Asaad G. Beshish[1]

[1]Department of Pediatrics, Division of Cardiology, Emory University School of Medicine, Children's Healthcare of Atlanta, Atlanta, GA, USA; [2]Emory University School of Medicine, Atlanta, GA, USA; [3]Qualitative Analyst, Children's Healthcare of Atlanta, Atlanta, GA, USA; [4]Senior Research Coordinator, Children's Healthcare of Atlanta, Atlanta, GA, USA and [5]Department of Surgery, Division of Cardiothoracic Surgery, Emory University School of Medicine, Children's Healthcare of Atlanta, Atlanta, GA, USA

Original Article

Cite this article: Madani R, Aronoff E, Posey J, Basu M, Zinyandu T, Chai P, Whitehill R, Maher KO, and Beshish AG (2023) Incidence and recovery of post-surgical heart block in children following cardiac surgery. *Cardiology in the Young* **33**: 1150–1156. doi: 10.1017/S1047951122002025

Received: 1 March 2022
Revised: 17 May 2022
Accepted: 17 June 2022
First published online: 29 July 2022

Keywords:
Congenital heart surgery; post-surgical heart block; pacemaker

Author for correspondence:
Rohit Madani, MD, Children's Healthcare of Atlanta, Emory University School of Medicine, 2835 Brandywine Rd, Suite 400, Atlanta, GA 30341, USA. Tel: +1 – 248 – 840 – 2619. E-mail: rsmadani@gmail.com

Abstract

Background: A subset of patients who develop post-surgical heart block have recovery of atrioventricular node function. Factors predicting recovery are not understood. We investigated our centre's incidence of post-surgical heart block and examine factors associated with recovery of atrioventricular node function. *Methods:* We conducted a single-centre retrospective study of patients 0 – 21 years who underwent cardiac surgery between January 2010 and December 2019 and experienced post-operative heart block. Data including patient and clinical characteristics and operative variables were collected and analysed. *Results:* Of 6333 surgical hospitalisations, 128 (2%) patients developed post-operative heart block. Of the 128 patients, 90 (70%) had return of atrioventricular node function, and 38 (30%) had 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 from onset of heart block to late atrioventricular node recovery was 13 days (Interquartile range: 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 post-operative steroids was similar between all groups ($p = 0.445$). Infectious or wound complications were similar between pacemaker groups ($p = 1$). *Conclusions:* Two per cent of patients who underwent congenital cardiac surgery developed post-operative heart block, and 0.6% underwent pacemaker placement. Early recovery of atrioventricular node was associated with greater weight at the 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.

Surgical heart block is a well-described complication of cardiac surgery for CHD. Prior reports estimate that atrioventricular block occurs in 1% – 6% of patients undergoing cardiac surgery.[1,2] A recent registry study from Pediatric Cardiac Critical Care Consortium found an incidence of post-operative heart block to be nearly 3%. However, almost 94% of these patients had resolution of atrioventricular block by post-operative day 10, resulting in 1% of patients receiving a permanent pacemaker.[1]

Post-surgical atrioventricular block is a complication with significant morbidity and mortality.[1,3,4] Patients requiring permanent pacemaker for surgical heart block have an overall 2.1 times longer length of stay and increased mortality when adjusting for surgical complexity.[3–5] Placement of pacemaker in children 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 permanent pacemaker be placed for post-surgical heart block after 7 – 10 days as a class-1 indication.[8] There is evidence that up to 97% of recovery of atrioventricular nodal function occurs within 9 days of surgery with post-surgical heart block following CHD repair.[1,2,9] The registry report by Romer et al suggested that longer cardiopulmonary bypass times and specific operations such as the Nikaidoh, double switch procedure, or ventricular septal defect creation/enlargement were associated with higher risk for needing a permanent pacemaker.[1] There are reports of late recovery of atrioventricular nodal function after surgical heart block, but factors predicting recovery are not well understood.[2,10–12] We sought to describe our centre's experience with surgical heart block following cardiac surgery for CHD and examine the factors associated with heart block and late recovery of atrioventricular nodal function.

Materials and methods

Cohort selection

This is a single-centre retrospective cohort study that included all patients 0 – 21 years of age who underwent cardiac surgery for palliation or repair of CHD and developed heart block post-operatively between 1 January, 2010 and 31 December, 2019 at Children's Healthcare of Atlanta, a free-standing, university-affiliated quaternary care children's hospital. An internal surgical database was queried, and cardiac surgical encounters were obtained, and patients who experienced heart block were identified by ICD-10 code diagnoses. The study was approved by the Children's Healthcare of Atlanta Institutional Review Board (IRB# 00000398).

Demographics (age, weight, gender, and race), clinical characteristics (cardiac ICU length of stay, post-operative length of stay, hospital length of stay, duration of mechanical ventilation, genetic syndrome), and operative variables (cardiopulmonary bypass time and aortic cross-clamp time) were collected. (Table 2) Patients with post-operative heart block that required ventricular pacing were stratified into 3 main outcome groups: 1) those who had spontaneous recovery of atrioventricular nodal function, 2) those who had permanent pacemaker placed but had no recovery of atrioventricular nodal function, and 3) those who recovered atrioventricular nodal function after permanent pacemaker implantation. Recovery of atrioventricular 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 using the Shapiro–Wilk test. Descriptive statistics were performed including counts, medians, and interquartile ranges. We used non-parametric 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 cut-off for significance. Statistical analyses were performed using SAS Enterprise Guide version 7.15 (SAS Institute, Inc., NC).

Results

Patient characteristics

A total of 6333 cardiac surgeries for CHD were performed between 1 January, 2010, and 31 December, 2019. Of this group, 2% (128/6333) patients developed post-surgical heart block, and 0.6% (38/6333) of them underwent permanent pacemaker placement. There were 6/38 patients (15.8%) who had recovery of atrioventricular nodal function following permanent pacemaker placement. There was no difference in demographics between the three groups with regard to age, race, weight at the time of index surgery, gender, preoperative need for antiarrhythmic medications, or presence of chromosomal abnormalities (Table 1). For patients who had transient atrioventricular block, 91.2% had recovery of atrioventricular nodal function 10 days after developing heart block and 100% at 19 days (Fig 1). Of the patients with single-ventricle physiology who experienced heart block and received a pacemaker, a greater proportion had atrioventricular nodal recovery than not (50% versus 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 cardiopulmonary bypass time was 121 minutes (interquartile range: 95 – 166) in the transient atrioventricular block group, 144 minutes (interquartile range 120 – 190) in the permanent pacemaker group without recovery, and 138 minutes (interquartile range 111 – 178) in the permanent pacemaker group with later recovery of atrioventricular nodal function (Table 1). The transient heart block group had shorter cardiopulmonary bypass times compared to those who had pacemaker placement (with or without recovery) ($p = 0.011$). There was no significant difference between the pacemaker patients who had and did not have spontaneous recovery of nodal function ($p = 0.963$). Median aortic cross-clamp time was 70 minutes (interquartile range 51 – 110) in the transient atrioventricular block group, 91 minutes (interquartile range 72 – 128) in the permanent pacemaker group without recovery, and 75 minutes (interquartile range 62 – 144) in the permanent pacemaker group with later recovery of atrioventricular nodal function ($p = 0.059$) (Table 1).

Medical characteristics

There was no difference in the rate of post-operative 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 cardiac ICU length of stay in the transient atrioventricular block group was 5 days (interquartile range 3 – 10) compared to 15 days (interquartile range 6.0 – 36.5) in those who underwent permanent pacemaker placement with or without recovery of atrioventricular nodal function ($p < 0.0001$) (Table 1). Various antiarrhythmic medications were used preoperatively (Table 3).

Recovery of atrioventricular nodal function

In those who had transient heart block, median time to recovery of atrioventricular nodal function was 2.0 days (interquartile range 1 – 6) with a median time to pacemaker placement of 8.0 days (interquartile range 7 – 12). There were 6 patients who had recovery of atrioventricular nodal function after placement of permanent pacemaker. Following the index surgery resulting in heart block, the median duration to pacemaker placement was 5.5 days (interquartile range 4 – 8) in patients who had late atrioventricular nodal function recovery versus 9.0 days (interquartile range 8 – 14) in those who did not have recovery of atrioventricular nodal function ($p = 0.006$) (Fig 2). Median time from index operation to recovery was 13 days (interquartile range 5 – 117).

In a subgroup analysis of patients stratified by age, those in the children group (aged 1 year to 18 years) who had permanent pacemaker placed without atrioventricular nodal recovery had lower weight (median 13.5 kg, interquartile range 11 – 18.2) compared to those who had permanent pacemaker placed but had recovery of atrioventricular nodal function (median 43.15 kg, interquartile range 28.1 – 58.5) (Table 4). In a subgroup analysis of the infant and adult cohorts (<1 year old and > 18 years old), weight at the time of surgery was not different between the three groups. Complication rates between these groups were similar ($p = 1$).

https://doi.org/10.1017/S1047951122002025 Published online by Cambridge University Press

Table 1. Patient characteristics

Variable	N	Transient AV block (n = 90)	AV block with PPM without recovery (n = 32)	AV block with PPM 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	n/a	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 Groups B and A $p < 0.0001$.
Abbreviations: AV = atrioventricular, CICU = cardiac ICU; PPM = permanent pacemaker.

Discussion

In this study, we demonstrate an incidence of early post-surgical heart block of 2% at our centre, 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 hospitalisations 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 permanent pacemaker placement compared to our study, where 0.6% of patients underwent permanent pacemaker placement. Of note, our study is more specific to paediatric cardiac surgery as our cohort contained only three adult patients 18 – 21 years of age, compared to 713 in the Romer study. They identified that longer cardiopulmonary bypass time was associated with increased risk for needing permanent pacemaker placement. Our study confirms this finding as well, with the median cardiopulmonary bypass time of 121 minutes in those with

https://doi.org/10.1017/S1047951122002025 Published online by Cambridge University Press

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
AV canal 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

ASD = atrial septal defect; AV canal complete: atrioventricular canal complete; DORV = double outlet right ventricle; PA/VSD = pulmonary atresia/ventricular septal defect; TGA = transposition of the great arteries; TOF = tetralogy of Fallot; VSD = ventricular septal defect.

Table 3. Preoperative antiarrhythmic therapies

Antiarrhythmic medication	Transient AV block [90 pts] N (%)	AV block with PPM without recovery [32 pts] N (%)	AV block with PPM with recovery [6 pts] N (%)
Carvedilol	9 (10%)	6 (18.8%)	
Digoxin	4 (4.4%)	2 (6.3%)	
Propranolol	1 (1.1%)		1 (16.7%)
Amiodarone	4 (4.4%)		
Metoprolol	2 (2.2%)		
Nadolol	2 (2.2%)		
Atenolol	2 (2.2%)		
Flecainide	1 (1.1%)		
Multiple	3 (3.3%)		

transient heart block compared to 144 and 138 minutes in those who had permanent pacemaker placed with recovery of atrioventricular nodal function and those who had permanent pacemaker 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 aetiology for this is not well known but may be related to longer atrioventricular node ischaemic time, or cardiopulmonary bypass time may be a surrogate for more difficult operations or ones with more challenging intracardiac visualisation.

We also describe the rate of resolution of post-surgical heart block in the largest group of children following cardiac surgery, to our knowledge. Of 6333 cardiac surgeries, 128 (2%) were complicated by atrioventricular block requiring ventricular pacing, and 38 (0.6%) had a permanent pacemaker placed. Of the patients that underwent pacemaker placement (n = 38), 6/38 (15.8%) had resolution of heart block. van Geldorp et al describe a group of patients with the resolution of atrioventricular block following initial pacemaker placement. They examined 2850 patients who underwent cardiac surgical procedures of whom 59 (2.1%) experienced chronic (>14 days) post-operative heart block. Of this group, 7 patients (7/59, 11.9%) demonstrated resolution of atrioventricular block following initial pacemaker placement.[2] Notably, that study did not analyse variables that are associated with recovery of atrioventricular nodal function. Our findings demonstrate a slightly higher (6/38, 15.8%) rate of recovery of atrioventricular nodal function following post-operative heart block. While the patients in our study who had recovery of atrioventricular nodal function after permanent pacemaker placement had median placement of pacemaker on post-operative day 5, all but one had recovery 7 days after the development of post-surgical atrioventricular block. Thus, these patients would have still met the current Pediatric and Congenital Electrophysiology Society/Heart Rhythm Society recommendation for permanent pacemaker placement at post-operative day 7 – 10.[8] Interestingly, had we waited for post-operative day 10 to determine the need for pacemaker implantation, 3 of our 38 patients would not have received pacemakers. Romer et al. suggested that in their large multi-centre cohort, that if atrioventricular nodal function recovers after post-operative heart block, this occurs by post-operative day 10 in 94% of patients.[1] Ours is also the first study to evaluate for factors that might predict recovery of atrioventricular nodal function. A greater proportion of patients with single-ventricle physiology had recovery of atrioventricular nodal function after pacemaker implantation compared to those who had permanent post-operative heart 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.

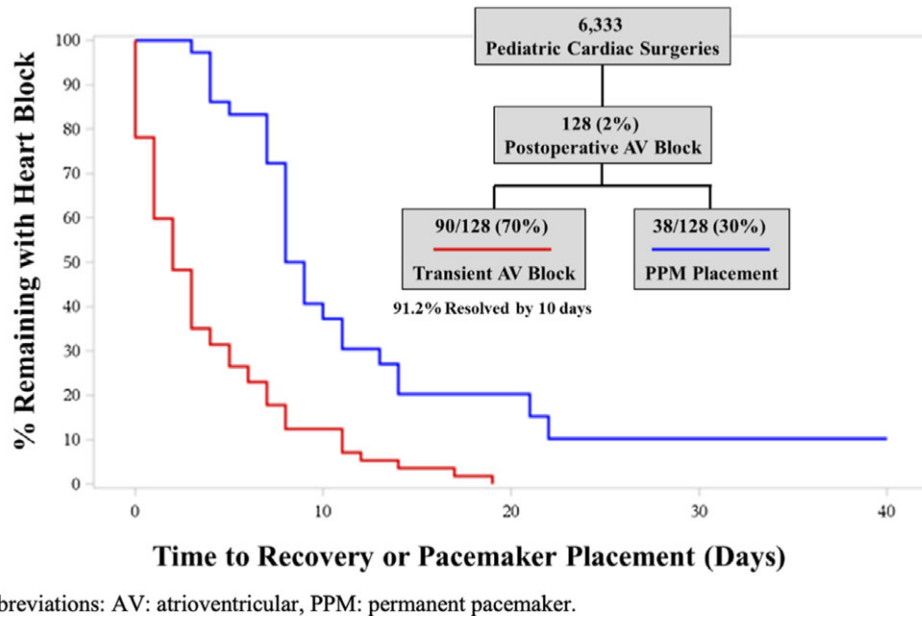

Figure 1. Kaplan–Meier plot showing time from onset of atrioventricular block to either spontaneous recovery of atrioventricular nodal function (red) or placement of permanent pacemaker (blue).

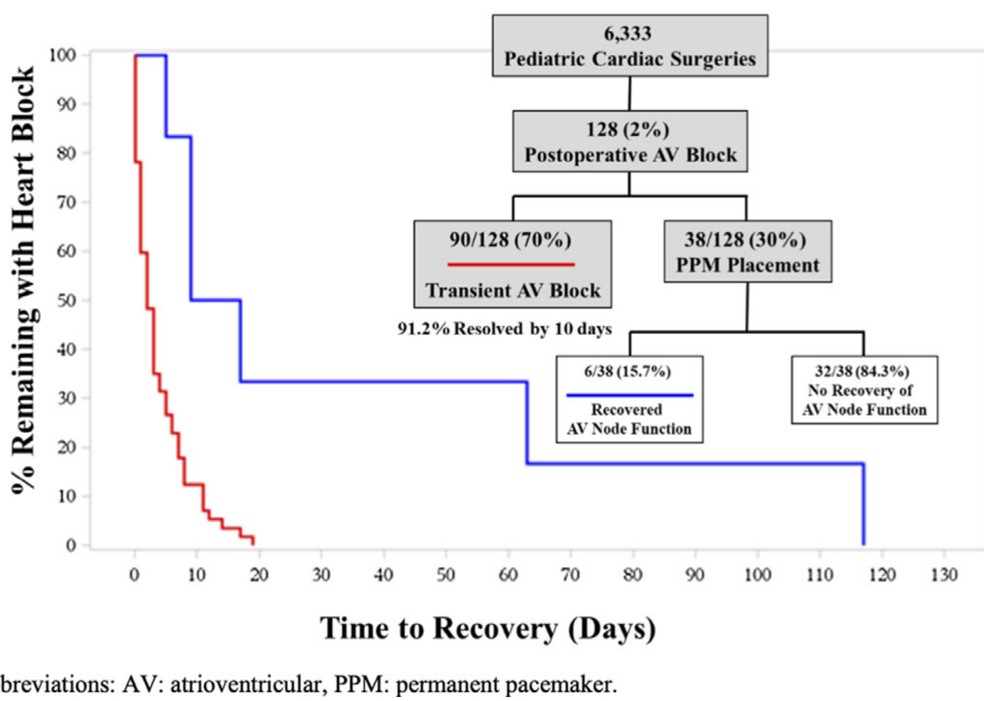

Figure 2. Kaplan–Meier plot showing time from onset of AV block to recovery of AV nodal function without pacemaker (red) or recovery after PPM was placed (blue).

Of those in the single-ventricle physiology late recovery group, one patient had ventricular septal defect 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 ventricular septal defect 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 suggest 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

https://doi.org/10.1017/S1047951122002025 Published online by Cambridge University Press

Table 4. Patients with permanent pacemaker with and without recovery

Variable	N	AV block with PPM but no recovery (n = 32)	AV block with PPM with recovery (n = 6)	*p*-value
Duration from surgery to PPM placement (Days)	36	9.0 (8.0 – 14.0)	5.5 (4.0 – 8.0)	**0.006**
Patient at dry weight at the time of PPM 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 infection	3	3 (9.38%)	0 (0%)	
Endocarditis	1	1 (3.13%)	0 (0%)	
PM pocket dehiscence	4	3 (9.38%)	1 (16.67%)	
Other	1	1 (3.13%)	0 (0%)	
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 the 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).
AV = atrioventricular; PPM = permanent pacemaker.

identified high-risk operations like Ebstein repair and Starnes procedure).[1]

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

In conclusion, post-surgical heart block occurs in 2% of patients undergoing cardiac surgery for CHD. In our study, 91% of resolution occurred by post-operative day 10. Permanent pacemaker placement occurred in 0.6% (38/6333) of patients, and permanent post-operative heart block occurred in 0.5% (32/6333) of patients. Higher weight, shorter cardiopulmonary bypass time, and presence of single-ventricle physiology are associated with the resolution of post-surgical heart block. Late recovery of atrioventricular node conduction following permanent pacemaker placement occurred in 15.8% (6/38) patients and is associated with greater age and weight, but is not associated with gender, post-operative steroids, infectious, or wound complications.

Acknowledgements. None.

Financial support. This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Conflicts of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the institutional committees (Institutional Review Board at the Children's Healthcare of Atlanta).

References

1. Romer AJ, Tabbutt S, Etheridge SP et al. Atrioventricular block after congenital heart surgery: Analysis from the Pediatric Cardiac Critical Care Consortium. J Thorac Cardiovasc Surg 2019; 157: 1168–1177 e1162.
2. van Geldorp IE, Vanagt WY, Vugts G et al. Late recovery of atrioventricular conduction after postsurgical chronic atrioventricular block is not exceptional. J Thorac Cardiovasc Surg 2013; 145: 1028–1032.
3. Anderson JB, Czosek RJ, Knilans TK, Meganathan K, Heaton P. Postoperative heart block in children with common forms of congenital heart disease: results from the KID Database. J Cardiovasc Electrophysiol 2012; 23: 1349–1354.
4. Murray LE, Smith AH, Flack EC, Crum K, Owen J, Kannankeril PJ. Genotypic and phenotypic predictors of complete heart block and recovery

https://doi.org/10.1017/S1047951122002025 Published online by Cambridge University Press

of conduction after surgical repair of congenital heart disease. Heart Rhythm 2017; 14: 402–409.
5. Liberman L, Silver ES, Chai PJ, Anderson BR. Incidence and characteristics of heart block after heart surgery in pediatric patients: A multicenter study. J Thorac Cardiovasc Surg 2016; 152: 197–202.
6. Wilhelm BJ, Thone M, El-Scheich T, Livert D, Angelico R, Osswald B. Complications and Risk Assessment of 25 Years in Pediatric Pacing. Ann Thorac Surg 2015; 100: 147–153.
7. Mah DY, Prakash A, Porras D, Fynn-Thompson F, DeWitt ES, Banka P. Coronary artery compression from epicardial leads: More common than we think. Heart Rhythm 2018; 15: 1439–1447.
8. Silka MJ, Shah MJ, Silva JNA et al. 2021 PACES Expert Consensus Statement on the Indications and Management of Cardiovascular Implantable Electronic Devices in Pediatric Patients: executive Summary. Heart Rhythm 2021; 18: 1925–1950.
9. Weindling SN, Saul JP, Gamble WJ, Mayer JE, Wessel D, Walsh EP. Duration of complete atrioventricular block after congenital heart disease surgery. Am J Cardiol 1998; 82: 525–527.
10. Batra AS, Wells WJ, Hinoki KW, Stanton RA, Silka MJ. Late recovery of atrioventricular conduction after pacemaker implantation for complete heart block associated with surgery for congenital heart disease. J Thorac Cardiovasc Surg 2003; 125: 1291–1293.
11. Reid JM, Coleman EN, Doig W. Reversion to sinus rhythm 11 years after surgically induced heart block. Br Heart J 1976; 38: 1217–1219.
12. Bruckheimer E, Berul CI, Kopf GS et al. Late recovery of surgically-induced atrioventricular block in patients with congenital heart disease. J Interv Card Electrophysiol 2002; 6: 191–195.
13. Oster ME, Chen S, Dagincourt N et al. Development and impact of arrhythmias after the Norwood procedure: A report from the Pediatric Heart Network. J Thorac Cardiovasc Surg 2017; 153: 638–645 e632.