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Pacemaker treatment after Fontan surgery—A Swedish national study

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Abstract

Objective: Fontan surgery is performed in children with univentricular heart defects. Previous data regarding permanent pacemaker implantation frequency and indications in Fontan patients are limited and conflicting. We examined the prevalence of and risk factors for pacemaker treatment in a consecutive national cohort of patients after Fontan surgery in Sweden.

Methods: We retrospectively reviewed all Swedish patients who underwent Fontan surgery from 1982 to 2017 (n = 599).

Results: After a mean follow-up of 12.2 years, 13% (78/599) of the patients with Fontan circulation had received pacemakers. Patients operated with the extracardiac conduit (EC) type of total cavopulmonary connection had a significantly lower prevalence of pacemaker implantation (6%) than patients with lateral tunnel (LT; 17%). Mortality did not differ between patients with (8%) and without pacemaker (5%). The most common pacemaker indication was sinus node dysfunction (SND) (64%). Pacemaker implantation due to SND was less common among patients with EC. Pacemaker implantation was significantly more common in patients with mitral atresia (MA; 44%), double outlet right ventricle (DORV; 24%) and double inlet left ventricle (DILV; 20%). In contrast, patients with pulmonary atresia with intact ventricular septum and hypoplastic left heart syndrome were significantly less likely to receive a pacemaker (3% and 6%, respectively).

Conclusions: Thirteen percent of Fontan patients received a permanent pacemaker, most frequently due to SND. EC was associated with a significantly lower prevalence of pacemaker than LT. Permanent pacemaker was more common in patients with MA, DORV, and DILV.

KEYWORDS

congenital heart disease, Fontan circulation, pacemaker, sinus node dysfunction

1 | INTRODUCTION

Long-time survival in patients with Fontan circulation has improved considerably.[1] Therefore, increased awareness of potential long-term complications that may affect survival and quality of life is important. Arrhythmias are known to be common postoperative complications after Fontan surgery, and bradyarrhythmias including sinus node dysfunction (SND) and atrioventricular (AV) block constitute major clinical problems.[2-4]

The Fontan type of surgery was sporadically used in Sweden until the beginning of the 1990s before developing into routine management in patients with univentricular heart defects. In most cases, neonatal surgery is performed to ensure sufficient blood supply to the systemic and pulmonary circulation. In most patients, bidirectional cavopulmonary anastomosis (BCPC) is performed during the first year of life and total cavopulmonary anastomosis (TCPC) at 2-4 years. The surgical technique used for the inferior vena cava connection in TCPC surgery has evolved from an intraatrial lateral tunnel (LT) to the extracardiac conduit (EC).

Previous studies have reported the need for permanent pacemaker implantation in 7%-25% of patients who undergo Fontan surgery.[2,4-6] The risk of pacemaker treatment has been shown to increase with time after Fontan surgery.[5] Some studies have found a single ventricle of left morphology to be a risk factor,[5,6] but others have not.[7,8] The risk for permanent pacemaker implantation was found to be higher after LT than EC in one study,[6] but this was not confirmed in other studies in which LT was not associated with a higher risk of pacemaker than EC, at least not after adjusting for time after Fontan surgery.[2,3,9]

Patients with Fontan circulation and concomitant pacemaker implantation have been shown to be at higher risk for adverse events, such as death or heart transplantation.[10] Among Fontan survivors in the Pediatric Heart Network Fontan cross-sectional study, patients with pacemakers had poorer functional status and mildly decreased systolic ventricular function than Fontan survivors without pacemakers.[5] Thus, the need for pacemaker implantation after Fontan surgery may be a predictor of negative health consequences for the patient. Accordingly, increased knowledge of prevalence and risk factors for pacemaker implantation after Fontan surgery could improve prediction and awareness for physicians and families.

Therefore, we investigated the prevalence of and risk factors for permanent pacemaker implantation in a complete national cohort operated on between 1982 and 2017.

2 | METHODS

Patients with Fontan circulation operated on in Sweden between 1982 and 2017 were identified using four separate registers: SWEDCON (The Swedish Registry of Congenital Heart Disease), the Swedish ICD and pacemaker registry, and local hospital registries. After identification of the patients, their diagnoses were confirmed with each hospital. Only patients discharged from hospital after complete TCPC surgery were included. All included patients were categorized as alive or deceased at May 1, 2018.

Clinical records were reviewed for gender, anatomical cardiac diagnosis, type of surgical procedures, time of cardiac surgeries, and complications after Fontan surgery, including onset of AV block, SND, and reports of supraventricular/ventricular arrhythmias and symptoms. Data on pacemaker implantation included indication for pacemaker, age at implantation, and temporal relation to surgical interventions. For 34 patients with and 84 patients without pacemaker treatment echocardiographic data on ventricular function and AV—valve regurgitation was available. Semi quantitatively assessed ventricular function was graded on a scale from I to IV, where I was evaluated as poor and IV as good. AV-valve regurgitation was graded on a scale from 0 to 3 with 0 as no regurgitation and 3 as a large regurgitation.

This study was approved by the Regional Ethical Review Board in Umea.

2.1 | Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp. Armonk, New York) and Matlab R2017b (Mathworks Inc, Natick, Massachusetts). Data were presented as frequencies, means with standard deviations (SD), or medians with ranges. Comparisons between groups were evaluated by the χ^2 test. Specifically for analysis of anatomical diagnoses, a χ^2 test first compared pacemaker prevalence among all diagnoses, and then the prevalence in one anatomical diagnosis was compared to all others. Two-sided P values < .05 were considered significant.

Kaplan-Meier analyses were performed to compare the frequency of pacemaker implantation in patients operated with the two surgical variants of TCPC (LT and EC). Time zero was the date of Fontan surgery. The Mann-Whitney U-test was used to compare ventricular function and AV-valve regurgitation in patients who later had a pacemaker implanted to patients without pacemakers. The Wilcoxon signed-rank test was used to compare ventricular function and AV-valve regurgitation before and after pacemaker implantation.

3 | RESULTS

3.1 | Clinical characteristics

The study included a total of 599 patients (37% female) with univentricular heart malformations who were discharged from the hospital after completion of Fontan circulation. The patients were followed up for a mean ± SD 12.2 ± 7.3 years (median 11.2, range .02-35.1 years) after Fontan surgery, for a total follow-up of 7281 patient-years. During follow-up, 13% (78/599) of the patients had a permanent pacemaker implanted (Table 1).

Eight percent (6/78) of the patients with a pacemaker and 5% (27/518) of the patients without a pacemaker were deceased. Data regarding whether the patient was alive or deceased was available in 596/599 cases.

TABLE 1 Demographics

	Overall cohort *n* = 599	No pacemaker *n* = 521 (87%)	Pacemaker *n* = 78 (13%)
Sex: Female/male	224/375 (37/63%)	199/322 (38/62%)	25/53 (32/68%)
Age at Fontan, years			
Mean ± SD Median (range)	3.5 ± 2.6 2.9 (.7 – 24.1)	3.5 ± 2.6 2.8 (.7 – 24.1)	3.6 ± 2.5 3.0 (1.2 – 15.0)
Follow-up, years from Fontan			
Mean ± SD Median (range)	12.2 ± 7.3 11.2 years (.02 – 35.1)	11.9 ± 7.2 10.9 (.02 – 29.6)	14.5 ± 7.2 15.0 (.4 – 35.1)
Type of Fontan, n (%)			
TCPC, EC	355	324	31 (9%)*
TCPC, LT	238	193	45 (19%)
AP connection	6	4	2 (33%)

Abbreviations: EC, extracardiac conduit; LT, lateral tunnel; TCPC, total cavopulmonary connection.
*Patients who received a pacemake before Fontan surgery are included.

3.2 | Surgical history of Fontan patients with pacemaker

The majority of patients had their first cardiac surgery in the neonatal period. Sixteen were operated on with Damus-Kaye-Stansel anastomosis and shunt, 14 had Norwood surgery, 23 pulmonary artery banding, and 21 only received a shunt (modified, classical Blalock-Taussig shunt or central shunt). Seven patients were not operated on during the neonatal period. Details regarding neonatal surgery were missing in two patients.

Staged Fontan was performed in 66 children. Of these children, six received a pacemaker before BCPC, six before Fontan, three at the time of Fontan, and 51 later. Eleven patients did not undergo staged Fontan but had both superior and inferior vena cava connections to the pulmonary arteries in a single procedure. Data regarding the timing of BCPC were missing for one patient. A total of 61 patients (51 with staged Fontan and 10 without staged Fontan) received a pacemaker after complete Fontan surgery; the mean time from Fontan procedure to pacemaker implantation was 3.9 ± 4.5 years (Figure 1). The mean age at pacemaker implantation in the whole group (before and after Fontan surgery) was 6.2 ± 4.9 years. Seventeen patients received a pacemaker within 30 days after Fontan surgery. Concerning type of Fontan surgery, 45 patients who received a pacemaker had an LT, 31 had an EC, and 2 had an atriopulmonary type Fontan.

Of the 231 patients with LT and 339 patients with EC who had no pacemaker after TCPC surgery, 39 (16.9%) with LT and 20 (5.9%) with EC later received a pacemaker (P = .004; Figure 2). Within 2 years after TCPC surgery, 14 (70%) of the 20 EC patients had received a pacemaker, whereas 15 (38%) of the 39 LT patients had received a pacemaker.

Seven patients were reoperated for conversion from LT to EC. Two of these patients who had pacemaker implanted after the conversion from LT to EC were excluded from the Kaplan-Meier analysis, and the other five received a pacemaker before conversion and were classified as having an LT.

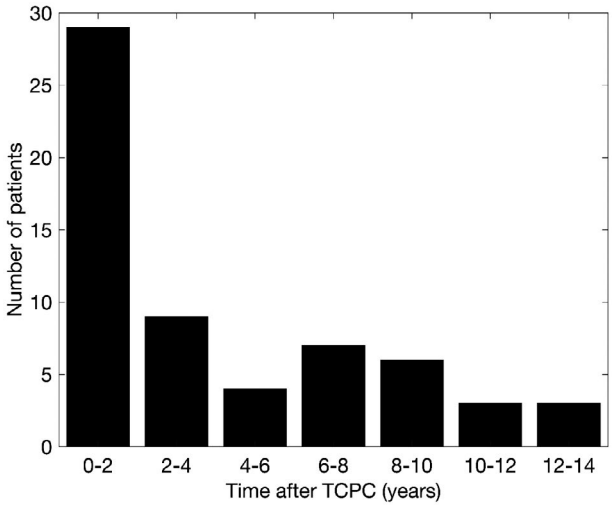

FIGURE 1 Years from TCPC procedure to pacemaker implantation in 61 patients

As the preferred surgical method in Sweden has switched from LT to EC (beginning in 1998), the time from Fontan surgery was longer in the LT group (mean ± SD 18.6 ± 5.6 years, median 20.2 years, maximum 30.6 years) than in the EC group (mean ± SD 8.0 ± 4.6 years, median 8.2 years, maximum 18.7 years). However, we chose to use the Kaplan-Meier analysis when comparing LT vs EC in order to avoid the effect of increasing incidence of pacemaker implantation with the length of follow-up time.

3.3 | Indication for pacemaker

Data concerning indications for pacemaker implantation were available in 97% (76/78) of patients. In the majority (64%, 49/76), the

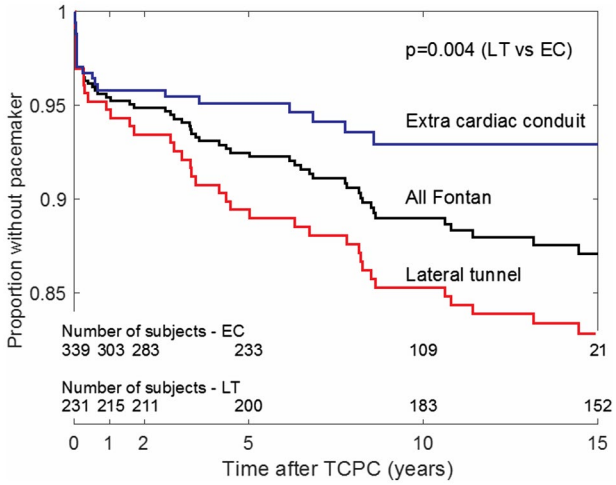

FIGURE 2 Kaplan-Meier curve showing the proportion of patients free from pacemaker treatment at different times after total cavopulmonary connection (TCPC)
Note. Numbers refer to the remaining number of EC/LT patients 0, 1, 2, 5, 10, and 15 years after TCPC.
Abbreviations: EC, extracardiac conduit, LT, lateral tunnel.

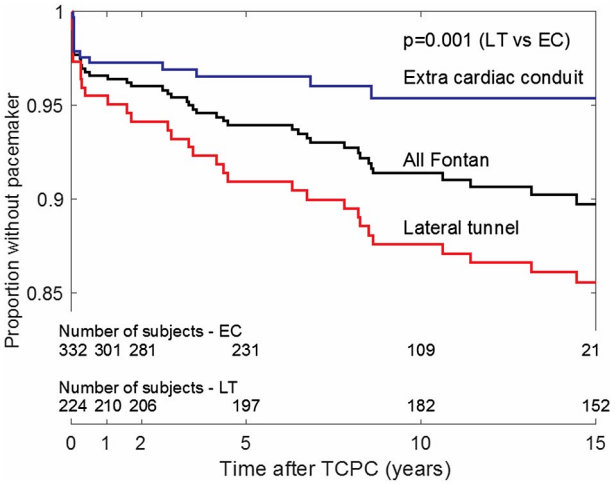

FIGURE 3 Kaplan-Meier curve of patients with sinus node dysfunction (SND) as the main indication for pacemaker
Note. The proportion of patients that were free from pacemaker treatment at different times after total cavopulmonary connection (TCPC) is shown. Numbers refers to the remaining number of EC/LT patients 0, 1, 2, 5, 10, and 15 years after TCPC.
Abbreviations: EC, extracardiac conduit; LT, lateral tunnel.

primary indication for pacemaker implantation was SND. In 32% of the patients (24/76), the indication was high degree AV block, and in 4% (3/76) the indication was protection against bradycardia due to treatment with antiarrhythmic drugs for ventricular or supraventricular tachyarrhythmias. No patient was treated with cardiac resynchronization therapy as an indication for pacemaker implantation (Table 2).

We also performed a Kaplan-Meier analysis of patients with SND as an indication for pacemaker implantation who received their pacemaker after TCPC (LT = 31, EC = 13). We found that pacemaker dependency because of SND was more common among patients with LT than among patients with EC (P = .001, Figure 3).

Patients with double inlet left ventricle (DILV), unbalanced atrioventricular defect, and hypoplastic left heart syndrome (HLHS) had a relatively high proportion of AV block as the indication for pacemaker (58%, 50%, and 50%, respectively; Figure 4). Thirty percent (7/23) of the AV blocks were postoperative, and 9% (2/23) developed at heart catheterization.

3.4 | Anatomical diagnosis

There was a significant overall difference in the proportion of pacemakers implanted between patients with different underlying anatomical diagnoses (P < .001). Pacemaker implantation was significantly more prevalent among patients with DILV (20%, 19/97, P = .036) compared to all other groups. Pacemaker implantation was also significantly more prevalent in patients with double outlet right ventricle (DORV; 24%, 11/46, P = .022) and mitral atresia (MA; 44%, 8/18, P < .001) compared to the other anatomical groups. In patients with HLHS, the prevalence of pacemaker implantation was significantly lower than in the other groups (6%, 6/103, P = .017). In patients with pulmonary atresia with intact ventricular septum (PA/IVS), pacemaker implantation was rare (3%, 2/58, P = .023). Fourteen percent (16/188) of patients with tricuspid atresia (TA) had a permanent pacemaker (Table 3).

Dextrocardia was present in 38 patients, and 16% (6/38) of them were implanted with a pacemaker. Of the 54 patients with heterotaxia syndrome, 22% (12/54) had a pacemaker (P = .035). Three of these patients (9%) had right isomerism and nine (41%) had left

TABLE 2 Main indications for pacemaker implantation

	Pacemaker indication n = 76		
	SND n = 49 (64%)	AV block n = 24 (32%)	Anti-brady n = 3 (4%)
Sex: Female/male	20/29 (41/59%)	4/20 (17/83%)	1/2 (33/67%)
EC	15 (50%)	13 (43%)	2 (7%)
LT	32 (73%)	11 (25%)	1 (2%)
AP-Fontan	2 (100%)	0	0

Abbreviations: Anti-brady, protection for bradycardia when treating with antiarrhythic drugs; AV, atrioventricular; EC, extracardiac conduit; LT, lateral tunnel; SND, sinus node dysfunction; type of Fontan, % of indication for pacemaker implantation within EC, LT, or AP-Fontan.

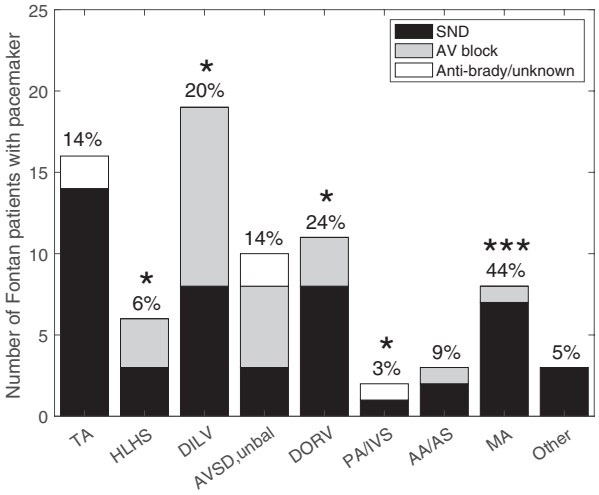

FIGURE 4 Number and proportion of patients with pacemaker within each morphological group, including the indication for pacemaker implantation
Abbreviations: AA, aortic atresia; Anti-brady, protection for bradycardia due to treatment with antiarrhythmic drugs for ventricular or supraventricular tachyarrhythmias; AS, aortic stenosis; AV, atrioventricular; AVSD, atrioventricular septal defect; DILV, double inlet left ventricle; DORV, double outlet right ventricle; HLHS, hypoplastic left heart syndrome; MA, mitral atresia; PA/IVS, pulmonary atresia with intact ventricular septum; SND, sinus node dysfunction; TA, tricuspid atresia. *P < .05, ***P < .001 compared to the average proportion of pacemaker implantations within the overall Fontan cohort.

isomerism; patients with left isomerism had a significantly higher prevalence of pacemaker implantation (P < .001). Out of 21 patients with double discordance as a part of their anatomical diagnosis, only one had a pacemaker (5%). Data concerning ventricle morphology were available for 96% of patients. Fourteen percent (44/307) of the patients with dominant left ventricle and 13% (33/248) of patients with a dominant right ventricle underwent pacemaker implantation.

3.5 | Symptoms

Data regarding symptoms before pacemaker implantation were described in only 59% (46/78) of the patients who underwent pacemaker implantation. Symptoms noted in the medical records of 46 patients before pacemaker implantation varied from none at all (n = 8) to circulatory instability/impaired hemodynamics (n = 8). Fatigue was the most commonly reported symptom (n = 22). Two patients had experienced syncope, four had palpitations or chest discomfort, and two reported headache. Other symptoms included sleeping disorder, failure to thrive, edema and ascites, and dizziness.

A history of paroxysmal supraventricular tachycardia before pacemaker implantation was reported in 19% (14/75) of patients and ventricular tachycardia in 3% (2/75) of patients.

In the 34 pacemaker treated patients with data on ventricular function and AV-regurgitation there was no significant difference before and after pacemaker implantation. Also, there was no difference in ventricular function or AV-regurgitation in these patients before pacemaker implantation compared with 84 Fontan patients without pacemaker treatment.

4 | DISCUSSION

In this national cohort of 599 patients with Fontan circulation operated on in Sweden between 1982 and 2017, permanent pacemaker implantation was performed in 13% after a mean follow-up of 12.2 years. Previous studies of patients with Fontan circulation reported a prevalence of pacemaker implantation of 7%-25%, increasing with longer follow-up after Fontan surgery.[2,4,5,9] A large proportion of the patients in our study received their permanent pacemaker during the first 2 years after Fontan completion (Figures 1 and 2), which was most apparent in the EC group. Compared to other studies with a shorter mean follow-up after Fontan surgery, patients in our study had a longer mean time from Fontan surgery to pacemaker implantation.[2,5]

In the present study, pacemaker therapy was significantly less common after EC than after LT type TCPC. This finding is in contrast to a study by Balaji[9] et al, where no difference regarding pacemaker implantation was found, but in line with the results reported by Downing et al, who also found an association between LT and need for pacemaker.[6] EC type TCPC, which minimizes the ischemic time and atrial suture lines, has been suggested to reduce the incidence of atrial tachycardia.[11] However, as the surgical procedure switched from LT to EC in Sweden beginning in 1998, we cannot yet estimate the long-term need for a pacemaker in patients who received an extracardiac tunnel. Another explanation for the lower incidence of pacemaker implantation in EC patients could be that the decision to implant a permanent pacemaker in Fontan patients might have changed over time, and thereby might not be directly related to the type of Fontan operation.

In the Swedish Fontan population, the most common indication for pacemaker implantation was SND, followed by a high degree AV block. This finding is in contrast with the study by Pundi et al, in which the main indication was late tachyarrhythmias.[4] One reason for the relatively low incidence of late tachy-arrhythmias in our cohort may be the few patients with atriopulmonary Fontan surgery. This surgical method includes more suture lines in the atria and enlargement of the atria, which have been shown to be associated with a higher risk of late arrhythmia.[7] SND is commonly noticed in patients operated on due to univentricular heart defects. Bossers et al reported in a study of 116 Fontan patients that SND was present in 29%, but only 3% of the 116 patients needed a pacemaker.[3] Cohen et al also demonstrated a high incidence of SND (44%), with only a minor proportion of the patients (7%) receiving a pacemaker after 3.5 years of follow-up.[12] We found a slightly larger proportion of 8% of patients treated with a permanent pacemaker due to SND.

Previous studies on the prevalence of SND following EC and LT have reported divergent results, with SND after EC being reported more frequently,[13,14] equally frequent,[3,12] and less frequently than

TABLE 3 Prevalence of pacemaker implantation in different anatomical groups

Anatomical diagnosis	*n* Overall cohort (% within diagnosis)	*n* Pacemaker (% within the diagnosis)	Risk for pacemaker vs all other groups χ^2 $P < .0001$ *P*
TA	117 (19.5)	16 (13.6)	.82
HLHS	*103 (17.2)*	*6 (5.8)*	*.02*
DILV	**97 (16.2)**	**19 (19.6)**	**.04**
AVSD, unbalanced	69 (11.5)	10 (14.5)	.70
DORV	**46 (7.7)**	**11 (23.9)**	**.02**
PA/IVS	*58 (9.7)*	*2 (3.4)*	*.02*
AA/AS	33 (5.5)	3 (9.1)	.78
MA	**18 (3.0)**	**8 (44.4)**	**<.001**
Other	58 (9.7)	3 (5.3)	.16
ALL	599 (100)	78 (13)	
Dextrocardia	38 (6.3)	6 (15.8)	.60
Heterotaxia	54 (9.0)	12 (22.2)	.04
Right isomerism	32	3 (9.4)	.53
Left isomerism	**22**	**9 (40.9)**	**<.001**
Double discordance*	21 (3.5)	1 (4.8)	.25
Morphology of dominant ventricle**			
Dominant LV	307 (53.6)	44 (14.3)	.59
Dominant RV	248 (43.3)	33 (13.3)	.85
Biventricular/ intermediate	18 (3.1)	1 (1.3)	

Abbreviations: AA, aortic atresia; AS, aortic stenosis; AVSD, atrioventricular septal defect; DILV, double inlet left ventricle; DORV, double outlet right ventricle; HLHS, hypoplastic left heart syndrome; LV, left ventricle; MA, mitral atresia; PA/IVS, pulmonary atresia with intact ventricular septum; RV, right ventricle; TA, tricuspid atresia. In patients with DORV, AA/AS, and MA, the majority of patients had LV hypoplasia.

*In the patients with double discordance, four had TA, two unbalanced AVSD, one DILV, one DORV, one PA/IVS, and twelve other.

**Data were missing concerning dominant ventricle in 26 patients.

after LT.[15] Interestingly, we found a greater need for a pacemaker in the LT group when analyzing only patients with SND as the indication for pacemaker implantation.

In our study, the second most common pacemaker indication was a high degree AV block. Among these patients, 56% were classified as congenital or progressive and 35% as surgical. Surgical AV block has been reported to have a significantly higher incidence in patients with univentricular heart defects (3.29%) compared to those undergoing intra-cardiac surgery to biventricular repair (.87%). The etiology is described as multifactorial; transection of the conduction system, as well as ischemia, edema, and blunt trauma as isolated features or in combination, are all described as probable causes of AV block.[16]

We found no significant difference in mortality between patients with and without pacemakers. Patients with Fontan circulation are a heterogeneous group including several different underlying anatomical congenital heart malformations. Some of the underlying heart defects share anatomical features, whereas others do not. In this cohort of all Swedish Fontan patients, we found that pacemaker implantation was significantly more common in patients with DILV, DORV, and MA but significantly less common in patients with HLHS and PA/IVS.

The findings of a high prevalence of pacemaker implantation in patients with DILV confirms earlier findings by Williams et al.[5] In patients with DILV, the proportion with AV block as the indication for pacemaker was high. DILV shares anatomic features with double discordance. A strong relationship between pacemaker and ventricular L-looping in a cohort of patients with Fontan circulation and pacemaker implantation was described previously.[5,7] We could not confirm this finding in our national cohort in which only 5% with double discordance had a pacemaker. In our study, left isomerism was common in the DORV group and contributed to the high number of pacemaker implantations in the DORV group (24%). We found a high number of pacemaker implantations in patients with left isomerism (40%). In all patients with left isomerism, SND was the indication for pacemaker treatment. Patients with left isomerism lack a normally located sinus node and are described as being at risk for developing both AV block and SND.[17] In patients with right isomerism, the prevalence of pacemaker implantation was not elevated.

To the best of our knowledge, MA has not been described previously as an anatomical diagnosis related to an increased risk of pacemaker treatment. Among 17 patients with MA in our cohort, 14 had an LT and 3 had an EC. The numbers are very small, and we found no significant difference; six patients (43%) with MA and LT and one patient (33%) with MA and EC had a pacemaker. Thus, this does not explain the high prevalence of pacemaker implantation in the MA group. MA or left AV valve atresia could also be classified as part of a diagnosis: DILV with MA or DORV with MA.[18] Among all patients in the Swedish cohort with MA as part of their cardiac malformation, pacemaker implantation was significantly more common than among the other Fontan patients. Patients with an absent or obstructive left AV valve are likely to develop left atrial hypertension with a risk of progressive deterioration of the AV conduction.[18] In this study, the indication for pacemaker implantation in patients with MA treatment was SND in seven cases and AV block in one case. A South Korean study in 2015 indicated an association with elevated LA pressure in patients with SND.[19] Thus, one could speculate a similar mechanism in patients with MA, Fontan circulation, and SND.

Pacemaker implantation was rare in the HLHS group compared to the other anatomical diagnoses among the patients with Fontan circulation. In another study of Fontan survivors, the incidence of pacemaker implantation was higher among patients with HLHS.[5] In our cohort, we only included patients who had been discharged from hospital after complete Fontan surgery. It is possible that if we had included all patients with HLHS, even those who never reached completed Fontan, pacemaker implantation would be more common in this group.

Regarding systemic ventricle morphology being a risk factor for pacemaker treatment in patients with Fontan circulation, we did not find any difference between left and right ventricle morphology. This finding is in line with in two earlier studies.[7,8] In our cohort, the proportion of pacemaker implantation in patients with left or right morphology of the systemic ventricle was almost equal.

Relation to symptoms is of importance in the decision-making process prior to pacemaker implantation. As fatigue is a very non-specific symptom, this finding may stress the importance of objective methods for regular assessment of SND, such as Holter monitoring and physical stress test.

The strengths of this study are that it is a national study with a long follow-up and few missing data. The limitations of this study are its retrospective nature, and that the decision regarding pacemaker implantation is, particularly in patients with SND, partly subjective. Patients who were not discharged from hospital after complete Fontan surgery were not included. This may have had an influence on our results. Regarding the high prevalence in pacing in MA patients, it should be considered that this is a multicenter study, and part of the findings could be a matter of anatomic definition. Furthermore, the follow up was longer in the LT group compared to the EC group. In order to avoid the effect of increasing incidence of pacemaker implantation with the length of follow-up, we used Kaplan-Meier analysis. The number of patients in the EC group was high at 10 years of follow-up. At 15 years after Fontan surgery, there were only 23 patients with EC not censored; therefore, we cannot estimate the need for a pacemaker in EC patients 10-15 years, or longer, after Fontan. In this study, data on symptoms before pacemaker implantation were known in only 59% of patients; thus, definite conclusions cannot be drawn.

In conclusion, the prevalence of pacemaker implantation in this Swedish national cohort of patients with Fontan circulation operated on between 1982 and 2017 was 13%. The most common indication was SND. The prevalence of pacemaker implantation was lower in patients operated on with an EC compared to patients operated on with an LT, and the prevalence of pacemaker implantation due to severe SND was lower in patients with an EC. We found no difference in mortality between patients with and without pacemakers. The risk of pacemaker was especially high in patients with MA, DORV, and DILV.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest with the contents of this article.

AUTHOR CONTRIBUTIONS

Concept/design, *data analysis/interpretation*, *drafting article*: Jenny Alenius Dahlqvist
Critical revision of article, *approval of article*: Jan Sunnegårdh, Katarina Hanséus, Eva Strömvall Larsson, Anders Nygren, Magnus Dalén, Håkan Berggren, Jens Johansson Ramgren
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